L. N.	Title of topic	Sub topics to be taught	Text /Ref. Book	Publisher, Edition and page number	Remarks
1.	Introduction of Indian agricultural heritage	• Definition of agriculture, heritage, agricultural heritage • Preamble of agricultural heritage • Agriculture heritage in India • Ancient literature on agriculture e.g. Rigveda, KrishiParashar	Glimpses of Agricultural heritage of India	Y. L. Nene, Munshiram Manoharlal Publishers Pvt. Ltd	
2.	Ancient agricultural practices	• Traditional farming practices in India, weather forcasting and drought prediction • Local farming knowledge in India and Gujarat with examples • Indigenous seed conservation and preservation • Traditional fore fathers knowledge of agriculture	Glimpses of Agricultural heritage of India	Y. L. Nene, Munshiram Manoharlal Publishers Pvt. Ltd	
3.	Relevance of heritage to present day agriculture, past and present status of agriculture and farmers in society	• KautilyasArthasastra • Physical geography of Indian sub-continent past and present • Indus valley civilization, vedic civilization and pastoralism • Harappa, Buddhist, Maurya, Gupta and Sangam period of agriculture	Glimpses of Agricultural heritage of India	Y. L. Nene, Munshiram Manoharlal Publishers Pvt. Ltd	
4.	Journey of Indian Agriculture and its development from past to modern era	• Period, events and ages of development of civilized agriculture • Development of Scientific agriculture in world • Advanced agriculture in 19th and 20th century	History of Agriculture in India Vol III	Randhava N. S., ICAR Publication	
5.	Plant production and protection through indigenous traditional knowledge	• Traditional tillage, cultivation, grain preservation, seed treatment technology and weed, disease and pest management practices	Indian Journal of Traditional Knowledge	NISCAIR, New Delhi	
6.	Crop voyage in India and world	• Description of Indian civilization and agriculture by different travelers from China, Europe and USA • Old and new world crop in detail with origin, country, introducer	Principles of of Agronomy	Reddy and Reddi, Kalyani Publication	
7.	Agriculture scope	• Detail scope of animal husbandry and crop production • Food production, supply, demand, export	Principles of Agronomy	S. R. Reddy, Kalyani Publication	
8.	Importance of agriculture and agricultural available in India	• Development of SAUs and ICAR with detail history • Important State, National and International agriculture institutes	Principles of Agronomy	S. R. Reddy, Kalyani Publication	
9.	Crop significance and classifications	• Classification of field crops according different criteria's	Hand Book of Agriculture	ICAR, Publication	

10.	National agricultural setup in India	• Structure of ICAR, SAUS, CAUs and Ministry of Agriculture (India and State)	Hand Book of Agriculture	ICAR, Publication	
11.	Current Scenario of Indian Agriculture	• Agriculture technology available in today's context e.g. Organic farming, Farming system, Precision farming, Microirrigation, Conservation Agriculture etc. • Place of Indian agriculture in Indian economy	Current Agriculture Research Journal	Bhopal, Madhya Pradesh	
12.	Indian agricultural concerns and future prospects	• Ill effects of Green Revolution, soil degradation, pollution (soil + water + air), malnutrition, water crisis, labour crisis, escalating input cost and produce prices and minimum support price of crop etc. • Vision of future agriculture in India, ecofriendly and low cost technology, protected cultivation, non conventional energy sources and its use, setting of agri/plant clinics and agri business centre, Use of ICT in crop production	Indian Farming	ICAR, New Delhi	

1. Introduction of Indian agricultural heritage

Globally Important Agricultural Heritage Systems (GIAHS), as defined by the FAO (Food and Agriculture Organization of the UNO), are: "Remarkable land use systems and landscapes which are rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development". Worldwide, specific agricultural systems and landscapes have been created, shaped and maintained by generations of farmers and herders based on diverse natural resources, using locally adapted management practices. Building on local knowledge and experience, these ingenious agricultural systems reflect the evolution of humankind, the diversity of its knowledge, and its profound relationship with nature. These systems have resulted not only in outstanding landscapes, maintenance and adaptation of globally significant agricultural biodiversity, indigenous knowledge systems and resilient ecosystems, but, above all, in the sustained provision of multiple goods and services, food and livelihood security for millions of local community members and indigenous peoples, well beyond their borders. For millennia communities of farmers, herders, fishers and forest people have developed complex, diverse, and locally adapted agricultural systems. These systems have been managed with time-tested, ingenious combinations of techniques and practices that have usually led to community food security, and the conservation of natural resources and biodiversity. Agricultural heritage systems can still be found throughout the world covering about 5 million hectares, which provide a vital combination of social, cultural, ecological and economical services to humankind. These “Globally Important Agricultural Heritage Systems-GIAHS” have resulted not only in outstanding landscapes of aesthetic beauty, maintenance of globally significant agricultural biodiversity, resilient ecosystems and a valuable cultural heritage. Above all these systems sustainabley provide multiple goods and services, food and livelihood security for millions of poor and small farmers. The existence of numerous GIAHS around the world testifies to the inventiveness and ingenuity of people in their use and management of the finite resources, biodiversity and ecosystem dynamics, and ingenious use of physical attributes of the landscape, codified in traditional but evolving knowledge, practices and technologies. Whether recognized or not by the scientific community, these ancestral agricultural systems constitute the foundation for contemporary and future agricultural innovations and technologies. Their cultural, ecological and agricultural diversity is still evident in many parts of the world, maintained as unique systems of agriculture. Through a remarkable process of co-evolution of Humankind and Nature,

GIAHS have emerged over centuries of cultural and biological interactions and synergies, representing the accumulated experiences of rural peoples.

Indian Agriculture

Indian agriculture began by 9000 BC as a result of early cultivation of plants and domestication of crops and animals. Settled life soon followed with implements and techniques being developed for agriculture. Double monsoons led to two harvests being reaped in one year. Indian products soon reached the world via existing trading networks and foreign crops were introduced to India. Plants and animals—considered essential to their survival by the Indians—came to be worshiped and venerated. The middle ages saw irrigation channels reach a new level of sophistication in India and Indian crops affecting the economies of other regions of the world under Islamic patronage. Land and water management systems were developed with an aim of providing uniform growth. Despite some stagnation during the later modern era the independent Republic of India was able to develop a comprehensive agricultural program.

Need and importance for studying Agricultural Heritage

Our agriculture has lot of inherited sustainable practices passed from one generation to other generation. And also agriculture in India is not an occupation; it is a way of life for many Indian populations. Hence the present day generation should be aware about our ancient and traditional agricultural systems and practices. This will enable us to build the future research strategy also. India has made tremendous progress in agriculture and its allied fields, but the emphasis on intensive use of inputs without considering their adverse impact of long term basis has created several problems related to sustainability of agriculture. Irrational use of chemical fertilizers, insecticides and exploration of natural resources is threatening the agro eco systems. Soil is getting impoverished, water and air getting polluted and there is an increasing erosion of plant and animal genetic resources. Therefore, attention in now shifting to sustainable form of agriculture. The indigenous technical knowledge (ITK) provides insight into the sustainable agriculture, because these innovations have been carried on from one generation to another as a family technology. There are several examples of valuable traditional technologies in India but unfortunately these small local systems are dying out. It is imperative that we collect, document and analyze these technologies so that the scientific principle/basis behind them could be properly understood. Once this done, it will be easier for us to further refine and upgrade them by blending them with the modern scientific technology.

Agriculture Heritage in India

Our heritage is unique than any other civilization. As a citizen of India, we must feel proud about our rich cultural heritage. Agriculture in India is not of recent origin, but has a long history dating back to Neolithic age of 7500-4000 B.C. It changed the life style of early man from nomadic hunter of wild berries and roots to cultivator of land. Agriculture is benefited from the wisdom and teachings of great saints. The wisdom gained and practices adopted have been passed down through generations. The traditional farmers have developed the nature friendly farming systems and practices such as mixed farming, mixed cropping, crop rotation etc. The great epics of ancient India convey the depth of knowledge possessed by the older generations of the farmers of India.

Objective of the course

Agriculture in India - Way of life and not an occupation

To increase awareness of the rich heritage of Indian agriculture which is unique than any other civilization.

To implant a sense of pride amongst the people, particularly agricultural students as our agriculture has sustainable practices for generations.

To stimulate scientific research based on traditional technology.

Definitions

HISTORY : Continuous record of past events

HERITAGE : Inherited values carried from one generation to other generation

AGRICULTURAL HERITAGE : Values and traditional practices adopted in ancient India which are more relevant for present day system.

History denotes the continuous record of past events, where as heritage indicates the inherited values carried from one generation to other generation. Agricultural heritage denotes the values and traditional practices adopted in ancient India, which are more relevant for present day system.

List of available documents on agriculture during ancient and medieval period

1. ***Rigveda*** **(c.3700 BC)**

Agricultural practices in the Vedic period presumably started from c.1500 BC and ended in c.500 BC, corresponds to last phase of the Chalcolithic period and Iron Age in India. The possible sites stretched from north-western parts of India to the entire alluvial of the river Ganges. The associated factors with agricultural practices in Vedic India to be included in the

present study are: (i) Soil, land and village settlement; (ii) Manure and manuring; (iii) Crop husbandry inclusive of plant protection measures, agricultural technology and agricultural implements; (iv) Irrigation system; (v) Animal husbandry and (vi) Meteorological observations in relation to crop prospects. The entire account has no treatise like approach but projected mostly through sacerdotal matters. The Vedic Aryans pursued pastoralism and agriculture as the mainstay of their livelihood. According to Max Muller the term A*rya*, derived from the root, *ar*, to stir, i.e., stirring of soil by means of stick or plough, shows Aryans were cultivators1 before separation as Indo-Iranian and Indo-Aryan. The Vedic Aryans for their existence on Indian soil had to fight against many obstacles. Appeasement of natural phenomena in form of anthropomorphic deities for existence and prosperity made them close to nature and natural objects. Analysis of related data on agriculture contained in the Vedic texts shows three prominent phases. The early phase shows struggle for fertile field. The twin god *Dya–va–-pr. thivi–* is extolled for snatching fertile field from the *dasyus* or Non-Aryans and granting to the Aryan people.2 Agricultural pursuits were thus not very easy for the Vedic Aryans at the early stage. Prayer to different godheads for copious rain and other favourable conditions congenial for raising of food crops (*anna*) and animal resources is frequent in the *Rigvedic mantras*. Agriculture occupied such an important place that *Su–rya* was conceived as having three bonds in three *lokas*. His bond in water, i.e. habitable world, explained by commentator Sa–yana are tillage, rain and seed.3 Thus in this hymn Vedic idea on three essentials of *Kr.s.i* (agriculture) is presented through this imagery of *Su–rya* in form of *Asfva*. A very few grain-crops are mentioned in the *R. gveda*. *Yava* (barley) is one among them. Obviously this shows the particular settlement area of the people at that time was favourable for cultivation of *yava*. Divinity was imposed on every conditions of nature. The entire agricultural operations were given a spiritual domination. This is found in the idea of *Ks.etrapati*, presiding deity of agriculture, indicating either *Rudra* or *Agni*, supervising all the agricultural activities.

2. *Atharvaveda* (c. 2000 BC)

The late Vedic period introduced manuring of *yava* (barley) seeds with clarified butter and honey as pre-sowing treatments of seeds. The *mantra*s uttered for this practice are laid down in the *Atharvaveda*. *Yava* (barley) was the only cultivated crop in the R. gvedic period. According to the story contained in the *Atharvaveda* , *yava*, the sweet corn was first cultivated by the gods on the bank of river Sarasvati– for the benefit of mankind. The great *Indra* was the furrow master and the *Maruts* were the ploughmen. Association with *Indra* and

Maruts suggests it as a rain-growth corn. Excepting bird no other pestiferous agents were known in the preceding period. A host of such elements infesting grains in the field and unfavourable natural phenomena causing harm to crops came to be known during the Atharvavedic period. The pests inclusive of natural phenomena were.

a) Borer (*tarda*) indicating either insect or bird, hooked insect (*saman.ka*),
noxious insect (*upakvasa)* and locust (*patan . ga*),

b) Rodents (*vyadvaras*) and rats (*a–khu)*

c) Reptiles

d) Natural phenomenon like lightening and sun. Charms and spells formed the preventive and remedial measures.

The late Vedic period introduced weed as pest in addition to those recognized in the *Atharvaveda*. Weed was particularly wheat-pest. Preventive and remedial measures were charms and spells in association with some substances appear to have pesticidal effects. These include: a) spreading of lead after furrowing, b) burying in field the metabolic product (grass) from the bowels of sacrificed cattle and some parts of particular plant substances. Weed control was also recommended by burying of several plant substances in the fields before sowing of seeds. The *Atharvaveda* refers winnowing fan (*sfu–rpa*) in this connection. Grains (here barley) were stored in a vessel (*urdara*). The next phase of the Vedic period, i.e., period of the *Atharvaveda* gave more stress on rain-water for irrigation. Utilization of river-water by diverting its course in channel became prominent. Green-manuring in soil fertility is a process that has continued from the Atharvavedic period till today.

3. *Ramayana* (c.2000 BC)

4. *Mahabharata* (c.1400 BC)

Mahabharata refers different names of river Sarasvati in its flows in different directions. There is mention of seven Sarasvatis indicating seven branches of river. The valley below Pehowa was known as Sapta Sarasvati i.e. the place where the river divided itself in seven streams. Saraswati disappeared in the desert at Vinasana before its meeting with Indus drainage. Its reappearance took place at Camasodbheda. Final union of Saraswati with sea has been mentioned in Rigveda and Mahabharata.

5. *Krishi-Parashara* (c.400 BC)

Krishi-Parashara (c. 400 BC) gives details of the design of the plow with Sanskrit names for different parts. This basic design has hardly undergone any change over centuries. A bamboo stick of a specific size was used to measure land. Vedic literature and Krishi-

Parashara also mention disc plow, seed drill, blade harrow (*bakhar*), wooden spike tooth harrow, plankers, axe, hoe, sickle, *supa* for winnowing and a vessel to measure grain (*udara*). Pairs of bullocks used for plowing in ancient days varied from one to eight. Krishi-Parashara (c. 400 BC) and Brhat Samhita give, what today one could describe as, simple astrological models for predicting rains in a particular season. Parashara's main technique of forecasting rain was based on the positions of the Moon and the Sun in the sky. In Krishi-Parashara, it is stated that crops grown without manure will not give yield and a method of preparing manure from cowdung is described. In Krishi-Parashara (c. 400 BC), a description of a cattle shed is found. Cleanliness of the shed was emphasized. To protect animals from diseases, cattle sheds were regularly fumigated with dried plant products that contained volatile compounds.

6. *Kautilya's Artha-sastra* (c.300 BC)
7. *Amarsimha's Amarkosha* (c.200 BC)
8. *Patanjali's Mahabhasya* (c.200 BC)
9. *Sangam* literature (Tamils) (200 BC-100 AD)
10. *Agnipurana* (c.400 ?)
11. *Varahamihir's Brhat Samhita* (c. 500 AD)
12. *Kashyapiyakrishisukti* (c.800Ad)
13. *Surapala's Vrikshayurveda* (c.1000 AD)
14. *Lokopakaram* by Chavundaraya (1025 AD)
15. *Someshwardeva's Manasollasa* (1131 AD)
16. *Saranghara's Upavanavioda* (c.1300 AD)
17. *Bhavaprakasha-Nighantu* (c.1500 AD)
18. *Chakrapani Mistra'sViswavallbha* (c.1580 AD)
19. *Dara Shikoh's Nuskha Dar Fanni-Falahat* (c.1650 Ad)
20. *Jati Jaichand's* dairy (1658-1714 AD)
21. Anonymous *Rajasthani* Manuscript (1877 AD)
22. Watt's Dictionary of Economic Products of India (1889-1893 AD)

2. Ancient agricultural practices

Traditional farming practices in India

Soil Classification

In ancient times geographical distribution by Surapala was jangala (arid), anupa (marshy) and samanya (ordinary). It is further divided by colour into black, white, pale, dark, red and yellow by taste into sweet, sour, salty, pungent, bitter and astringent. Samanya land was suitable for all kinds of trees. Rig-veda identified productive and non-productive soils. There were 12 classification based on soil fertility, irrigation and physical characteristics. These soil classifications are as follows :

1. *Urvara* (fertile)
2. *Ushara* (barren)
3. *Maru* (desert)
4. *Aprahata* (fallow)
5. *Shadvala* (grassy)
6. *Pankikala* (muddy)
7. *Jalaprayah* (water)
8. *Kachchaha* (land contiguous to water)
9. *Sharkara* (full of pebbles)
10. *Sharkaravari* (sandy)
11. *Nadimatruka* (land water from river)
12. *Devamatruka* (rainfed)

Another classification based on crops suitable

a. *Vrdiheyam* (rice (rainfed) / corn)
b. *Shaleyam* (kamala (wet) rice)
c. *Tilyam* (sesamum)
d. *Mashyam* (blackgram)
e. *Maudginam* (mung bean)

Sangam, Tamil literature classified soils as mullai (forest), Kuringi (hills), marudham (cultivable) and neithal (coastal).

Maintenance of soil productivity

Traditional soil management practices are the product of centuries of accumulated knowledge, experience and wisdom refined and perpetuated over generations. These practices were evolved within the framework of local technical possibilities. They enlivened the soil, strengthened the natural resources diversify and maintained the production levels in accordance with the carrying capacity of agro-ecosystem without damaging it. Ancient farmers mostly relied on crop residues, manures, legumes and neem for enriching soil fertility. In Kirishi - parashara, it is stated that crops grown without manure will not give yield and stressed the importance of manures. He also recommended compost preparation from cow dung. The dried, powdered cow dung is placed in pit for decomposition where weed seeds are destroyed. The time duration for composting is two weeks. Kautilya mentioned the use of cowdung, animal bones, fishes, milk as manure. Surapala describes the ancient practice of preparing liquid manure (kunapa) prepared by boiling a mixture of animal excreta, bone marrow, flesh, dead fish in an iron pot and then add it to sesame oil cake, honey and ghee. This is clearly evident that present day Panchakavya is prepared in the same way and used in all crops.

Liquid manure (Kunapa) : Preparation of kunapa involves boiling flesh, fat, and marrow of animals such as pig, fish, sheep or goats in water, placing it in earthen pot, and adding milk, powders of sesame oil cake, black gram boiled in honey, decoction of pulses, ghee and hot water. There is no fixed proportion of ingredients. The pot is put in a warm place for two weeks. This fermented liquid manure is called kunapa.

Green manures :

In Rajasthan : Prosopis cineraria - brings up moisture and nutrients from the underground and leaves used as green manure.

In Tamil Nadu : Calotropis gigantiea, Mortinda tinctoria Theprosia purpurea, Jatropha, Ipomoea Adathoda

In North India : A traditional weed Kochia indica used as green manure. Ancient farmers adopted crop rotation and inter cropping to restore soil fertility. Mixed or inter cropping with legumes in cereal and oil seed cultivation were widely practices. All these practices adopted in ancient time are now being recommended today under organic farming concept.

Water harvesting and irrigation developments during different periods – water storage – distribution and relevance to modern agriculture.

The need for continuous supply of water for irrigation whether from canal, well, pond or lake is realized as the most important for agriculture in ancient period. The different irrigation principles adopted in ancient period are :

- Construction of large mud embankment on a stone foundation for diverting flood water.
- Building of small tanks.
- Severe penalty was imposed when water is let out other than sluice gate.
- Extensive tank irrigation systems were adopted in Sri Lanka and later in South India. In Sri Lanka ancient kings practiced that not even a drop of rainfall should go to sea without benefiting man.
- The topography of Telengana region of Andhra Pradesh and Karnataka is ideally suited for the construction of tanks. A special feature of tanks in Telengana tank construction in series, by bunding the same valley at several points and surplus water from lower elevation and so on. Even now the tanks constructed by chola king in the same way exist today in Tamil Nadu.
- It is also suggested that preference of the use of water should be in the order of food crop, vegetables and flowers.

Table 1: History of irrigation development in India

SN	Period		Irrigation development
1.	Ancient Period	2500 - 1000 BC	People settled near the banks of river / tanks for the purpose of getting water for drinking and irrigation.
2.	Chalcolithic	3000 - 1700 BC	Practice of irrigation to crops was evolved.
3.	Vedic period	1500 - 1600 BC	People employed craftsman to dig channels from rivers to their fields. Well irrigation through kuccha and puccha wells and were practiced
4.	Pandyas / Cholal chera‟s Period	(1st Century 300 AD)	Irrigated rice cultivation started during this period. Dams and Tanks were constructed for irrigation.
5.	Medieval period	(1200 -1700 AD)	Irrigated agriculture was developed during Mogul period. Canals, Dams and Tanks were constructed (e.g.) 1. Construction of western yamuna canal 2. Constructions of Anantaraja sagar.

Methods of conserving rain water

In ancient days itself, people, especially Indians, know the methods of conservation of rain water. There are evidences that, even during Harappan period, there was very good system of water management as could be seen in the latest excavation at Dholavira in Kachch. Rain water harvesting structures in the low rainfall areas of Rajasthan, harvesting springs in hilly areas and mountainous region and percolation ponds and tanks in southern India. In Tamil Nadu, the ancient people stored rainwater in public, placed separately one for drinking purposes and another for bathing and other domestic purposses and called them as Ooranies. The various methods of rainwater harvesting are classified below under two category, Traditional and Modern methods. Traditional rainwater harvesting, which is still prevalent in rural areas, was done in surface storage bodies like lakes, ponds, irrigation tanks, temple tanks etc. In urban areas, due to shrinking of open spaces, rainwater will have to necessarily be harvested as ground water, Hence harvesting in such places will depend very much on the nature of the soil *viz*., clayey, sandy etc. The below listed are the various kinds of traditional rainwater harvesting methods. The Modern methods of rainwater harvesting are categorised under two, they are Artifical Recharging and Rain Water Harvesting. The former is classified into Absorption Pit Method, Absorption Well Method, Well cum Bore Method and Recharge trench cum injection well. The later is categorised into Individual Houses and Grouped Houses which are further classified into Percolation Pit Method, Bore Well with Settlement Tank, Open Well Method with filter bed Sump and percolation Pit with Bore Method.

Bamboo method of rainwater harvesting

In Meghalaya, an indegenious system of tapping of stream and springwater by using bamboo pipes to irrigate plantations is widely prevalent. It is so perfected that about 18-20 litres of water entering the bamboo pipe system per minute gets transported over several hundred metres and finally gets reduced to 20-80 drops per minute at the site of the plant.

Kunds of Thar Desert

In the sandier tracts, the villagers of the Thar Desert had evolved an indegenious system of rainwater harvesting known as kunds or kundis. Kund. Usually constructed with local materials or cement, kunds were more prevalent in the western arid regions of Rajasthan, and in areas where the limited groundwater available is moderate to highly saline. Groundwater in Barmer, for instance, in nearly 76 per cent of the district‟s area, has total

dissolved salts (TDS) ranging from 1,500-10,000 parts per million (ppm). Under such conditions, kunds provide convenient, clean and sweetwater for drinking.

Traditional Rain water harvesting

The traditional rainwater harvesting methods in North India is surface water harvesting methods are viz., Tanka, Nada, Nadi, Talai, Talab, Khadin Sar, Sagar and Samend.

***Tanka*:** It is constructed of on farm, country yard and fort. The shape is normally circular / square. Dimension is 2 m dia. 3 m deep capacity 10000 lit

***Talai*:** Similar to Tanka, still deeper (2-3cm depth). Special attention paid for selection of location such that there is adequate flow of rain water into Talai

***Nada*:** In this method, low lying areas in between hillocks is excavated as pit and provided embankment to arrest rain water from these hillocks.

***Nadi*:** Compared to Nada. the Nadi is bigger in size. A village or group of Villages uses the run off water collected in the Nadi.

***Talab*:** It is relatively shallow and spread over to more area compared to Nadi. It is generally constructed in rangeland. The catchment area of Talab is 480 ha., can lost for many years.

***Khadin*:** Accumulation of run off water in between hillocks is known as Khadin. Khadin means cultivation crops. The khadin water is generally used for crop cultivation and animals.

***Sar, Sagar* and *Samand*:** It is used to harvest rainwater for irrigation purpose. Even today this structure provides excellent source of reservoir and also tourist spot.

Weather forcasting

Astronomy – Prediction of rains:

PARASHARA, VARAHAMIHARA PANCHANG

Modern scientific knowledge of methods of weather forecasting have originated recently. But ancient indigenous knowledge in unique to our country. Indian had glorious scientific and technological tradition in the past. A scientific study of meteorology was made by our ancient astronomers and astrologers. Even today, it is common that village astrologers (pandits) are right in surprisingly high percentage of their weather predications. Observation coupled with experience over centuries enhanced to develop meteorology.

The ancient / indigenous method of weather forecast may be broadly classified into two categories.

1. Observational method
    - Atmospheric changes
    - Bio-indicators
    - Chemical changes
    - Physical changes
    - Cloud forms and other sky features

2. Theoretical methods (or) Astrological factors (or) planetary factors
    - Computation of planetary positions and conjunctions of planets and stars
    - Study of solar ingress and particular date of months
    - Study of Nakshatra Chakras
    - Study of Nadi Chakras
    - Dashatapa Siddhanta

Almanacs in Indian astronomy and astrology (Panchangs)

According to the Encyclopedia Britannica (1969), " an almanac is a books or table containing a calendar of the days, weeks and months of the year, a register of ecclesiastical festivals and saint"s day and a record of various astronomical phenomena, often with weather prognostications and seasonal suggestions for countrymen".

In India, the classical Hindu almanac is known as „Panchang". This book published yearly, and is the basic book of the people all over India. For astrologers, it is one daily basis and is extensively used by the people all over India. For astrologers, it is one of the basic books for making astrological calculators, casting horoscopes, and for making predictions. For farmers, it is an astrological guide to start any farming activity.

The word „panchang" has it"s roots in two Sanskrit words, viz., „panch" and „ang", which means „five" and „body part/limb" respectively. These parts are

1. Tithi (or) Lunarday – Total of thirty tithes in a lunar month, fifteen in each fortnight.
2. Vara or week day – seven varas, (Monday-Sunday)
3. Nakshatra (or) asterism (or) constellation – Total of twenty seven nakshtras named according to the yagataras (or) identifying stars of each of the twenty seven equal parts of the ecliptic (or) solar path.
4. Yoga (or) time during which the joint motion of the sun and the moon covers the space of the nakshatra (there are twenty seven yogas).
5. Karana (or) half of a lunar day (or) half – tithi.

The other items considered for astrological prediction are

1. Rashi (or) twelve equal parts of the Zodic belt, hence twelve rashis
2. Planets
3. Solar months and solar year
4. Lunar months and lunar year
5. Era

Theoretical basis of weather forecasting in ancient literature and panchangs

According to varahamihira and other scholars, the formation of clouds (or) garbhadharana takes place 195 days before their birth (or) delivery (or) garbhaprasava. During his period clouds were grouped as Abartak (Avartak), Sambartak (Samvartak), Pushkara and Drona. It abartak is dominating one year, rain will be received in certain places in that year; if sambartak, rain will be received in all of the country; if pushkara, the quantity of will be very less; and if drona, that year will receive abundant rain water.

It is also true even today, the cloud classification indicates Cirrus, Cirrostratus, Cirro Cumulus, Altostratus, Altocumulus, Stratocumulus, Stratus, Nimbo Stratus, Cumulus and Cumulonimbus. Among this Nimbostratus and Cumulonimbus gives rainfall to the earth.

According to the ruling planet of a year, overall rainfall of that particular year should be anticipated as follows:

S.No.	**Ruling planet**	**Rainfall**
1.	Sun	Moderate
2.	Moon	Very heavy
3.	Mars	Scanty
4.	Mercury	Good
5.	Jupiter	Very good
6.	Venus	Good
7.	Saturn	Very low (Stormy wind)

For predicting the monsoon and its subsequent effects on weather, all panchang makers consider three different Nadi Siddhantas (Capsular theories) commonly known as Nadi charkas. These are :

1. Dwinadi charks
2. Trinadi charks
3. Saptanadi charks

Table 2:Arrangement of nakshatras in Saptanadis and its associated effect on weather

Seven nadis	Effect on weather
Chanda	Bright sunshine, no rainfall
Vata	Sunshine and wind, normal rainfall
Vanhi	Strong hot wind (Westerlies)
Soumya	Normal rainfall
Meera	Very good rainfall
Jala	Abundant rainfall
Amrita	Heavy to very heavy rainfall causing flood

Prediction analysis and discussion

The analysis indicates that rainfall predictions made in panchangas based on ancient astrological theories are, on an average, better than and in some cases at par with the predictions made by Govt. meteorological department through modern techniques and procedures.

(E.g.) The yearly fully corrected predictions of rainfall made during 1946-1955 were 75,78,74 and 75% respectively for different panchangam. The seasonal prediction also indicated that it was 89% for summer, 55% for rainy, 90% for winter and 78% for overall.

Method for measurement of rainfall

The method of measurement of rainfall is described by Varahamihira. A circular vessel with a diameter equal to one (human) arm or the distance measured by the width of 20 (human) fingers and with a depth equal to the distance measured by the width of eight fingers should be accepted for measurement of rainfall. When this vessel is completely filled with rainwater, the rainfall should be equal to 50 palas or one adhaka. This method has been explained by the Parashara.

According to Parashara, the basic unit of rainfall is adhaka.

1 adhaka = ¼ drona (eq.1)

1 drona = 4 adhakas = 6.4 cm (eq.6)

Krishi – Panchang

The researcher developed the Krishi panchang (or) Agroalmanac (or) Agro-panchang. It may be defined as basic astro-agricultural guide book/calendar published annually, giving calendrical information on various aspects of agricultural and allied, activities, basically suggesting region wise, seasonwise and cropwise. Crop strategy based on astro – meteorological prediction, giving auspicious time for undertaking various farm related

operations, along with a list for performing religious rites, festivals, observing fasts and some non-astrological agricultural guidance, primarily useful for the farming communities and persons having interest in agricultural development.

The contents of the proposed Krishi-Panchang can broadly be categorized into two kanor groups as fallows :

1. Information which changes every year

    - Annual date and Holiday calendar
    - Month – wise daily guide for the whole year
    - "Rashiphal", i.e., month-wise forecasting of persons having different zodiac sings.
    - Daily/monthly/annual weather forecasting for the particular year
    - Crop prospects of that year based on planetary positions
    - Season-wise crop strategy based on anticipated weather

2. Information which remains same irrespective of any particular year

    - Theories relating to agricultural and meteorological forecasting
    - Auspicious moments for agricultural and allied activities
    - Some general agricultural guidance

Panchang-making

The content and coverage of the proposed Krishi-Panchang, indicate that only qualified astrologers cannot prepare the whole content on their own, rather an editorial board comprising of both qualified astrologers and crop specialists can do justice. While preparing the Panchang, the – editional board members should keep in mind the following important points :

- The Krishi-Panchang is largely meant for the local farming communities, having very low educational status. Hence, it must be in the local colloquial language to facilitate reading and comprehension.
- Care should be taken to make the Krishi-Panchang easily understandable and clear in its meaning.
- It should be very comprehensive in its content and coverage with proven predictive information only.
- It should not contain any astrological details or complexities which would go beyond the understanding capability of our less educated farmers and agriculturists.
- It should be attractive in colour, and presentation of information should be systematic according to season (kharif, rabi, and summer) and crops.
- It must be low-priced/nominal-priced, within the affordable range of small and marginal farmers.

More important, is, the must be made available to the farmers and needy persons sufficiently in advance, i.e., at least 1-2 months before the start of the agriculture year (July-June).

Local knowledge used to predict drought and weather pattern

Table 3:Drought prediction and mitigation

SN	Predictors/Signs	Description
1	Pigeon feathers	Pigeon lying on the ground by spreading its feathers, the indication of drought
2	Sound of wild cat	If the wild cat make sound with *Dhul*/*Mul* and people as to the wild cat and response with *dhul* then drought may occur
3	Ants upward movement	If ant starts to move upward from down, rain may come
4	Red colour in the west sky	If the sky shows bright red colour in the west sky during sunset, drought may ome in the following year
5	Sun lights kid	If sunny days show illusion like *roder bachha*, drought may occur
6	Thunder in the east sky	If frequent thunder happen in the east sky at night. This indicates drought in the next year
7	Abundance of termites	When large number of termites found in the mound, drought is the immense issue for the year
8	Visibility of black ant	Appearance of black ants and storing grain and eggs in safer places indicate that the rain follows for the couple of days
9	Hoppers fly	If hopper fly randomly, drought may occur
10	Dark clouds in the west sky	The appearance of dark clouds on the west, the immediate hail storm accompanied by thunder, lighting and kalboishakh
11	Chirping of Fatik bird	The chirping of Fatik bird during October to April is a sign of rainfall
12	Rainbow	If rainbow come in the eastern sky, there would be chance of drought and if it comes in the western sky that indicates sure rains

Table 4. Local knowledge used to reduce drought impact and extreme weather

SN	Practice	Description
1	Frogs marriage	Arrange marriage for the frog to invite immediate rainfall to end the drought
2	Use mulch	Farmers were used straw and water hyacinth as the mulch materials in the horticultural production at their homestead to protect drought impact on production
3	Orchard establishment	Farmers were established mango orchard at their homestead and the crop field to mitigate drought impacts as a whole
4	Planting trees	Long back peoples in the area were planted trees especially palm trees to protect drought and its impacts as a whole
5	Short term mitigation	Farmers alone or along with family members were migrated to the urban areas for livelihoods and return to the home after drought effects
6	Home ardening	Peoples started vegetable gardening in their homestead to protect drought impact on agricultural production

Local Farming Knowledge in India

Presently, the loss of biological diversity and erosion of traditional knowledge systems (TKS) are issues of great concern. Most of these systems of knowledge are unique and are often known only to a few individuals or communities**.** This traditional knowledge includes mental inventories of local biological resources, animal breeds, local plant, and crop and tree species. Traditional knowledge may include information about trees and plants that grow well together, about indicator plants that show the soil salinity, or are known to flower at the beginning of the rains. It includes practices and technologies, such as seed treatment and storage methods, and tools used for planting and harvesting. Traditional knowledge encompasses belief systems that play a fundamental role in people's livelihood, maintaining their health, and protecting and replenishing the environment. and value which include traditional knowledge.

The following traditional agro ecosystems were adapted to minimize crop loss due to insect and pests:

(a) *Ploughing*, hoeing and basin preparation to influence soil inhabiting pests through "microclimate manipulation", e.g. goat droppings burnt along with dried *Euphorbia spp.* to maintain a smoke blanket layer throughout the night arresting the pathogenic activity,

(b) *Intercropping* of diverse plant species to provide habitats for the natural enemies of

insect pests as well as alternative host plants for pests, and also to prevent competition of crops from weeds,

(c) *Shifting* cultivation that helped the easy migration of natural pest predators from the surrounding forest,

(d) *Genetic diversity* of cropping systems followed to delay the onset of diseases and reduce the spread of disease-carrying spores, and modify environmental conditions less favorable to the spread of certain diseases,

(e) Practice of integrated crop-livestock systems to balance the biomass and nutrient inputs and outputs.

Examples of traditional knowledge and practices

Animal healthcare practices

- Hot soup of Cumin and garlic being analgesic and antipyretic fed to animals affected by fever and cold.
- Use of bark of belly tree/crushed leaves of karnu tree as antiseptic for speedy healing.
- Mixture of ash of Burning grass (*Jawanlari)* and black cloth along with oil fed to cows to cure dysentery.
- Mixture of sulphur and mustard oil for prevention and control of skin diseases.
- Use of bamboo leaves and bark boiled with paddy husk and fed to cows for expulsion of placenta.
- Treatment of diarrhea with leaves of *Leucas lanata* (*Safeda*) and bamboo leaves.
- Traditional moulting practices - Dipping in water, applying ash and mud, quarantine the birds to dark locations in separate mini huts, fixing feathers on to the beak followed for shedding and regrowth of feathers and rejuvenation of poultry birds.
- Use of garlic *(Allium sativum) and* vinegar for deworming.
- Juice of marigold/ *Annona squamosa* leaves to kills maggots and heal wound.

Plant protection and Post-harvest management

- Packaging of food commodities using containers made of bamboo sticks and internally lined with cow dung for grains, potato, maize cobs, etc or lime and sand for millets.
- Use of neem/mint/walnut/*sweet flag* leaves/*Pongamia pinnata* as antimicrobial agent for grain storage.
- Storage of pulses by mixing with turmeric powder or mustard oil.

- Storage for seed crops in under ground pits dug in fields with a pitcher and covering the top of pit with ash and soil to create zero energy cool chambers.
- Pickled mango, lime, etc. packed in sterilized earthen pots using fumes generated from burning red chilies along with *Asafoetida* and mustard oil.
- Storage of cabbage, ginger was done under ground pits which provided cool condition for storage ensuring freshness for prolonged use.
- Storage of sugar/jaggery in large earthen pots with top cover made of wood.
- Enhancement of shelf life of fruit and vegetables by wrapping in moist gunny bags.
- Use of smoke for protection of fruit crops from frost damage.
- Practice of applying a thin paste of cow dung, clay and cow urine to pruned ends of twigs and cuts to prevent access to pathogens.
- Use of wood ash on vegetables to ward off pests and to enhance nutrient status of soil.
- Use of kerosene oil to kill stem and shoot borers.
- Use of powder of leaves and pods of *Mucuna prurita* to reduce rat damage to the crop.
- Use of crushed seeds/extracted oil of castor against Rhinoceros beetle, Nematodes infestation in coconut, Pulses and cereal seeds.
- Use of chilies and other hot peppers powder against caterpillars, flies, aphids, ants and other pests of vegetables.
- Use of Pulses soaked in whey to prevent wilting.
- *Euphorbia neriifolia* milk for seed protection of various crops like paddy, castor, pearl millet, maize and Sorghum.

Weather forecasting

- Presence of visible spectrum with a greater diameter around the sun than around the moon, indicates rainfall after a day or two.
- On a hot summer day cry of the bird called *Nailu* for water brings rainfall.
- If centipedes emerge from their holes carrying their eggs in swarms an early rainfall is predicted.
- If Dragon fly swarm in a large group over water surface a dry weather is predicted, if they swarm over open dry lands then early rainfall is predicted.
- If the first 10-15 of the month May-June are very hot a good rainfall is predicted.

Sustainable natural resources management

- Indigenous techniques of harvesting honey and beeswax from bees, using various

indigenous styles of hives.

- *Polygonum hydropiper* Linn. (Smart weed) used as fish toxicant for catching fish from natural aquatic resources as well as for removal of uneconomical fishes from the aquaculture pond.
- Mollusc shells-*Anadara granosa* (*Khola)*, *Meritrix meritrix* (*Gondhi*), *Meritrix casta.* (*Pati*) and *Ceritidea cingulata* (*Genda*) traditionally used for lime preparation.
- Inhibition of bacterial growth in milk by keeping under the pyramids made out of natural materials as wood.
- Use of indigenous fishing instrument *Polo* for capturing fishes in low water raising.
- *Alnus nepalensis* cultivated in *Jhum* in Nagaland has multiple usages as a nitrogen fixing tree, as fodder and timber, and retains soil fertility.

Soil and water management

- Construction of *kuhls*/wooden water channels/ *Virdas*/*Khadins* for irrigation.
- Drip and pitcher irrigation in areas with scanty rainfall.
- Use of bamboo channels with small holes made at the internodes for water trickling.
- Roof water harvesting and collection of water in dug out structures (Wells, *Bawdi*).
- *Sorangas* in Karnataka in the lateritic regions to tap the moisture trapped in the large sand depositions, *Ahar-pyne* traditional irrigation system in Bihar
- Harvesting of dew and fog water.
- Conservation of soil moisture by mulching: Wet soil mixed with seeds of rye (*Brassica nigra*) is placed inside the holes left between the stones of terrace risers for minimization of water need for germination and use of the unused space of terrace riser for vegetable cultivation.
- Earthen bunds made of different materials like stones and sticks, *Kana bundi* using the crop residue, *Vetiver zizaniodes* grass for controlling soil erosion.
- Methods used for improvement in soil fertility by burning *Butea monosperma* and *Madhuca indica*) leaves and branches, cultivation of crops with trees such as *Sesbania grandiflora*, *Leucaena lecocephala* or other leguminous plants, local weeds.
- Indicators to assess the fertility of soils by better growth of weeds like *Setaria tomentosa* in light soil, vigorous growth of *Desmostachya bipinnata* and *Cenchrus spp*, *Echinochloa colonum* growth for better paddy yield.

Indigenous seed conservation and preservation

Conservation of seed is the conservation of planet (*Srishti*). Seed contains the basic DNA, which is capable to produce the plant of the same kind. For protection of seed material, the practices of our ancestors are evident from pre-historic, historic and *vedic* periods. Storage of seed in cylindrical pits dug in earth or in granaries or in containers made of ropes and plastered with mud or in well baked clay pots, scaring away birds with sling balls, initiation of mixed cropping technique, controlled use of water irrigation in fields, etc. are the some specific practices found in use during these periods. Many examples of crop and seed protection such as making din and noise for bird scaring in maize fields, setting traps or digging pits and fix traps in the fields to keep away the wild animals. Use of cow dung, milky juice of *Solanum indicum,* coconut water, *Emblica ribes,* cow urine and *ghee* (butter oil), etc. for treatment of seed material were practiced during vedic era. For control of pulses bruchid (*Callosorbruchus chinensis*) the oil of *Mentha spicata,* or *M. arvensis* or *M. piperita* was found very useful. Gunny bags are used for bulk storage of cowpea (*Vigna unguiculata*) seeds. For prophylactic treatment, these bags are soaked in 15% concentration of leaf extracts of *Pongamia pinnata* or *Justicica gendarussa.*

The use of wooden and cow dung ash and red baked soil as seed dresser because the quantity of silica in these might have deterred the egg formation and larvae feeding. The use of ash and soil as indigenous pesticides is reported in so many literatures. Similarly the uses of *Vitex negundo, Azadirachta indica, Eucatyplus* are very common and effective treatments. The uses of various plant parts as storage pesticides, because these plant parts emit a pungent type smell. This is because of availability of essential oil in the plant parts. The emission of a kind of smell acts as a repellent of insect and deters their survival. *N*eem (*Azadirachta indica* A. Juss) contains meliacin, nimbin, nimbinene, nimbandiol and azadiractin, walnut (*Juglens regia* L.) leaves contains ascorbic acid, carotene and juglone. *Bakayan* (*Melia azadirachta* L.) contains meliacin, turmeric (*Curcuma longa* L.) contains phenolic compound known as curcuminoides, lemon (*Citrus limon* L.) contains lemon oil, citric acid and pectin and mustard oil contains allyal isothiocynate. All these substances found in the above plant materials have been reported to be antifeedants against several pests.

Table 5: Plant parts and other materials used for seed/grain protection

SN	Materials used for pest control	Crops	Types of material
1	*Bach* (*Acorus calamus* L.); rhizome and leaves	Cereals and pulses	Seeds and grains
2	Peach (*Prunus persica* L.);leaves	Cereals and pulses	Seeds and grains
3	Neem (*Azadirachta indica* A. Juss); leaves	Cereals, oil seeds and pulses	Seeds and grains
4	*Timur* (*Zanthozylum armatum* DC.); leaves	Cereals, pulses and oils seeds	Seeds and grains
5	Walnut (*Juglens regia* L.); leaves	Cereals and pulses	Seeds and grains
6	*Bakayan* (*Melia azadiracta* L.); leaves	Cereals and pulses	Seeds and grains
7	Turmeric (*Curcuma longa* L.); leaves	Cereals and pulses	Seeds and grains
8	Lemon (*Citrus limon* L.); leaves	Cereals and pulses	Seed and grains
9	Wooden ash	Wheat, barley and rice seed material	Seeds
10	Cow dung ash	Cereals	Seeds
11	Cow dung + cow urine	Cereals and pulses	Seeds
12	Kerosene oil	Pulses	Seeds
13	Lime powder	Pulses	Seeds
14	Mustard oil	Pulses	Seeds and grains
15	Red roasted soil	Cereals and pulses	Seeds

Local farming knowledge in Gujarat

Traditional knowledge in food and fibre

Tribals in south Gujarat region use more than 43 species as fodder plants. Fibers are extracted from varied sources by the tribals. The people of the coastal region extract fibers from palms. In forest areas, fiber-yielding trees like *Combretum ovalifolium*, *Butea parviflora* and *Derris scandens* are used for ropes. Roots of *palash* are also woven into ropes. In Dangs, ropes made from fibers extracted from the leaves of *Ketki* are durable and used for tying cattle, as these ropes do not hurt their skin. Kotwalia community is specialised in making decorative bamboo artifacts.

Traditional Grain Storage Structures in Gujarat

Kothi: These storage containers, mostly known as *Kothi* are made out of leaner bamboo strips. Weaving patterns depend upon thesize of the grain to be stored. They are known by different names in different parts of the state such as *Mosti* (pic. h) in Vadodara and Chhotaudepur districts, *Porsi* and *Porso* in Panchmahal and Dahod districts, *Kothi* in Sabarkantha, Vadodara, Narmada, Tapi, Surat, Valsad and Dang districts. The outer surface of the storage structure is generally covered with fine mixture of loam, cow dung and husk. It prevents spillage and strengthens the storage structure.

Folding Kothi: A few communities in Dang district use folding grain storage containers. They look like carpets weaved using leaner bamboo strips only. These carpets are rectangular in shape but they have two bamboos weaved at their ends, what seems like these bamboos are knotted together, which makes a cylinder to store grains . This kind of grain storage structures are almost 6 feet tall and 200 kg to 250 kg grain storage capacity and have no permanent base or lid. Just like other *Kothi*, it is also covered entirely with fine mixture of loam, cow dung and husk. Top is also covered with dry *Tectona grandis* L leaves and sealed with fine mixture of loam, cow dung and husk.

Nagli ni kothi (Kothi for Eleusine coracanaL): Nagli (*Eleusine coracana* L) and Vara (*Panicum sumatranse* Roth) are lesser known cereal crops planted mostly in central and south Gujarat. These grains are very small in size hence, stored in very complexly woven storage containers. These containers are smaller in size, almost 2 feet tall, and dome shaped with flat base, movable and light weight.

Kanthi ni Kothi (Kothi made of Nyctanthes arbortristis L): All the above mentioned storage containers are made either from *Dendrocalamus strictus* (Nees) or from *Bambusa arudinacea* (Willd). But there are a few locations where the local inhibitors use plants apart from bamboo to make grain storage containers. *Bhils* from Sabarkantha district use *Nyctanthes arbortristis* L to make almost 8 feet tall cylindrical grain storage containers.

Dudhi ni Kothi (Kothi made of Wrightia tinctoria RBr): Some tribes of Vadodara, Chhotaudepur and Narmada districts use *Wrightia tinctoria* R Br twigs to make huge cylindrical grain storage structures. Due to the high amount of latex present in the plant makes the containers termite resistant. These *Kothi* are usually 5 feet tall and mounted on a platform made of mud and interwoven fresh twigs of *Wrightia tinctoria* R Br.

Gara ni Kothi (Kothi of Mud): Kutch is the far North-Eastern district of the state with diffused scrub forest and arid to semiarid climatic conditions. It is difficult to find resources like *Dendrocalamus strictus* Nees or *Bambusa arudinacea* (Retz) Willd naturally in Kutch due to the climatic conditions. Hence, residents of this district have come up with a solution of storage structures majorly made of mud. These storage structures are made of loam, donkey dung, wheat husk, and yellow salty clay typically found in Kutch.

Gara ni char-paiee Kothi (Four legged Kothi of Mud): Dwellers of Sabarkantha district use this kind of storage structures which are difficult to make as compared to the structures made of Bamboo. They are entirely made of loam, cow dung, and wheat husk and very heavy in weight yet movable. These structures are cylindrical in shape, almost 5 feet tall with a huge intake at the top to pour grains in and four legs at the bottom which keep the storage container elevated from the ground. These storage structures are highly durable and used for generations.

Dangar ni Kundi (Kundi for Paddy storage): These storage structures are reported form Sabarkantha district which are used to store paddy. They look like *char-paiee Kothi* and

made of loam, cow dung, and wheat husk but small in size with a huge intake at the top and three or four legs at the bottom which keeps the storage elevated from the ground. They are 1-1.5 feet tall, movable and long-lasting.

Methods of Grain Preservation

Many domestic grain storage practices are followed in Gujarat. Most of them have one or more ecofriendly natural resource used to store grains round the year.

Castor Oil: It is the most common practice followed in which sundried grains are smeared with a little amount of castor oil. Wheat, Rice, and a variety of pulses are stored using castor oil. Excess amount of castor oil changes the natural taste of grain and so it is made sure that the seeds are just smeared with oil. Almost 1kg oil is needed to preserve 100kg of grains.

Leaves of Azadirachta indica A Juss: Dried leaves of *Azadirachta indica* A Juss are mixed with sundried grains and stored into traditional storage containers. This practice is common in most areas of the state. Aspiration cleaning is must before using seeds. *Bhils* of Central Gujarat use *Azadirachta indica* A Juss leaves in a different way, by adding dried leaves of *Azadirachta indica* A Juss to the mixture of loam, cow dung and husk which is used to cover inner and outer surfaces of storage containers which provides protection against pest.

Leaves of Calotropis procera (Ait): Fresh leaves of *Calotropis procera* (Ait) are collected and dried in shed. These leaves are spread on the inner surface of the storage containers such a way that they cover the whole inner surface of the container.

Para ni Thepli (Dice made of Mercury)

This is an interesting technique which includes a heavy metal – Mercury. Take 100gm of Fuller‟s earth (Multani Mitti), 200gm of clay and 200gm of dried cow dung powder. Mix it well and add 10ml of Mercury in it. Then add some water and make dough. Make small round shaped *thepli* (dices) out of this dough and sundry them. Put almost 50 of such *thepli* with every 100 kg of grains. This *thepli* can be used for 10 to 15 years.

Cow dung ash

Cow dung is burned on a clean surface and ash is collected. This ash is mixed with grains while storing them in the storage containers. For that a 3 inch layer of ash is made at the bottom of the container. On which, almost 10 inch of layer is made of the grains. Then againa 3 inch layer of ash is spread over. Whole structure is filled with grains and ash likewise, layer by layer. Aspiration cleaning is must before using seeds.

Other Storage practices

Bamboo shoots preservation
Hibiscus sabdariffa L leaves preservation
Earthen vegetable preservation
Preservation in Salt
Fruit preservation in saltwater

Fishing ITK in Gujarat

Saurashtra peninsula is the major fishing area of the state. It consists of seven districts namely Amreli, Bhavnagar, Jamnagar, Surendranagar, Junagadh, Rajkot and Porbandar. Saurashtra region occupies about 50 percent of state,s coastline, and accounts for more than 70 percent of fish production of Gujarat state. Fishing has therefore become a flourshing industry in this area . The detailed description of the ITK‟s collected from Saurashtra region of Gujarat are given below.

Catching whale shark by trawlers: This method is known to all trawlers from Porbandar to Jaffrabad. The shark fins, oil from liver, and flesh had fetched good returns for these fishermen.

Wooden wada fish catching technique: This is an age old technique in vogue by the traditional fishermen of Jamnagar district. Mostly the catch consists of Sciaenids.

Fish harvesting by stone wada: This is an age old technique for catching fish. The catch comprises miscellaneous varieties, and ensures fish for family and the surplus is sold in the local market. The bigger varieties are iced and sold in nearby cities.

Mechanically shocking the fishes: Wherever there are rocky coasts with puddles, traditional fishermen usually go for single line hooking. If the place does not fetch any hooking, then the fishermen move to the next nearby area. While walking through intertidal areas, he may come across such puddles in which fishes may be there. Usually children of these fishermen scout these areas, & they have been observed to carry out this operation. For the poor fishermen, catching of these fishes does add to their bread basket.

Indian Sea bass catch from underneath boulders on coast: The fishermen who operate hook & line carry out this operation when they move along a rocky coast line. This operation has been observed in Beyt Dwarka & Mithapur. Indian sea bass being a priced fish, and the fish usually caught being of a big size, this method cannot be avoided by the scouting fishermen.

Extracting Solen from muddy coast: When wooden wada fishermen go for collection of fish in the wada, both to & fro, they need to walk on such areas, where these Razor Clams are found. By this method, they can remove the animal from its daily fishing path, & forms their food.

Catching sand crab Description of the ITK: Sand crabs live in sandy beaches often digging burrows in sand move quite fast and bigger ones which is to be caught when gets inside burrows with sandy beaches is packed with dry sand. When excavated, the dry sand can be distinguished from wet sand which when dug up and then the crab can be found at the end of the dry sand channel.

Cast netting of inshore sepia: This technique has been in use by Veraval fishermen and the same technique (without the use of petromax) is used by Miyani fishermen for cast netting oil sardines from near shore waters through dugout canoes.
Natural thermal fatality: Fishermen know that at particular time of the year, the air as well as the seawater temperature gets to higher levels by mid day, and this kills the fish near costal waters.

Traditional water harvesting techniques

In Gujarat, the traditional water harvesting techniques has been revived and 35 other Villages of Amreli district are known for their hard, rocky terrain on account of their peculiar geological features. These areas could not conserve rain water. However, the situation has been changed by raising dykes to check rain water along with the putting up of check dams and percolation tanks. Water and famine in these perpetually drought prone rural areas of Gujarat has become a thing of the past with flourishing green farmland fields one from all side.

The *Tanka* of Bharuch.

The Zoroastrians are believed to have brought the concept of harvesting water from ancient Iran to Bharuch. The „Tanka" is an underground tank, accommodated inside the house, made of chiseled blocks of stone, in lime mortar. It is made waterproof by an indigenous herbal mix, which seals minor cracks and prevents bacteriological growth inside the Tanka. The size of the Tanka is large enough to store sufficient drinking water for a family for six to eight months. An average storing capacity of the Tanka is around 25,000litres. When required to be cleaned, Tankas must be emptied manually, they are large enough for people to enter and work inside.

The Tanka feeds on the rainwater collected through roof runoff. A simple system of collection, via a 3″ to 4″ pipe, depends on successive sumps whose water is collected, while settled impurities are flushed out through an overflow pipe. The Tanka has a hatch cover, which is kept closed except for the time when water is needed. The water retention capacity of these Tankas is seen in the form of a particular „danger level" indicated inside the tank by the depiction of a sculptured „fish". Filling above this mark was considered dangerous as the hydraulic pressure inside may well exceed the retaining capacity of the tank wall. Most owners clean the Tanka only once in 5 to 10 years. The water quality of the Bharuch Tankas has been tested and found to be potable by W.H.O. standards.

Virda

Virdas yield fresh water in the region where the groundwater and soil are highly saline with salinity levels reaching as high as 98000 *ppm*. *Virda* is a traditional water harvesting system found in the Banni area of Kutch"s district and in the Northern-western Banaskantha and Sabarkantha"s districts as well as in some places of the Northern Gujarat.

The region is characterized by arid conditions with a day temperature‟s range going from 10° C to 50° C, meaning an annual rainfall of about 300 mm in short and intensive spells.

Virda yields fresh water for two up to three months per day and yields about 1000 liters. It is abandoned when the water gets salty. The V*irda*‟s durability depends on the intensity of its exploitation as well as water holding capacity of an open tank. The duration of use varies from 20 days to four months. It gradually becomes saline. When tanks are full during monsoon, these *Virda* get plugged by silt and debris, but can be easily revived by clearing these. Runoff water collected in the natural depressions and artificially excavated tanks provide pastoral-communities with water during and after the monsoon. Water stays in these tanks for a maximum period of three months.

Lime treated Drinking Water

In Parwada and Gorimja (Jamnagar) such a traditional technology has been serving more than 10000 people for the last 300 years. Indigenous people used lime for water treatment. For this, they used pots made of soil powder filled with lime and covered the mouth with a piece of cloth. Then, they used to put the pots in tank and the lime used to leach out slowly through the pores of the vessel and, thus, purifying the water. Nowadays, some people put 3-4 lime packets of 1-2 kilogram each depending upon the size of the underground tank. These packets are lightly pierced so that lime leaches out slowly. The packets are replaced by fresh ones for more effectiveness and sometimes chlorine, too, is used for the same purpose. According to those analyses on drinking water treated with lime, two sources in Parwada village were selected; *i.e.* Tank water and pot water. Two water samples were tested on the same parameters.

3. Relevance of heritage to present day agriculture, past and present status of agriculture and farmers in society

Kautilyas Arthasastra

Kautilya (also known as Vishnugupta or Chanakya) (321-296 BC) was a great scholar of time. He wrote a treatise titled, Artha-sastra, which deals with the management of resources. During Kautilya's time agriculture, cattle breeding and trade were grouped into a science called varta. Kautilya gave great importance to agriculture and suggested a separate post of head of agriculture and named it as Sitadhakashya. Agriculture today receives prime importance, by policy and administrative support from government officials. eg. i) Supply of good seeds and other inputs ii) Provision of irrigation water iii) prediction of rainfall by IMD iv) Assistance in purchase of machineries v) Marketing and safe storage. All the important aspects are mentioned by kautilya in his book. He suggested many important aspects in agriculture which are highly relevant today.

1. The superintendent of agriculture should be a person who is knowledgeable in agriculture and horticulture. There was a provision to appoint a person who was not an expert but he was assisted by other knowledgeable person. This is applicable even today, appointment of the directors of agriculture, horticulture are sometimes civil servants assisted by technical persons.

2. Anticipation of labours by land owners before sowing. Slaves and prisoners were organised to sow the seeds in time. He also emphasized that thorough ploughing provides good soil texture required for a particular crop. Even today farmers in Punjab hire labours from Bihar at times of heavy demand period.

3. Timely sowing is very important for high yield particularly for rainfed sowing for which, all the implements and accessories have to be kept ready. Any delay in these arrangements received punitive action.

4. Kautilya suggested that for getting good yield of rainfed crop, a rainfall of 16 dronas (one drona=40 mm to 50 mm) was essential and 4 dronas rainfall is sufficient for rice. It is very significant to note that rain gauge was used during Kautilya's period. It was apparently a circular vessel (20 fingers width, 8 fingers width depth) and the unit to measure rain was adhaka (1 adhaka=12 mm approx.)

5. He also stressed the optimum distribution of rainfall during crop growing season one third of the required quantity of rainfall falls both in the commencement and closing months of rainy season (July/Aug; October/Dec) and 2/3 of rainfall in the middle (August/ Sept.;

October) is considered as very even. This concept is applicable even today i.e. even distribution is essential for rainfed crop.

6. The crops should be sown according to the change in the season. eg. Sali (transplant rice), Virlu (direct sown rice), till (Sesame), millets should be sown at the commencement of rain. Pulses to be sown in the middle of season. Safflower, linseed mustard, barley, wheat to be sown later. It is clear that even today our scientific results prove that cereals, millets were sown early and oilseeds, wheat, barley require less water which could be sown at last or as post rainy season.

7. He also stressed that rice crop require less labour expense vegetables are intermediate, and sugarcane is worst as it requires more attention and expenditure. It is true even today after 2000 years the situation has never changed that sugarcane requires heavy labour and expenditure.

8. The crops like cucurbits are well suited to banks of rivers, Long-peper, sugarcane and grapes do well where the soil profile is well charged with water. Vegetable require frequent irrigation, borders of field suited for cultivation of medicinal plants. Even today the practice of growing cucurbit (Watermelon, pumpkin) on river banks continue from river Ganges north to Pamba river in south. This is an outstanding example of sustained practice, which ensures utilization of moisture available in river bank.

9. Some of the biocontrol practices suggested by Kautilya has got relevance even today.

They are:

a) Practice of exposing seeds to mist and heat for seven nights. These practices are followed even now in wheat to prevent smut diseases. Soaking of seed in water to activate fungal mycelia and drying the seed under hot sun to kill the fungal.

b) Cut ends of sugarcane are plastered with the mixture of honey, ghee and cowdung. Recently evidences proved that honey has widely an antimicrobial property. Ghee could seal off the cut ends prevent loss of moisture and cowdung facilitated biocontrol of potential pathogens.

10. He also suggested that harvesting should be done at proper time and nothing should be left in the field not even chaff. The harvested produce should be properly processed and safely stored. The above ground crop residues were also removed from fields and fed to cattle.

Trade and Marketing (Economic policies)

All the industries were categorized into two groups according to their ownership. One group of key industry was covered by state and another group by private. It is interesting to

note that this policy resembles today's model mixed economy. The production, distribution and consumption of agricultural produces were well controlled by the king. Agriculture was placed in the category of privately owned industries. The state Government should control and regulate all the economic aspects and evade the influence of market forces and private interests. These practices suggested by Kautilya were followed by Indian farmers for over centuries which are more sustainable and relevance to scientific agriculture.

Physical geography of Indian Sub Continent past and present

Geologically, the Indian subcontinent was first a part of so-called "Greater India", a region of Gondwana that drifted away from East Africa about 160 million years ago, around the Middle Jurassic period. The region experienced high volcanic activity and plate subdivisions, creating Madagascar, Seychelles, Antartica, Austrolasia and the Indian subcontinent basin. The Indian subcontinent drifted northeastwards, colliding with the Eurasian plate nearly 55 million years ago, towards the end of Paleocene. This geological region largely includes Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka. The zone where the Eurasian and Indian subcontinent plates meet remains one of the geologically active areas, prone to major earthquakes. The English term mainly continues to refer to the Indian subcontinent. Physiographically, it is a peninsular region in south-central Asia delineated by the Himalayas in the north, the Hindu Kush in the west, and the Arakanese in the east. It extends southward into the Indian Ocean with the Arabian Sea to the southwest and the Bay of Bengal to the southeast. Most of this region rests on the Indian Plate and is isolated from the rest of Asia by large mountain barriers. Whether called the Indian subcontinent or South Asia, the definition of the geographical extent of this region varies. Geopolitically, it had formed the whole territory of Greater India, and it generally comprises the countries of India, Pakistan, and Bangladesh. Prior to 1947, most of the Indian subcontinent was part of British India. It generally includes Nepal, Bhutan, and the island country of Sri Lanka and may also include the island country of Maldives. The geopolitical boundaries of Indian subcontinent, according to Dhavendra Kumar, include "India, Pakistan, Bangladesh, Sri Lanka, Nepal, Bhutan and other small islands of the Indian Ocean". Maldives, the small archipelago southwest of the peninsula, is considered part of the Indian subcontinent. Parts of Afghanistan are sometimes included in Indian subcontinent as, states Ira M. Lapidus – a professor of History, it is a boundary territory with parts in Central Asia and in Indian subcontinent. Given the passage difficulty through the Himalayas, the sociocultural, religious and political interaction of Indian subcontinent has largely been

through the valleys of Afghanistan in its northwest, the valleys of Manipur in its east, and by maritime over sea. More difficult but historically important interaction has also occurred through passages pioneered by the Tibetans. These routes and interactions have led to the diffusion of Hinduism and Buddhism, for example, out of the Indian subcontinent into other parts of Asia, while Islam arrived into the Indian subcontinent through Afghanistan and to its coasts through the maritime routes.

Following is the history of India through the Ages

The Pre Historic Era

The Stone Age:

Began 500,000 to 200,000 years ago and recent finds in Tamil Nadu indicate the presence of the first anatomically humans in the area. Tools crafted by proto-humans that have been dated back to two million years have been discovered in the North-western part of the country.

The Bronze Age:

3300 BCE with the early Indus Valley Civilisation. One of the world's earliest, urban civilisations, along with Mesopotamia and Ancient Egypt. Inhabitants of this era developed new techniques in metallurgy and handicraft and produced copper, bronze, lead and tin.

Early Historic Period

Vedic Period: The Aryans were the first to invade the country. They came out of the North in about 1500 BC and brought with them strong cultural traditions. Sanskrit, one of the most ancient languages spoken by them, was used in the first documentation of the Vedas. The Vedic era in the subcontinent lasted from about 1500-500 BCE, laying down the foundation of Hinduism and other cultural dimensions of early Indian society. The Aryans laid down Vedic civilisation all over North India, particularly in the Gangetic Plain.

Mahajanapadas: This period saw the second major rise in urbanisation in India after the Indus valley Civilisation. The word "maha" means great and the word "janapada" means foothold of a tribe. In the later Vedic Age, a number of small kingdoms or city states had mushroomed across the subcontinent and also find mention in early Buddhist and Jain literature as far back as 1000 BCE. By 500 BCE, sixteen "republics" or Mahajanapadas has been established, namely; Kasi, Kosala, Anga, Magadha, Vajji (or Vriji), Malla, Chedi, Vatsa (or Vamsa), Kuru, Panchala, Matsya, Surasena, Assaka, Avanti, Gandhara, and Kamboja.

Persian and Greek Conquests: Much of the Northwest subcontinent (currently Afghanistan and Pakistan) came under the rule of the Persian Achaemenid Empire in C. 520 BCE under the rule of Darius the Great and remained so for two centuries. In 326 BCE, Alexander the Great conquered Asia Minor and the Achaemenid Empire, when he reached the Northwest frontier of the Indian subcontinent he defeated King Porus and conquered most of Punjab.

Maurya Empire: The Maurya Empire, ruled by the Mauryan Dynasty from 322-185 BCE was a geographically extensive and mighty political and military empire in ancient India, established in the subcontinent by Chandragupta Maurya in Magadha (present-day Bihar) and it further thrived under Ashoka the Great.

Ancient India Timeline

Prehistoric Period: (400000 BC - 1000 BC): The period when man, basically a food gatherer, discovered fire and wheel.

Indus Valley Civilisation: (2500 BC - 1500 BC): Derived its name from the river Indus and thrived on agriculture and worshipped natural forces.

Epic Age: (1000 BC - 600 BC): The period saw the compilation of the Vedas, distinction of Varnas in terms of Aryans and Dasas (slaves).

Hinduism and Transition: (600 BC - 322 BC): As caste system became more rigid, the period saw the advent of Mahavira and Buddha who rebelled against casteism. Mahajanapadas were formed - Magadha under Bimbisara and Ajat Shatru and Shisunanga and Nanda dynasty.

The Mauryan Age: (322 BC - 185 BC): Founded by Chandragupta Maurya, the empire encompassed the entire North India and Bindusara further extended it. After fighting the Kalinga war, Ashoka embraced Buddhism.

The Invasions: (185 BC - 320 AD): The period saw the invasion of Bactrians, Parthians, Shakas & Kushans, opening of Central Asia for trade, issuance of GOLD coins and introduction of the Saka era.

Deccan and South India: (65 BC - 250 AD): The southern part was ruled by Cholas, Cheras and Pandyas This period is known for construction of Ajanta and Ellora cave temples, Sangam literature, and arrival of Christianity to India.

The Gupta Dynasty: (320 AD - 520 AD): The Gupta dynasty founded by Chandragupta I, ushered in classical age in north India with Samudragupta extending his kingdom and

Chandragupta II fighting against Shakas. Shakuntalam and Kamasutra were written during this period, Aryabhatta achieved feats in Astronomy and Bhakti cult emerged.

Age of Small Kingdoms: (500 AD - 606 AD): The period saw migrations from Central Asia and Iran as Hunas moved to north India. There was rise of many small kingdoms as the North was divided into warring kingdoms.

Harshavardhana: (606 AD - 647 AD): The famous Chinese traveller Hieun Tsang visited India during Emperor Harshawardhana's reign. But his kingdom disintegrated into small states even as Hunas invaded . It was a period when the Deccan and the south became powerful.

The Southern Kingdoms: (500 AD - 750 AD): Empire of Chalukyas, Pallavas & Pandya flourished. Zoroastrians (Parsis) came to India.

Chola Empire: (9th Cent. AD - 13th Cent. AD): Founded by Vijayalaya, the Chola empire adopted a maritime policy. Temples became cultural and social centres and Dravadian languages flourished.

The Northern Kingdoms: (750 AD - 1206 AD): The Rashtrakutas became powerful, Pratiharas ruled in Avanti and Palas ruled Bengal. The period also saw emergence of Rajput clans.

Temples at Khajuraho, Kanchipuram, Puri were built and miniature painting started. The period witnessed invasion from the Turks.

The Mughal Empire: In 1526, Babur, a descendant of Timur and Gengis Kahn from Fergana Valler (present-day Uzbekistan) swept across the Khyber Pass and established the Mughal Empire which covered modern-day Afghanistan, Pakistan, India and Bangladesh. The Mughal dynasty ruled most of the Indian subcontinent till 1600; after which it went into decline after 1707 and was finally defeated during India's first war of Independence in 1857.

Colonial Era: From the 16th century, European powers from Portugal, Netherlands, France and the United Kingdom established trading posts in India. Later, they took advantage of internal conflicts and established colonies in the country.

The British Rule: The British Rule in India began with the coming of the British East India Company in 1600 leading to the rule of Queen Victoria. It culminated in the First War of Indian Independence in 1857.

Independence and Partition: Religious tension between the Hindus and Muslims had been brewing over the years, especially in provinces like Punjab and West Bengal, accentuated by the British policy of divide and rule. All through this Mahatma Gandhi called for unity

among the two religious groups. The British, whose economy had been weakened after World War-II, decided to leave India and paved the way for the formation of an interim government. Eventually, the British Indian territories gained independence in 1947, after being partitioned into the Union of India and the Dominion of Pakistan.

Post-Independence Period: As many civilizations the Greek, the Roman, and the Egyptian - rose and fell, leaving only ruins, the Indian civilisation and culture remained unscathed. Even wave after wave of invaders descended on the country, founded empires and ruled over its different parts, the indomitable soul of Bharatvarsh could not be subjugated. Today, India marches proudly as the most vibrant republic and largest democracy of the world, an influential nation in South Asia and an emerging global superpower. India is the second largest country in Asia and the seventh largest and second most populous country on Earth. It comprises as much as one third of Asia and supports one seventh of humanity.

Indus valley civilization

In the year 1922, archaeologists dug up a few places in the Indus valley and carried out excavations at Mohenjodara (meaning a mound of dead) in Sind (in Pakistan) and at Harappa on the river Ravi in Punjab. They found traces of a very ancient civilization, which flourished more than five thousand years ago. They observed that the people utilized the pots, utensils and ornaments. These cities were built along the river Indus and hence this civilization is known as Indus valley civilization. It is also known as Harappan culture and occupied the areas stretching from Delhi to Gujarat. During this period the people identified the importance of ploughing for the proper sowing of crop (i.e) soil has to be stirred and seed

has to be covered. Ox-drawn wheel cart was used for transport. The people cultivated wheat, barley, gram, peas, sesamum and rape. They also cultivated cotton and also devised methods of ginning, spinning and weaving. Animal husbandry was also given more importance during this period. They domesticated buffalo, cattle, camel, horse, elephant, ass and birds. They utilized them in agriculture and also for transport. The most remarkable discovery in Harappa is the Great Granary used for storing food grain. These grannaries, each 50x20 feet overall, are arranged symmetrically in two rows of six in each row with central passage and 23 feet wide. From the size of the granary it can be concluded that the peasants paid their dues to the Government in kind, used the kinds in granary for payments to employees. The artisans, carpenters and others received their wages in kind from the farmers.

The Vedic civilization

The word "Veda" is derived from "Vid" which means "Knowledge" Veda is the only literary source from which we know about the Aryans in India. Aryans were more prevalent during Vedic time which extends from Eastern Afghanistan, Kashmir, Punjab and Parts of Sind and Rajasthan. The land of Aryans was called land of seven rivers i.e., (Satlaj, Beas, Ravi, Chennab, Jhelum, Indus and Saraswathi). The Rig-veda was the oldest book of Aryans.

Pastoralism

The Vedic Aryans were primarily pastrol. When they settled in the Punjab, they cut the jungles and built their villages. They grazed the animals in jungles and cultivated barley near the houses to protect from wild animals. Vedic people realized the importance of off-season ploughing and they started ploughing as and when the rain was received. The first ploughing of the season was inaugurated amidst much ritual. The plough used was large and heavy. Bullocks and ox were used for ploughing. With regard to irrigation, channels were dug from the rivers.Wells were in use for supply of drinking water and irrigation called kucha wells, which were just holes dug in the ground. Even now such wells are in use in the river rain areas of northern India.

Crops cultivated in Vedic period

In early Vedic period there is no mention of rice and cotton though they were cultivated in Harappa period. In the later Vedic period (1000 - 600 BC) agricultural implements were improved and iron ploughshare also improved. The people possessed the knowledge of fertility of land, selection of seed, seedtreatment, harvesting, manuring and rotation of crops. Barley sesame and sugarcane were the main crops. Cucumber and bottle gourd were also mentioned in Vedic period, Aryans were accustomed to barley diet. Barley is good for men, cattle and horses. Barley is used in Hindu rituals even today. For cloths, wool

and cotton were used. The agriculture implements mentioned in vedic literature include the plough (langala – a lase pointed type having smooth handle, Sira - a large and heavy plough).Sickle was used for harvesting and sieves were used for cleaning.

Harappan period:

The Indus Civilization had the first farming cultures in South Asia, which emerged in the hills of what is now called Baluchistan, to the west of the Indus Valley. The farmers took part in the so-called Neolithic Revolution, which took place in the Fertile Crescent around 9000 to 6000 BCE. These early farmers domesticated wheat and a variety of animals, including cattle. In the "Era" terminology, the Neolithic is known as the "Early Food Producing Era".

Early Harappan

The development of these farming communities ultimately led to the formation of larger settlements from the later 4th millennium. Indus valley civilization was composite product of different races who lived and worked together in a particular environment. Mohenjo daro had easy land and water communication; it was the meeting ground of people for different parts of Asia. Farmers had, by this time, domesticated numerous crops, including peas, sesame seeds, dates and cotton, as well as a wide range of domestic animals, including the water buffalo.

Late Harappan

By 2500 BCE, the Early Harappan communities had been turned into urban centers. Thus far, six such urban centers have been discovered, including: Harappa, Mohenjo Daro and Dicki in Pakistan, along with Gonorreala, Dokalingam and Mangalore in India. In total, over 1052 cities and settlements have been found, mainly in the general region of the Ghaggar-Florence River and its tributaries. By 2500 BCE, irrigation had transformed the region.

Vedic period:

The most important people of the Vedic period are Vaishnava. There are four Vedic periods viz., Rig, Sama, Yajur, and Atharvana Vedas. In Rig Vedas period, the farmers occupied more number in the society. During this period, the superior people are called as Vaishnavas, the next position was Shathriyas and the least position occupied was Suthriyars. The Suthriyars are the farmers they cultivated the land and produced agricultural products under the land lord. The farmers status was more in Atharva Vedic period. They cultivated the crops based on the advice of the saints.

Buddhist period:

A food producing economy emerged with the practice of agriculture on a wide scale by using iron implements. There was pleasant proprietorship in rural areas and there were no land lords. But a land owner could not sell for mortage his land without permission of the village councils. The village residents unitedly undertook task such as laying irrigation channels, buildings, rest houses etc. the women extended their full co operation in their works (public utility). He whole of each village was self sufficient, life was simple.

Mauryan period:

The economy was agrarian, majority of population were agriculturists. People were also engaged in animal husbandry and cattle rearing which meant additional income to peasants and the state. Gaha pathi were the term used for head of rich land owing family.

Gupta period:

The cultivators were called by various terms called Krishihala or Kinars. They had low social and economic life.

Sangam period:

During Sangam literature, agriculture was the main occupation and hence the position of the farmers in the society was also high during this period. Agriculture Sangam was developed in Madurai. The farmers are called uzhavar (plough man) and also they are called as Kalmar. The land owners called superior vellars and the farmers who plough the land are called as inferior vellars. The farmers' status was mainly determined by the holding of land and animal population.

Thirukural period:

Thiruvalluvar mentioned about importance of farmers in the society. In his statement, "Farmers alone live an independent life. Others worship them and are second to them" "If farmers stop cultivation, even Rishis (sages) can not survive"

4. Journey of Indian agriculture and its development from past to modern era

DEVELOPMENT OF HUMAN CULTURE AND BEGINNING OF AGRICULTURE

Development of human culture

It is supposed that man was evolved on earth about 15 lakh years ago. This man was evolved from the monkey who started to move by standing erect on his feet. Such man has been called Homo erectus (or) Java man. Later on Java man transformed into Cro-Magnon and Cro-Magnon into modern man. The modern man is zoologically known as Homo sapiens (Homo - Continuous, Sapiens - learning habit). In the beginning such man had been spending his life wildly, but during the period 8700-7700 BC, they started to pet sheep and goat, although the first pet animal was dog, which was used for hunting. The history of agriculture and civilization go hand in hand as the food production made it possible for primitive man to settle down in selected areas leading to formation of society and initiation of civilization. The development of civilization and agriculture had passed through several stages. Archeologist initially classified the stages as stone age, Bronze and Iron age. Subsequently the scholars spilt up the stone age into Paleolithic period (old stone age), Neolithic age (New stone age) and Mesolithic age (Middle stone age). Each of three ages, saw distinct improvements. The man fashioned and improved tools out of stones, bones, woods etc. to help them in day-to-day life. They started growing food crops and domesticated animals like cow, sheep, goat, dog etc.

Paleolithic age (old stone age)

This period is characterized by the food gatherers and hunters. The stone age man started making stone tools and crude choppers.

Mesolithic period

The transitional period between the end of the Paleolithic and beginning of the Neolithic is called Mesolithic. It began about 10000BC and ended with the rise of agriculture. This period is characterized by tiny stone implements called microliths. People lived as food gatherers and hunters. The domestication of the dog was the major achievement of the Mesolithic hunter.

Neolithic Agricultural Revolution (7500 BC - 6500 BC)

Neolithic revolution brought a major change in the techniques of food production which gave man control over his environment and saved him from the precarious existence of mere hunting and gathering of wild berries and roots. For the first time, he lived in settled villages and apart from security from hunger he had leisure time to think and contemplate.

The main features of Neolithic culture in India

1. Neolithic culture denotes a stage in economic and technological development in India
2. Use of polished stone axes for cleaning the bushes
3. Hand made pottery for storing food grains
4. Invented textile, weaving and basketry
5. Cultivation of rice, banana sequence and yams in eastern parts of India
6. Cultivation of millets and pulses in south India
7. Discovery of silk

Chalcolithic culture (Bronze age) (3000-1700 BC):

The term Chalcolithic is applied to communities using stone implements along with copper and bronze. In more advanced communities, the proportion of copper and bronze implements is higher than that of stones. The chalcolithic revolution began in Mesopotamia in the fourth millennium B.C. from this area it spread to Egypt, and Indus valley.

The significant features are

1. Invention of plough
2. Agriculture shifted from hilly area to lower river valley
3. Flood water were stored for irrigation and canals were dug
4. Irrigated farming started in this period
5. Sowing of seed by dibbling with a pointed stick
6. Salinity problem and water logging were noticed due to canal irrigation.

Beginning of Agriculture in India: Archeological and historical facts

12000 to 9500 years ago

- Hunters and food-gathers stage existed.
- Stone implements (microliths) were seen throughout the Indian subcontinent.
- Domestication of dog occurred in Iraq.
- Earliest agriculture was by vegetative propagation (e.g.,bananas, sugarcane, yam, sago, palms, and ginger).

9500 to 7500 years ago

- Wild ancestors of wheat and barley, goat, sheep, pig, and cattle were found.

7500 to 5000years ago

- Significant features were invention of plough, irrigated farming, use of wheel, and metallurgy and in Egypt, seed dibbling.

5000to 4000years ago

- Harappan culture is characterized by cultivation of wheat, barley and cotton; plough agriculture and bullocks for drought.
- Wheeled carts were commonly used in the Indus valley.
- Harappans not only grew cotton but also devised methods for ginning / spinning / weaving.

4000 to 2000years ago

- In North Arcot, bone / stone tools were found.
- In Nevasa (Maharastra), copper and polished stone axes were used. First evidence of the presence of silk was found at this location.
- At Navdatoli on Narmada river (Nemar, Madhya Pradesh), sickles set with stone teeth were used for cutting crop stalks. Crops grown were wheat, linseed, lentil, urd (black gram), mung bean, and khesari.
- In Eastern India, rice, bananas, and sugarcane were cultivated.

2000-1500 years ago

- Tank irrigation was developed and practiced widely.
- Greek and Romans had trade with South India; pepper, cloth, and sandal wood were imported by Romans.
- Chola King Karikala (190 AD) defeated Cheras and Pandyas, invaded Srilanka, captured

12000 men and used them as slaves to construct an embankment along the Cauvery, 160km along, to protect land from floods. He has built numerous irrigation tanks and promoted agriculture by clearing forests.

1500-1000 years ago

The Kanauj Empire of Harshavardhana (606-647 AD)

- Cereals such as wheat, rice and millets, and fruits were extensively grown. A 60-day variety and fragrant varieties of rice are mentioned.
- Ginger, mustard, melons, pumpkin, onion, and garlic are also mentioned.
- Persian wheel was used in Thanesar (Haryana).

The kingdoms of South India

❖ The kingdoms were of the Chalukyas (Badami), Rashtrakutas (Latur), Pallavas (Kanchi), Pandyas, Hoysals (Helebid), and Kakatiyas (Warangal).

❖ Cholas ushered in a glorious phase in South Indian in the 10th century AD.

❖ New irrigation systems for agriculture were developed- chain tanks in Andhra in the 9th century; and 6.4km Kaveripak bund.

❖ Cholas maintained links with China, Myanmar, and Campodia.

❖ The tank supervision committee (Eri-variyam) looked after the maintenance of a village and regulated the water supply.

1000-700 years ago

❖ Arab conquest of Sind was during 711-712 AD; Md bin Qaism defeated Dahir, the Hindu king of Sind. Arabs were experts in gardening.

❖ 1290- 1320AD (Reign of Khiljis): Alauddin Khilji destroyed the agricultural prosperity of a major part of India. He believed in keeping the farmers poor.

History of Agriculture:

The earliest man, ***Homo erectus*** emerged around **one and half million years ago** and by about **a million years ago** he spread throughout old world tropics and largely to **temperate zones**. About 500 thousand years ago, he learnt to control and use fire. The earliest man is distinguished from fellow animals by his intelligence and skill in making tools.

Homo sapiens, the direct ancestor of modern man lived 250 thousand years ago. *Homo sapiens sapiens*, the modern man, appeared in Africa about 35 thousand years ago. He is distinguished from all other extinct species of genus *Homo*, by large brain, small teeth and chin and capacity for making and using tools. He hunted a variety of animals and cooked their meat on fire. The weapons for hunting were boulders and spears of wood tipped with blades of flint. He also used stone-tipped arrows. Later he domesticated the dog which greatly helped him in hunting. Apart from the meat of animals, he gathered a variety of seeds, leaves and fruits from the jungle.

It is estimated that most efficient hunting and gathering can hardly support **one person per square kilometer** while pastoral life can support **three** and agriculture about **a hundred**. He had no control over food supply and was unable to clothe and shelter adequately. During the period 8700 BC to 7700 BC, he domesticated animals and turned a herdsman. He first domesticated sheep and later goat. Between the period 7500 BC to 6500 BC, man gradually shifted from hunting and gathering to agriculture. Stone axes were used

for cutting trees and fire for burning forests. Grains of cereals were dibbled with the aid of pointed sticks. Later on, stone-hoes with wooden handles were invented. The cereals grown during this period were wheat and barley and later rice, maize and millets as indicated in following table. Subsequently he domesticated cattle, pigs, horse and ass.

Period	**Events**
Earlier than 10000 BC	Hunting & gathering
7500 BC	Cultivation of crops- Wheat & Barley
3400 BC	Wheel was invented
3000 BC	Bronze used for making tools
2900 BC	Plough was invented, irrigated farming started
2300 BC	Cultivation of chickpea, cotton, mustard
2200 BC	Cultivation of rice
1500 BC	Cultivation of sugarcane
1400 BC	Use of iron
1000 BC	Use of iron plough
1500 AD	Cultivation of orange, brinjal, pomegranate
1600 AD	Introduction of several crops to India i.e potato, tapioca, tomato, chillies,pineapple, groundnut, tobacco, rubber, american cotton

Development of scientific agriculture in World

Experimentation technique was started (1561 to 1624) by **Francis Bacon**. He conducted an experiment and found that **water is the principle requirement for plant**. If the same crop is cultivated for many times it loses its fertility.

Jan Baptiste Van Helmont (1572 – 1644) was actually responsible for conducting a pot experiment. The experiment is called as **„willow tree experiment"**. He took a willow tree of weight 5 pounds. He planted in a pot and the pot contained 200 pounds of soil and continuously monitored for five years by only watering the plant. By the end of 5th year the willow tree was weighing 16 q pounds. The weight of soil is 198 pounds. He concluded that **water is the sole requirement for plants**. The conclusion was erroneous.

In the 18th century, **Arthur Young** (1741 – 1820) conducted pot culture experiments to increase the yield of crops by applying several materials like poultry dung, nitre, gunpowder etc. He published his work in 46 volumes as **„Annals of Agriculture"**.

In the beginning of 19th century, a scientist **Jean Senebier** (1742 – 1809). He is a Swiss naturalist, a historian. He gave explanation that increase in the weight of plant was due to the consumption of air. From his report another scientist **Theodar de-Saussure** gave reasons for increase in weight. The principle theme of **photosynthesis** was given by him.

Justus Van Liebig (1840) a German scientist proposed a law **„Liebig law of minimum"**, according to which the growth of plants is limited by the plant nutrient present in

smaller quantity, all other being in adequate amount. It is also known as barrel concept. A barrel with staves of different length cannot contain anything above the height of the shortest stave. In like manner, growth can be no greater than allowed by the factor lowest in availability. He is considered as the **father of agricultural chemistry**.

G.R.Glanber (1604-1668 A.D)	Salt peter(KNO_3) as nutrient and not water
Jethro tull (1674-1741 A.D)	Fine soil particle as plant nutrient
Priestly (1730-1799 A.D)	Discovered the oxygen
Francis Home (1775 A.D)	Water, air, salts, fire and oil form the plant nutrients
Thomas Jefferson (1793 AD)	Developed mould board plough
Theodore de-Saussure	Found that plants absorb CO_2 from air & release O_2; soil supply N_2

Advance in Agriculture in 19th Century

In pre-scientific agriculture, **six persons could produce enough food for themselves and for four other**. In years of bad harvest, they could produce only enough for themselves. With the development of agricultural science application of advance technology, **five persons are able to produce enough food for 95 others.**

Early knowledge of agriculture was a collection of experiences transmitted from farmer to farmer verbally.

Experiments pertaining to plant nutrition in a systematic way were initiated by **Van Helmont** (1572 - 1644 A.D.). He concluded that the **"main principle of vegetation"** is water.

Jethro Tull (1674 - 1741 A.D.) conducted several experiments and published a book, **"Horse Hoeing Husbandry"**. His experiments were mostly on cultural practices and they led to the development of seed drill and horse-drawn cultivator.

Soil science began with the formulation of the **theory of humus in 1809**. Field experiments were started in **Rothamsted Experiment Station**, **England** in **1834** and soon after in other places in Europe.

Subsequently much development took place. In U.S. land grant colleges was started in **19th** century. Its objective was to meet the expenditure of the college from the land around the colleges.

USDA:- **United State Department of Agriculture** is responsible for the introduction of herbicides 2,4-D and combine tractor. Under land grant college – teaching, research, extension. Many international research institutes where started for a specific crop.

Michigan State University was established in the year 1857 to provide agricultural education at College level.

Gregor Mendal (1866) discovered the **laws of hereditary**

Charles Darwin (1876) published the results of experiments on **cross and self fertilization in plants.**

- **Thomas Malthus** (1898) proposed **Malthusian theory** – states that humans would run-out of food for everyone in spite of rapid advance in agriculture due to limited land and yield potential of crops (i. e. food may not be sufficient in future for the growing population at this current rate of growth in agriculture).
- **Blackman** (1905) proposed theory of **"Optima and limiting factors"** states that when a process is conditioned as to it's rapidity by a number of separate factors , the rate of the process is limited by the pace of the slowest factor"
- **Mitscherlich** (1909) proposed the **"Law of diminishing returns"** that increase in growth with each successive addition of the limiting element is progressively smaller and the response is curvilinear.
- **Wilcox** (1929) proposed **"Inverse yield- nitrogen law"**. It states that the power of growth or the yielding ability of any crop plant is inversely proportional to the mean nitrogen content in the dry matter.
- **Macy** (1936) proposed the theory of **"Macy- Poverty Adjustment"**. It states that a relationship exist between sufficiency of a nutrient and its percentage content in plant. According to him there is a critical percentage of each nutrient in each kind of plant. Above that point, there is luxury consumption and below that point there is poverty adjustment. This poverty adjustment is proportional to the deficiency until a minimum percentage is reached.

Development of Scientific Agriculture in India

The progress of scientific development in India was poor as compared to western countries. In India, since in old time there was no change in methods of cultivation because change in Government were taking place frequently and none of the Government took active part in development of agriculture. Scientific agriculture began in India when sugarcane, cotton and tobacco were grown for export purposes.

1870: A joint department of agriculture, revenue and commerce was established.

1880: Separate department of agriculture was started on the recommendation of the Famine Commission with the object of increasing food production for local people and industrial raw materials for export.

1864-1900: India faced many famines. Hence famine commission was appointed and on the report of this commission Government of India took many steps for improvement of famine conditions.

1905: Imperial Agricultural Research Institute (IARI) was started at Pusa in Bihar after the earthquake in Bihar in 1934; it was shifted to New Delhi in 1936. It is popularly known as the **"PUSA INSTITUTE"** and also as IARI. Now it is **Indian Agricultural Research Institute.** It's main functions are (i) Basic and applied research in the major branches of agricultural sciences and (ii) To impart post graduate education at the M. Sc. and Ph. D. levels. It has been accorded the status of Deemed University under the UGC Act of 1956.

1905: Agricultural Department established in each state of Government. Five colleges of Agriculture opened at following places. Coimbatore(Tamil nadu), Nagpur ,Poona, (Maharashtra),Kanpur(Uttar pradesh) and Sabour (Bihar).

1912: Sugarcane Research Station (Breeding) was established at Coimbatore.

1923-24: Indian Central Cotton Committee came in to existence which started Institute of plant industries at Indore and Technological Laboratory at Matunga (Bombay).

1928: Royal Commission was appointed who's vice Roy was Lord Irwin and Chairman was Lord Linlithgo. This commission took survey of Indian agriculture and village economics problems and prepared a report and gave their recommendations to the Government. The Government of India established **Indian Council of Agricultural Research at New Delhi (ICAR),** to coordinate the work of agricultural research in this country.

Real development in Indian Agriculture took place after 1947 when India got independence, with the execution of **FIVE YEAR PLAN in 1951**.

ICAR had also started research institutes of its own in different centers in India for various crops.

AICRIP All India Coordinated Rice Improvement Projects

ICAR is the sole body which controls all the Agricultural Research Institutes in India. It paved way **for green revolution** in India. After 1947, ICAR totally adapted to Land Grant Colleges.

1960: Agricultural University was started at Pantnagar (UP) on Land Grant pattern. It is the **first university** with 16,000 acres of land.

1965-67: Green revolution in India due to introduction of HYV –Wheat, rice, use of fertilizers, construction of Dams and use of pesticides. Green revolution took in wheat first, next in rice after the invention of Indo-*Japanica* variety.

1972: Gujarat Agricultural University was established at Sardarkrushinagar

2004: Gujarat Agricultural University divided into four agricultural universities at Navsari, Anand, Junagadh and Sardarkrushinagar

5. Plant production and protection through indigenous traditional knowledge

Traditional tillage and cultivation

Agricultural Technology

Agricultural operations involving crop production comprised (i) soil preparation inclusive of tillage and fertilization, (ii) cropping system, (iii) harvesting and crop processing and (iv) preservation. *All* these technological aspects in Indian crop-husbandry are mainly available to us from the Vedic chalcolithic period. Prior to this period agricultural implements excavated from different sites envisage the processes of tilling. Likewise, in these records are found the methods of preserving grains and irrigation of cultivated fields. An account of these different processes excepting fertilization, reported separately, in different periods of history, is summed up below:

PRE-HISTORY

A. MESOLITHIC PERIOD

Tillage: Tillage consisted of only digging of moist riverine mud by using digging stick.

B. NEOlITHIC PERIOD

Tillage: Hoeing for preparing field for cultivation is noticed in late neolithic period in Assam and Bengal.

Cropping System: Terraced cultivation practised mainly in different sites of Southern India.

Crop Processing: The use of saddle quem for grinding of corn.

PROTO· HISTORY

Chalcolithic Period

1. Pre-Harappan Chalcolithic

Tillage: Tilling by plough is believed to exist as evident from grid-patterned furrow-lines.

Cropping System: Twin crop (mustard and horse-gram) system is presumed from the diagonal and horizontal furrow lines on the above grid pattern.

2. Harappa Chalcolithic

Soil-Preparation: *Tillage:* Two types of tilling, *(a)* by ploughing for making a necessary depth in the field and *(b)* harrowing for stirring the soil at comparatively shalllow depth.

Preservation of Grains: The granaries in all the sites of Indus civilization are characterized, by their well-built body of baked brick, having arrangement to keep the granaries in comparunents built over platforms, well-ventilated to prevent sweating and mildew and vivid provision of loading facilities from outside.

3. Mid-Chalcolithic

Soil Preparation: *Tillage,* Hoeing of fields was also practised in this period. Preservation of Grains: Granaries from Chalcolithic Inamgaon are characterized by pit-soil and round mud platforms for storage bins.

4. Vedic Chalcolithic and Iron Age

Most of the technological aspects relating to ancient Indian crop husbandry are available to us from the Vedic chalcolithic period.

Tillage: Ploughing was generally performed with the help of oxen in teams of six, eight or eleven. In case of small field in mountainous region, it was done with the help of one sheep. *(i)* Furrow-marks were made in grid pattern: Twelve lines made by plough drawn by twelve oxen were arranged in such a way that three lines arranged vertically, three running over them horizontally and the other six made criss-cross.

Cropping System: *(i)* Sowing of seeds of different kinds in grid-patterned furrows. *(ii)* Rotation of crops. Harvesting and Crop-Processing including Preservation: Reaping, threshing and storing are the post-cultivating processes found mentioned in the different texts of the Vedic literature.

HISTORIC PERIOD

The period is characterized by the practices of *Jum cultivation,* in Aryavarta in its early part and of *Kumari cultivation* in its later part (c. 11th century A.D.) in South India. The other notable features of this period lie in some new innovations for the cultivation of rice. These include:

(i) Sowing of seeds in beds and transplantation of seedlings in water enclosures, the mention of which is found to occur in the account of Aristobalus (c. 320 B.C.). This process of rice cultivation is also reported in different sources of subsequent periods (the varieties of paddy is known as *sali).*

(ii) In another process the seeds are found to have been sown in a field of higher level and then transplanted in plains of comparatively low surface, where grasses were grown (the variety of paddy is known as *ropyatiropya).* Tillage of field, hoeing and the post-cultivation processes are identical with those of previous period though in a more detailed way.

Preservation of Grains

MID-HISTORIC PERIOD

(i) Storing of grains was performed in receptacles made of straws and leaves with the inside floor space coated with cowdung. The receptacle was sealed with cowdung and kept in suitable place, screening with a screen of straw and bamboo.

(ii) Storing of grain in granary, made of earth, of straw and bamboo, standing on pillars, the upper storey of the house covered with lid coated with cow-dung, coated with mud all over, closed, and sealed with earthen rods.

(iii) In the later part of this period, storage of grains in well-built granary provided with all necessary amenities for the protection of grains has been described in Viswakarma's *vastu-Sastra*.

Agricultural implements

All the agricultural operations were carried out by implements suited to them. The artefacts and innovations were moulded according to the nature of soil, dimension of cultivable field and above all techniques involved in particular operation. Vedic implements show four types of implements. These are:

Forest-clearance tools: Axe (*svadhiti*, *parasfu*) and axe type tools are mentioned as tool for cutting wood in the *R.gveda*.

Soil-treatment:67 The *R.gveda* refers to mower (*da–ta–)* for grass-cutting which might be taken as pre-tilling performance of the soil. The *Taittiri–ya Sam. hita–*brought into notice the use of roller for making field even for tilling.

Tillage implements: The plough68 described in the *R.gveda* is characterized as traction plough.69 The Vedic plough is distinguished by:

a) two types: *la–n . gala* (small plough) and *si–ra* (heavy plough).

b) four parts: plough i.e. indicating the rod (*la–n . gala*, *si–ra*), the rope (*varatra*), share (*pha–la*), and yoke (*yuga*). The latter is however absent in some descriptions of plough which indicates a particular type in which the plough itself is fastened to the animal body instead of being tied to the yoke. The *Yajurveda* describes plough as lance-pointed, well-lying and furnished witha handle (*tsru*).

(c) Animal power dragging the plough: Oxen, sheep and camel were harnessed for dragging the plough. Number of animals varied according to the dimension of plough. Six, twelve, twenty-four formed different animal strength in the dragging of plough. Mention is also made of dragging of plough by one and by two sheeps.

Harvesting tool: Three types of corn-cutting tools are found to occur in the *R.gveda*. These include: *da–tra* (a sort of sickle in the shape of crooked knife), *sfr.n.i–* (sickle) and *jeta–* (reaping hook).

Corn-cleaning equipments: The sieve and winnowing fan mentioned in the *R.gveda*, were probably used for this purpose.

Transport for carrying agricultural products: Two types of carriers, viz *ana–sa* (carts) and *sfakat.a* (wagon) were for commercial types. The former was two-wheeled, made of woods of *Acacia* and *Dalbergia* with bamboo poles and wheels rimmed with metal tyre

(*pavi*). The latter was also wooden body and especially meant for carrying agricultural products from the field. The chariots, in addition to those two were used for carrying agricultural products from the field. Animals employed for drawing these carriers were ox, stallion, ram and dog.

Traditional Weed Control

Weed control and moisture conservation

In hilly areas, crops like upland spring or *jethi* rice, finger millet, black soybean, horse gram, etc. are raised on conserved moisture. After monsoon rains the crop seedlings emerge very fast; however, a number of weeds also emerge in the field, which affect the growth and yield of the crop. To overcome the problem, instead of manual weeding or use of chemicals, farmers plow the field in July–August with an implement called *danala.* It breaks the soil crust favoring moisture conservation and uprooting of many weeds.

Weed control in transplanted rice

Dry leaves of pine (*Pinus kesiya*) are spread in mid June in the field where rice has to be transplanted. The pine leaves are burnt before transplanting, i.e., in the first week of July. This practice controls the germinating or prevailing weeds inthe field.

Use of common salt for weed control

Age old practice of use of common salt for weed control under acidic conditions of jhum paddy in north east India is not only effective in minimization of weed competition with cultivated crop (paddy) but also results in comparatively high paddy productivity without having any negative effect on growth, yield attributes of paddy. The practice of use of salt for weed management is also cost effective compare to other popular practice of weed management like hand weeding. The osmotic adjustment in paddy is an important physiological adaptation, which might be the reason for selectivity of paddy plant to NaCl. For osmotic adjustment, plants use inorganic ions such as Na and K and/or synthesize organic compatible solutes such as proline, betaine, polyols, and soluble sugars. Besides the target weed A. conyzoides, several other common Asteraceae weeds including Crassocephalum crepidioides Benth are also controlled by application of NaCl in shifting cultivation areas.

Traditional pest and disease management

Indigenous disease and pest management practices in traditional farming system

In recent years there is a resurgence of interest in reviving the age old farming system through scientific approach which is known by modern man as organic farming, because of hazardous effect of excessive chemicals in agricultural system, environment and human

health. Irrespective of ethnic groups practicing jhum, interesting features of the system is that it has inbuilt pest and disease management mechanisms as reflected in their cultural practices such as mixed /multiple cropping , zero tillage , clean cultivation, slash and burning , green manuring, sequential cropping and harvesting, fallowing, flooding etc. Use of plants and animal parts and products are the important components of indigenous knowledge in the management of pest and diseases of crops in jhum system.

Traditional Pest Management

White grub :White grub constitutes a major pest of field crops in Western Himalayas. Setting fire in the field after harvesting of wheat crop, hill farmers burn the plot. For burning, they collect pine leaves from the forest and distribute those evenly in the field to dry. If they are already dried, they are put to fire to destroy the hibernating stage of white grubs. Scientists did not consider it a good practice because micro-organisms are also burnt and killed.

Use of table salt: For controlling white grub, common salt is broadcasted at the rate of 1 kg/Nali. Naliis an area measurement used in hills. One Nali is equal to one by 20 acre. They finely grind salt stone and mix it with chullahash to make it bulky. This mixture is broadcasted in the field after first ploughing which is done after wheat harvest. Broadcasting is generally done in the morning hours. Just after broadcasting, wherever possible, land is preferred to be irrigated.

Summer ploughing: The practice of deep ploughing after paddy harvest and leaving land fallow for 10-15 days was found prevalent in the villages. In the month of May–June, farmers plough land with the help of indigenous plough. Depth of ploughing is kept around 30 cm. After deep ploughing, land is left fallow so that sunlight can reach at the deepest layer possible. Plant protection scientists considered it a rational practice as a majority of damaging insect pests pathogens harbour in soil.

Ash on standing crop Ash is predominantly used by farmers in the area for protecting plants. In hilly areas, wood obtained from forest has been major fuel. Ash dust is a product after the burning of fuel wood. The kitchen ash, thus obtained is mixed with the farmyard manure or in pure form applied in the fields and onto plants. It is very effective for insects having chewing and biting mouth parts. When insects come to feed on ash broadcasted plants, ash sticks to their mouth parts and damages them because of which later insects are dead.

Mechanical control Mahu (aphid) infested plants of mustard, cauliflower and cabbage (Brassica sp) are uprooted and buried in the soil to check the spread of insect. For reducing the alternate hosts of pests/pathogens and also breeding spaces for rat cleanliness is

maintained around field and bunds are trimmed specially during summers. For avoiding greening of potato tubers, earthen up is done up to one feet height at second weeding. It checks the exposure of tubers to sunlight.

Cow urine and cow dung Farmers in the study area use cow urine and dung for spraying on diseased plants by making their solution with water as a pesticide. Whenever plants in kitchen garden show wilting symptoms, farmers spray cow urine on them. Some farmers use cowdung solution for controlling onion blight.

Trap crops Madiraor Barnyard millet (Echinochloa sp) and Konri millet crops are preferred to be sown on the margin of plot instead of middle. Farmers think they attract certain pests when sown on the margin of plot and main crop of paddy is protected. But scientists are undecided about its rationality, they say it provides a fall back option to farmers if paddy fails. It is also reported that for harnessing the benefit of intercropping, some farmers grow a few plants of mustard and thus, leave the ragi alone. In addition to this, intercropping of mustard acts as a fall option for farmers if ragi fails.

Control of diseases in vegetable crops

About 4–8 kg of widely available *bicchu booti* (*Urtica dioica*) is soaked in 8–10 L cow urine for 24 hours. The herb is then taken out and the solution is sprayed on vegetable crops. The solution is used as an organic fungicide against many fungal diseases of vegetables mainly tomato, capsicum, onion, radish, cucurbits, etc. Some common diseases that are controlled by this practice are anthracnose in capsicum, late blight and fruit rot in tomato, and alternaria blight in cucurbits. The following precaution should be taken while cutting the herb: one should not touch the grass as it causes painful itching for 2–4 hours.

Grain preservation

Traditional storage practices

A detailed description of the indigenous technologies being followed by farmers in dry tracts of Tamil Nadu for storing grains and seeds were collected and presented below:

Red gram storage with common salt

Farmers with their indigenous knowledge used common salt in red gram (*Cajanus cajan*) grains storage. In this practice, about 200 gm of salt was mixed for a kg of red gram grains manually. Due to this practice, insects were kept away from the stored grains.

Ash seed treatment in sorghum

Ash was mixed with the sorghum (*Sorghum bicolor*) seeds at the ratio of 1:4. After the ash treatment, sorghum seeds were tied airtight in the jute gunny bags. Farmers strongly believed that ash application controlled losses considerably up to an extent of 80%.

Farmers using this technology stored the sorghum grains for 6 months without any storage pest problems.

Ragi storage with neem and *thumbai* leaves

The strong odour of these leaves keep the storage pests like lesser grain borers (*Rhyzopertha dominica*), saw toothed beetle (*Oryzaephilus surinamemsis*) and flat grain beetle (*Cryptolestes minutus*) away. Neem leaves and *thumbai* being organic repellants were also safe to use.

Paddy storage

Farmers constructed the granary rooms with perfect plan during the construction of house itself. The platform of this granary room was made of wooden boards while its sides had brick and cement walls. It has an opening or a net protected door like structure for ventilation. The grains to be stored were spread in the wooden platform and an earthen pot ¾ of its volume filled with water was kept inside the granary rooms. This would attract and kill the rice moth. Since, this structure was at 243.84 cm height from the ground, rodents and other pest damages were found to be comparatively less and also the grains were found moisture free.

Storage of grains using camphor

In this practice, about 1gm of camphor piece per 5 kg of grains was placed as such in the jute gunny bags. This practice of placing camphor inside the grain storage bag repelled the storage pests due to the strong odour emanated from camphor. A short-term storage of grains up to 3 months was possible with this traditional storage method.

Storage of seeds with lime

Farmers traditionally followed a practice of storing pulse grains along with lime powder. In this practice, farmers dusted about 10 gm of lime per kg of grains. After thorough mixing they stored them in jute gunny bags. The lime had a property of emitting irritating odour that repelled insects and prevented the grains from damage. By this way, grains could be stored for even one year.

Gingelly seeds storage

In gingelly seeds storage, mixing a handful of (nearly 100gm) paddy (*Oryza sativa*) in storage container significantly reduced the infestation of Indian meal moth (*Plodia interpunctella*) and prevented the damage of seeds for the next three month storage period. This was possible because the larvae of Indian meal moth had a habit of webbing the gingelly seeds with its secretion. Hence, these pests avoid the feeding of gingelly seeds stored along with paddy.

Neem oil in seed storage

For 1 kg of pulses seed 20 ml of neem oil was used. Manually farmers applied the neem oil over the seeds to coat the seeds uniformly. Neem oil acted as repellent against

several insects such as weevils, red flour beetles (*Tribolium castaneum*), Long headed flour beetle (*Latheticus oryzae*) and fig moth (*Ephestia cautella*), etc. Some farmers used neem oil mixed with coconut oil/castor oil (1:1) for treating the seed materials against the storage pests.

Storage of vegetable seeds with cow dung

After proper drying, the seeds were stored in cow dung. Farmers collected fresh cow dung and made plate like round shaped structures by tapping it with hand locally called *varati*. Vegetable seeds were then embedded in the cow dung and then dried under sun for 2-3 days. After drying, the seeds get sticked on to the *Varati.* These *Varaties* were then stored in open / inside wooden boxes. The farmers stored the vegetable seeds by this method even up to one year. Farmers believed that cow dung has pesticidal property, which would keep the seeds away from storage pests. Also believed that cow dung's immunostimulant properties increased the germination (90%) and viability of the seeds considerably. Fresh cow dung has to be used for effective storage.

***Pungam* leaves in paddy storage**

These leaves acted as a repellent against Angoumois grain moth (*Sitotroga cerealella*) and rice weevils (*Sitophilus oryzae*). The strong odour released from *pumgam* leaves avoided the pest attack. Some farmers placed these *pungam* leaves directly in the gunny bags and stored the grains.

Paddy husk in managing storage pests

Farmers stored the paddy grains in earthen pods and placed paddy husk in top layer (5cm) above it. Farmers had found that storage pests unpreferred these earthen pots stored with paddy husk.

Oil storage practices

Farmwomen practiced an indigenous method of storing groundnut (*Arachis hypogaea*) oil by placing tamarind (*Tamarindus indicus*) in the oil storage container. In this practice, for storing 5 L of groundnut oil, about ¼ kg of tamarind was placed inside the oil container. The mouth of the container/vessel was then tightly closed with cotton cloth. Some farmers also sealed the small opening in the oil container with the help of tamarind. use of coriander (*Coriandrum sativum*) seeds and salt in oil storage. In this practice, for a litre of oil, farmers placed 100 gm of coriander seeds and a spoon of salt inside the oil stored tin container. The oil was exposed to sun for few hrs and kept closed in airtight condition. Coriander seeds produced pleasant odour in the oil, whereas salt was believed to reduce rancidity and spoilage of oil.

Table 1: Indigenous traditional pest and disease management techniques of different crops

SN	Name of indigenous traditional knowledge (ITK)	Details of ITK	Rationale
1	Management of seed health free from pest and diseases in jhum, terrace, sedentary and home garden traditional farming system.	(i) Collection of healthy seeds before general harvest (ii) hanging over fire furnace/ kitchen for constant smoking (iii) mixing with ashes of fire wood (iv)smoking well dried healthy seeds with edible and non- edible oils (v) Mixing with neem seed powder etc and storing the same in a seed bin. (vi) using aromatic plants such as citronella grass, lemon grass, peels of pomelo etc against maize weevil by mixing /placing these plants over maize grains granary.	Rationale: Unsuitable environment is created to inhibit the growth and proliferation of pest and other microorganisms. Aromatic plants act as repellent or fumigant e .g; Leguminous seeds ,vegetable seeds, maize etc.
2	Methods of keeping seeds free from pest and diseases for use in traditional farming system	Seeds of maize and leguminous crops are often kept intact along with their outer husk and hang over the kitchen/ furnace. Here, maize cobs are tied up in bunches of 10 - 12 cobs by folding their next to outermost husk and hang over the wooden beams of kitchen and sometimes roof beam in the periphery of the house.	Rationale: Open air mixed with smoke seemed to inhibit the pest and pathogen as well as the entry of this pest take time through hard husk of maize and beans.
3	Storage method of paddy in traditional granary for keeping away pest and pathogens.	Specially prepared bamboo granaries plastered with mixture of fresh cowdung and mustard oil cakes are in use for storing paddy on the top of which branches with leaves of *Zanthoxylum acanthopodium* are placed to keep away pest mostly white butterflies -a common pest-of the stored paddy grains. Paddy granaries are either placed near the kitchen or vicinity to kitchen in a separate house. Further, *Zanthoxylum acanthopodium*-a plant of carminative properties emits unpleasant smell that inhibits the white flies.	Rationale: Well plastering of bamboo crevices inhibits the entry of pest and pathogen. It may also be possible that oil cakes emits unfavourable odour to pest and diseases.
4	Foliar application of plant and animal products for the management of pest and diseases.	Following traditional methods are used for the management of pest and diseases of crops: (i) foliar application of wood ashes in the wee hours of the day keeps away aphids pod borers and diseases from plants (mostly vegetables) (ii) Dusting finely ground tobacco leaves keep the aphid pest and diseases away from plants. (iii)Hookah water is very much effective for controlling pest and diseases of major and minor crops such as blast of rice, pod borers, sucking bugs of vegetables etc.	Rationale: Thin film of ash coat with dew inhibits the attack of pest and pathogens. Ash also acts as a nutrient when it gets washed due to rain. Tobacco leaves and hookah water which contains nicotine prevents the foliages from pest and pathogens.

		(iv) Dusting with saw dust is also sometimes used but their effect is not encouraging. (v) Fish and meat wash water application is also a mild deterrent in keeping away of pest due to unpleasant environment for the proliferation of pest and pathogens.	
5	Management of fungal diseases and insect pest of upland paddy.	Pest and diseases of paddy are controlled/managed using the following traditional methods: (i) By spreading leaves of *Artemisia vulgaris, Croton caudatus, Munromia wallichi, Adhatoda vessica etc.* (ii) By erecting or pegging branches of *Cymbopogon Khasianum, Saccharum spantaneum which* inhibits stem borer of paddy.	Rationale: Leaves of these medicinal plants on decomposition release substances /molecules which inhibit the pest and pathogen of paddy in jhum land
6	Management of diseases and pest of rice through plant products	Pest and diseases are also managed by (i) Pomace (wine residue) Here, well fermented wine pomace usually made up of millets are placed at the source of irrigation canal of terrace rice fields which slowly spread over the rice field and inhibits the growth of pests such as leaf folder and blast of rice . (ii) Oak tree bark are also grounded and placed over the source of irrigation canal which inhibits the insect pests of rice such as brown plant hoppers.	Rationale: Unpleasant odour of pomace may be the reason behind inhibiting the fungal disease and leaf folder in particular.
7	Management of blast and chara problem in terrace as well as in settled wet land paddy.	Traditional farmers use paddy husk before five months to contain the blast of rice at 0.3 to 0.5 ton/h for effective control of blast disease of rice. Paddy husk also makes clay/ loamy soil porous for better aeration of plants /tillers. Chara, a green alga infested field water is drained off first and paddy husk were applied to get rid of chara problem in the field .This method is also effective for controlling blast of paddy.	Rationale: After draining of water, chara get settled on the ground which when paddy husk is applied suppress the chara and get decomposed which becomes nutrients of the plant on irrigation of field again. Chara do not have the chance to come up and suck the nutrient meant for paddy again
9	Control of nematodes in ginger chillies, tomato and turmeric by intercropping Chrysanthemum *coronarium.*	Nematodes of turmeric, tomato, chillies and ginger are controlled by either intercropping with *Chrysanthemum coronarium, Tagetes erecta,* or growing *Tagetes erecta* as border crops. This is a very effective method and often farmers incorporate leaves of these trap crops into the soil to enhance effectiveness and nutrients enrichment of crops.	Rationale: The sharp smell of trap crops may be the reason in the inhibition of nematodes.
10	Cultural practices in the management of crops on jhum system	The pest and diseases of paddy (major crop)and vegetables (i) Burning of slashed debries which kills the resident pests and pathogens from the system because many plants and grasses serves as the alternate host of crops .This clean cultivation practices enable farmers to harvest crops less infected by pest and pathogen. (ii) Zero tillage practices (often seeds are sown by dibbling methods) enables the	

		natural growth of nodulated frankia found in socially valued alder trees and undisturbed mycorrhizal root of slashed plants that promotes the healthy growth of crop plants. (iii) Mulching through the removal of unwanted weeds soon after the establishment of paddy .The decomposed mulch may inhibit the pathogen propagules and also provide nutrients to crop plants. It also protects the soil from erosion in jhum slopes. Thus, mulching has multipurpose use in jhum system. (iv) Mixed cultivation of rice with sparsely grown maize, legume crops, job's tear (C*oix* lacryma jobi. *L)*, shorghum and ground vegetables, protects the diseases and pest of rice probably due to the physical barriers of intercrops in the movement of air borne propagules, augmenting microclimate and humidity etc Maize and sorghum not only provide food but also acts as perch for birds to feed on insects and pest of paddy in jhum field. Further, maize plants also serve to locate the burrows of rodents that destroypaddy crops.	
	Cultural practices for insect, pest control in wet valley land paddy and sedentary dry land farming system.	Farmers often plough their field repeatedly soon after harvest for exposing soil inhabiting insect pests, arthopods, nematode etc. to harsh weather and to facilitate natural predators . Insects such as grasshopper, crickets and borers lay their eggs in the upper layer of soil in paddy fields eventually exposed during the course of repeated operation and their eggs either desiccate or preyed by the Egrets and their natural predators. This indigenous repeated ploughing technique for getting rid of soil borne insects which damage paddy crops is very effective in wet land system and dry sedentary farming system.	
	Control of rodents by smokes through burning of paddy husk and dry chillies.	Rodents cause heavy loss to paddy in jhum fields. To control this menace burrows of rats are stuffed with smoke by burning paddy husk and land race dry chillies variety. Complete control over rodents depends on the number of burrows plugged by smokes	Rationale: The suffocating pungent smokes promptly affect the respiration systems of rats and killed.
	Traditional ecotechnologies for the management of disease in traditional land use system	Traditional technologies such as bamboo drip method of irrigation of terrace rice which makes rice crops free from contaminated water borne diseases as seen in Arunachal Pradesh, bench terracing in higher elevation for soil conservation *vis-à-vis* nutrient loss to avoid diseases of crops due to nutrient deficiencies, well adapted techniques of growing potato in the higher elevation compared to paddy at lower elevation to match the soil fertility gradient, emphasis of farmers to grow tuberous crops in shorter jhum cycles as compared to cereals under longer jhum cycles are some of the need based techniques adopted by traditional farmers to avoid nutrient deficiency diseases in crops under traditional land use system in north east.	

Table 2: Important botanicals and botanical preparations in pest and disease management

SN	Name of Plant	Pest or disease controlled in crop	Remarks
1	Dried peels of mandarin	Rice: Storage pest	Controls insect pest in rice. Peeled rind are placed sporadically in the field after transplanting for management of stem borer in rice
2	Hatibar (Agave sissalana)	Vegetables: ants	The fermented mixture of Agave sissalana. Piper nigrum, Vernonia amygdalina and Nicotiana tabaccum is used in Kenya for management of termites in field.
3	Datura	Ants	The plant extract is mixed with cow urine before drenching the soil
4	Neem	Storage pest of paddy	The disagreeable odour as well as insecticidal properties of the leaves keeps away stored grain pesta including weevil and grain moth
5	Tobacco	Management of leech	It acts as a repellent
6	Turmeric	Management of ant	The required quantity of turmeric powder is mixed with water and drenched at the base of the ant infested plant
7	Fermented plant extracts mixture of titeypati, banmara and *Lantana camara*	Tomato and chilli: aphids and white flies	It has anti feedant and repellent effect against insect pest

Table 3: Traditional methods of seed treatment and storage used by farmers

Crop	Method of seed treatment and storage	Scientific interpretation
Paddy	Seeds stored in salt water (1:10), stirred, and kept aside (generally for 2 kg of seed, 1 kg of salt and 10 L of water is effective). After an hour, light and chaffy seeds which were floating were removed and hard seeds that settled down were dried in shade.	Adding salt to water increases its density and helps in separation of light and chaffy seeds. This also helps in increasing germination
	Seeds were soaked in water overnight, dried in shade, and placed in a pit containing tree saw dust and sheep manure. The pit was made airtight. Seeds were removed after two days, dried, and used for sowing.	Keeping seeds along with sheep manure in an airtight container creates heating inside the pit which is required for initiation of germination. Chemical reactions inside the seed prefer warm conditions to start
	A small bag containing seeds (approximately 10–15 kg) was placed at the entrance of the house instead of a door mat. This can be stored for 1 to 2 years.	Whoever enters the house will step on the bag. This repeated stepping on the bag disturbs insects which are trying to establish and feed on the seed.
	Seed bags of 10 kg were dissolved in 1:10 solution of salt and water. The seeds were dried and used for sowing within 72 hours.	The salt treatment of seed helps in breaking dormancy and tolerating drought stress.
Sorghum	Seeds were treated with dried cow dung powder and cow urine before sowing. For one kg of seed approximately 100 g cow	Cow urine contains 2.5% urea which is known to break dormancy and improve germinat. Cow dung powder protects the

	dung powder and 250 ml cow urine were used for better germination. Cow dung powder was also used for storage of seeds.	seed from humidity and hence improves longevity of seed. Cow dung was used with ghee and honey in ancient times for treating seeds as documented by Kautilya in Arthashastra.
	Seeds were treated with lime water. One kg of lime was dissolved in 10 L of water and kept for 10 days. The superfi cial water was collected and seeds were soaked in it overnight. The seeds were dried in shade and used for sowing.	Lime or calcium hydroxide is known to protect seed against seedborne diseases such as smut and bunt.
	Good ear heads were selected and kept open in fog in *rabi* (postrainy) season and kept inside a pot containing neem leaves.	The neem leaves protect seed from seed borer and beetles (Karthikeyan *et al.,* 2009). The exposure to fog may result in breaking of dormancy and bring drought tolerance (Shigihara *et al.,* 2008).
	Good ear heads were harvested along with awns and kept in the center of dried paddy grass heap (called *banave*).	Seed along with awns create hindrance for insect activity and thereby protect seed from insect damage. The selection of good ear heads and drying of seeds is an ancient practice to ensure seed longevity.
Pigeonpea	Seeds were kept along with horse gram seed and plant dust in an airtight container. Dust and seeds are separated before sowing.	The dust of horse gram is known to absorb excess moisture in the seeds and helps in storage for longer duration.
	Seeds were coated with fine red soil of the village pond or hill, dried in shade, and stored. For 10 kg of seed, 1 kg of soil is used.	The fine red soil smeared on seed creates a hard surface which is impermeable and protects seed against attack of storage pests. It also resists moisture permeability.
	Seeds were treated with pongamia leaf extract and dried before sowing.	Strong odor of pongamia leaves repels storage insects
	Seeds were kept in a gunny bag along with *Guntur* chili powder and neem leaf powder.	The chili powder contains capsacin which is known to inhibit lipid peroxidation which in turn slows down seed ageing. The *Guntur* type is known for its high pungency. The neem leaf powder acts as a repellent.
	Seeds were kept with powder of bitter gourd or drumstick seed extract for 3–6 months.	The toxic nature of drumstick and bitter gourd seeds not only repels insects but also protects from pathogens associated with seed.
Chickpea	Seeds were stored along with mint leaves (*pudina*) or sweet flag (*baje*) root powder.	Strong odor of sweet flag repels storage insects
	Seeds were treated with citronella leaf oil, cotton seed oil, soybean oil, or castor seed oil; 500 ml of oil was used for 100 kg of seed.	The strong odor of these oils repels storage pests and microbes like *Alternaria* and *Fusarium.*
Pigeonpea and chickpea	Seeds of these crops were kept along with small millets like pearl millet or foxtail millet or finger millet and stored in an earthen pot. The pot was made airtight by smearing cowdung. For 5 kg of seed, 1 kg of millets was used.	The coarse seed surface of minor or small millets absorbs moisture of seed of pulses and helps in better storage.

Green gram	Seeds were kept on a layer of ash in an earthen pot and covered with another layer of ash. Then another pot was kept on it and cow dung was smeared to make it airtight.	The insects inside the seed will be suffocated and die and also the seed can be stored for a longer period since seeds will not absorb moisture from outside.
	Ten kg of seed was mixed with 250 g chili powder and 1 kg of *ragi* or fi nger millet fl our, and then kept in a bamboo pot along with paddy husk.	Chili powder provides repellence against storage pests while flours prevent attack of secondary pests. The use of fl ours to preserve seeds is an ancient practice as mentioned in Varahamihira's *Brihat Jataka*.
Chili	Seedlings of chili were removed from the nursery bed and treated with 1:3 solution of cow urine and water.	Cow urine helps in protecting seedlings against damping-off caused by *Rhizoctonia solani.*
	A gunny bag was immersed in hot water and seeds were placed in it and kept for a day. The seeds were then used to sow on the seed bed.	The pre-germinated seed when sown on the seed bed helps to get more usable transplants and improve vigor.
Sunf lower	Seeds were kept inside the dried fruits of sponge gourd after removing the seeds. These fruits were kept in an airtight container.	The fruits of sponge gourd act as protective capsules against insect pests and protect sunflower seed during storage.
Cotton	Seeds were treated with ash and cow dung slurry and dried in shade before sowing.	Cow dung slurry helps to remove the fiber attached to the seed and thus facilitate sowing. Ash along with cow dung slurry is known to control diseases caused by *Rhizoctonia solani*. Cotton and other hard seeds were smeared with cow dung before sowing as in Kautilya's Arthashastra

6. Crop voyage in India and world

Description of Indian civilization and agriculture by travelers from China, Europe and USA

Indus valley civilization: Allchins, relying on Lambrick, who, according to them, had personal knowledge of Sind, describe as follows how crops were grown in the riverain tract of the Indus. "The principal food grains, that is wheat and barley, would have been grown as spring *(rabi)* crops: that is to say, sown at the end of the inundation upon land which had been submerged by spill from the river or one of its natural flood channels, and reaped in March or April. The Greek writers highly praised the fertility of Indian soil and favourable climate condition describing the principal agricultural products of the land. The Greek writers also affirm that India has a double rainfall and the Indians generally gather two harvests. - Megasthenes witnesses - the sowing of wheat in early, winter rains and of rice, 'bosporum', sesamum and millets in the summer solstice (Diodorus, II, 36). **Megasthenes** adds further to the winter crops, viz., "wheat, barley, pulse and other esculent fruits unknown to us".

The Chinese pilgrim **Hsieun Tsang** who arrived at the monastic University of Nalanda in 630 A.D. mentioned the gardening as: "The temple arose into the mists and the shrine halls stood
high above the clouds . . . streams of blue water wound through the parks; green lotus flowers sparkled among the blossoms of sandal trees and a mango grove spread outside the enclosure."

Protection of cultivators: Sher Shah had genuine concern for the peasantry and safety of their crops. One of the regulations made by Sher shah was this: That his victorious standards should cause no injury to the cultivations of the people; and when he marched he personally examined into the state of the cultivation, and stationed horsemen round it to prevent people from trespassing on any one`s field. As regards the peasantry and their condition, there is reliable evidence in the observations of the European travellers who travelled in India in the seventeenth century. Evidence of the structure of the Mughal gardens and plants grown in them is in the Persian classics illustrated during the reign of Akbar. Among them is *Diwan-i-Anwari,* a collection of poems by the Persian poet Anwari, who flourished in the latter part of twelfth century. It contains some excellent paintings on gardens and gardening. **Abu-l-Fazl** mentions three kinds of sugarcane, viz. *paunda,* black and ordinary. **Abu-l-Fazl** provides a list of twenty-one fragrant flowering plants along with the colour of their flowers and the season of flowering in the **AiniAkbari**. **Terry**, an English traveler, writes, _The country was

abounding with musk-melons. One could also find water-melons, pomegranates, lemons, oranges, dates, figs, grapes, coconut, plantains, mangoes, pineapples, pears, apples, etc.' Terry also mentions the use of coffee by some people. He writes, _Many religious people drank a –wholesome liquor" which they called coffee. Black seeds were boiled in water, which also become black. It altered the taste of water very little. It quickened the spirit and cleansed the blood.

Francois Bernier: Of the European travelers who come to India during the Mughal rule, the most intelligent and learned was Francois Bernier a Frenchman. Bernier gives a vivid description of Bengal its landscape people and its plant and animals products. With extensive fields of rice, sugar, corn, three or four sorts of vegetables, mustured, seasems for oils and small mulberry trees two or three feet (61 to 91 cm) in height, for the food of silk worms.

Meadows Taylor states –The Bahmanis constructed irrigation works in the eastern provinces, which incidentally did good to the peasantry while primarily securing the crown revenue. **Vincent Smith** points out that those items to their credit weigh lightly against the wholesale devastation wrought by their credit weight lightly against the wholesale devastation wrought by their wars, massacres, and burnings. Their rule was harsh and showed little regard for the welfare of Hindu peasants, who were seldom allowed to retain the fruits of their labour much more than would suffice to keep body and soul together.

Herodotus (484-425 BC) the father of history reported in his writings that the wild Indian (cotton) trees possessed in their fruits fleeces, superseding those of sheep in beauty and excellence from which the natives used to weave cloth. Herodotus further wrote that –trees which grow wild in India and the fruit of which bear wool exceeding in beauty and fineness that of sheep wool Indians make their clothes with this tree wool". Some traveller writers fabricated stories of a lamb sitting inside the fruit. **Marco Pola**, a Venetian, who traveled widely throughout the Asia in AD 1290 said that the coast of Coromandel (Madras, India) produced the finest and most beautiful cotton in the world. Indian cloth, particularly the Dacca muslin was renowned all over the world and has been described as _webs of woven wind' by oriental poets. It was so fine that it could hardly be felt in the hands. It is said that when such muslins were laid on the grass to bleach and the dew had fallen, it was no longer visible. A whole garment made from it could be drawn through a wedding ring of medium size. There is also the often repeated tale of Moghul princes who put on seven layers of

muslin and still the contours of her body were so visible that she had to be admonisher by her father, Muhamed Bin Thuklak.

Development of New world crops

The encounter of America by Christopher Columbus in 1492 was the greatest event of the late Middle Ages and is a convenient benchmark to date the beginning of the Modern Era. Three great cultures coexisted in America, although they were unaware of each other: Aztec, Mayan, and Incan. These were monumental civilizations similar in many respects to that in ancient Egypt with enormous temples in the form of pyramids, pictorial writing, a system of cities and government, a bewildering theology, magnificent art, and a developed agriculture. These cultures also had a dark side—slavery, constant warfare, the offering of living human hearts as sacrifice, and cannibalism. Ironically, Columbus, in searching for Asia, did discover their descendants. However, much more valuable than gold and silver treasures were the new crops from the New World that have continually enriched the bounty and cuisine of Europe and the world. Important New World crops are presented (Table 1). We review the history and images of New World crops with particular relevance to horticulture.

NEW WORLD CROPS

Grains and pseudograins

Various grains and pseudograins were domesticated in the New World, including maize (Zea mays), amaranth (Amaranthus spp.), wild rice (Zizania palustris L.), and quinoa (Chenopodium quinoa). Maize has become the most important world grain, surpassing wheat, rice, sorghum, and millets. Maize is presently the principal source of animal feed, especially for pigs and chickens, human food (e.g., cornbread, grits, sweet corn, tortillas, and popcorn), as a source of sugars (corn sweetener), and now as a major source of energy (ethanol). Maize was cultivated by Aztec, Mayan, and Incan farmers, and its production and use made settled life and civilization possible. The significance of maize as a major staple among the native people of the New World is evident in the deification of this crop and its popularity as a common feature of ceramic pottery.

Legumes

New World legumes such as common bean, lima bean, and peanut (groundnut) were destined to become important world food crops. The peanut, found in ceramics from the Moche culture in Peru, was spread worldwide by European traders and became particularly

important in Africa after being brought there from Brazil. Phaseolus bean was vital to New World agriculture for agronomic, nutritional, and culinary reasons. Beans and maize were sown in the same hole and the two crops complemented each other. Maize acted as a support for the climbing beans, and nitrogen-fixing bean as a result of rhizobium bacteria provided this element to the soil. The mixture of beans and tortillas (maize pancakes) provide a complete protein food that was the basis of Aztec and Mayan diets. It remains the basis of Mexican cuisine to this day.

Cucurbits

The New World cucurbits, Cucurbita moschata, C. pepo, C. maxima (squashes and pumpkins), and Sechium edule (chayote), were important crops of the indigenous population and were grown for their fruit and seed. Representation of C. pepo can be found in Incan ceramic pottery. The New World cucurbits became prominent in Renaissance herbals in the 16th century and the genre known as natura morta (still life) popular in the 17th and 18th century.

Solanaceous fruit crops

Capsicum peppers and pepino, important food crops with ceremonial and medicinal uses in pre-Columbian America, are represented in various indigenous ceramics. Because Columbus was looking for black pepper, the discovery of the even more pungent fruits of various species of Capsicum led to their immediate acceptance and popularity throughout the world, particularly in Asia and China where they became an important part of their cuisine. European herbal images of capsicum pepper are abundant and sculpted forms can be found on the door of the Pisa Cathedral (Italy) along with tomato. Tomato fruit, because of its resemblance to the poisonous Old World mandrake, was treated with skepticism but soon was consumed raw and cooked to become an integral part of Italian cuisine, and now is one of the most important fresh and processed world vegetables.

Root and tuber crops

Indigenous people in the New World domesticated a number of starchy vegetables, including cassava, potato, and sweetpotato, that have become very important world crops. There are numerous images of potato in pre- Columbian sculpture, and potato culture of the Incas is illustrated in a calendar presented to the King of Spain in 1580. Potato has become one of the 10 most important world food crops.

Fruit crops

There are various temperate, subtropical and tropical fruits in the New World that have become valuable world crops and many such as various annonas, guava, jaboticaba, and

mamey that are still not fully used. Brambles. Rubus species are abundantly found across North America with the blackberry (Rubus subg. Rubus), red raspberry, and black raspberry (R. idaeus and R. occidentalis, respectively) being the most well known and most important commercially. The seeds of cacao originating in the Amazon Basin were long prized in Mesoamerica and the seeds once used as currency by the Aztecs; the fruits are a common feature in pre-Columbian pottery. Ground fermented cocoa bean is the main source of chocolate. The pulp surrounding the seed is delicious and remains to be commercially exploited. The beverage xocolatl, a Nahuatl word meaning bitter water, was introduced to the Spanish court in 1544 and soon became very popular in Europe when the hot chili flavoring was replaced with sugar. Cactus fruits. The cactus family (Cactaceae) is confined to the New World but has been distributed worldwide. Cacti have become important world crops for fruit (cactus pear, pitaya), vegetables (cladodes), animal feed, and ornamentals. Pineapple. Columbus in his second voyage of 1493 found domesticated pineapple on the island of Guadeloupe, an island in the eastern Caribbean, and described it as pin˜a de India because of its resemblance to a pinecone.

Papaya. This tropical fruit is now ubiquitous as a backyard tree in the tropics worldwide and has become an important export in Brazil, Hawaii, Mexico, and Thailand. Strawberry the small-fruited diploid was well known in Europe but the modern largefruited octoploid strawberry (2n = 8x = 56) is derived from F. chiloensis and F. virginiana that hybridized in France. Large whitefruited forms of F. chiloensis were found growing in Chile.

Ornamentals

The Americas have been the source of over 1000 garden plants. Various ornamentals including dahlia, fuchsia, helianthus, and petunia have become very important in floriculture and are now grown worldwide. Helianthus, the sunflower, has long been associated with America as a food and medicinal plant and became an important ornamental and oilseed crop in the 20th century. Industrial crops Four New World crops, cotton (Gossypium), Para´ rubber (Hevea brasiliensis), tobacco (Nicotiana spp.), and quinine (extracted from Cinchona sp.), exploited by indigenous Americans were to have important effects on world history. American cotton, derived from two species of Gossypium, G. hirsutum from Central America and G. barbadense from Brazil, accounts for the majority of world cotton production as a result of its longer, stronger fibers compared with Old World cottons. The resinous latex from the tropical Amazonian tree H. brasiliensis is used for the production of rubber, which has important uses in transportation, clothing, and the electrical industry. Rubber has become one

of the most vital industrial crops, but the industry is now concentrated in Southeast Asia, particularly Malaysia.

Table 1. Selected crops indigenous to the New World.

	New World crops	Binomial	New World origin
A	**Cereals and pseudo cereals**		
1	Amaranth	Amaranthus spp.	Mexico
2	Maize	Zea mays	Mesoamerica
3	Quinoa	Chenopodium quinoa	Andean highlands
4	Wild rice	Zizania palustris	Northern North America
B	**Legumes**		
	Common bean	Phaseolus vulgaris	South America
	Lima bean	Phaseolus lunatus	South America
	Peanut	Arachis hypogaea	Brazilian–Paraguayan Center
C	**Cucurbits**		
	Chayote	Sechium edule	Mexico, Central America
	Pumpkin	Cucurbita maxima	South America
	Squash	Cucurbita moschata, C. pepo	Mexico
D	**Solanaceous fruits**		
	Capsicum peppers	Capsicum annuum, C. bacattum, C. chinenese, C. frutescens, C. pubescens	South America, northern Peru
	Ground cherry, husk tomato	Physalis peruviana, P. philadelphica	Central America
	Pepino	Solanum muricatum	Tropical America
	Tomato	Solanum lycopersicum	Western South America, domesticated in Mexico
E	**Roots and tubers**		
	Cassava	Manihot utilissima	Brazil
	Potato	Solanum tuberosum	Peru
	Sweetpotato	Ipomoea batatas	Central America
F	**Fruits and nuts**		
	Annona	Annona cherimola	Brazil
	Avocado	Persea americana	Mesoamerica
	Black raspberry	Rubus occidentalis	North America
	Brazil nut	Bertholletia excelsa	Amazon
	Blueberry	Vaccinium corymbosum	North America
	Cacao	Theobroma cacao	Tropical America
	Cactus	Opuntia ficus-indica	Mexico
	Cashew	Anacardium esculenta	Brazil
	Cranberry	Vaccinium macrocarpon	North America
	Guava	Psidium guajava	Tropical America
	Jaboticaba	Myrciaria cauliflora	South America
	Mamey	Mammea americana	West Indies, northern South America
	Papaya	Carica papaya	Tropical America
	Pineapple	Ananas comosus	Tropical South America
	Pitaya	Stenocereus spp.	Mexico
	Strawberry	Fragaria chiloensis Fragaria virginiana	Pacific Coast, North and South America Eastern, North America

	Soursop	Annona muricata	Peru–Ecuador
G	**Industrials**		
	Cotton	Gossypium hirsutum, G. barbadense	Central America, Brazil
	Quinine	Cinchona calisaya	Peru
	Rubber	Hevea brasiliensis	Amazon
	Tobacco	Nicotiana rustica, N. tabacum	Mexico, Central America
H	**Ornamentals**		
	Dahlia	Dahlia spp.	Mesoamerica
	Fuchsia	Fuchsia triphylla	Hispaniola; South America
	Helianthus (sunflower)	Helianthus annuus	North America
	Petunia	Petunia spp.	South America

CROPS – INDIGENOUS AND INTRODUCED - HISTORY OF RICE, SUGARCANE AND COTTON

Since time immemorial, cereals, particularly wheat, rice, and maize are considered to be life sustaining crops for humans. Even in future these crops will play a pivotal role in food security system of several nations across the world. The utilization of cereals as food and feed, and for industrial purpose is around 1792 million out of which wheat, rice, and coarse grains contribute nearly 35.4%, 20.8%, and 53.7% respectively. In the past fifty years the world has witnessed structural change in cereal economics: Long run trend towards wheat and rice and to some extent for maize, while replacement of coarse grain crops occurred. Developing countries achieved higher growth in production and consumption and at the same time recorded rise in deficits. Rapid expansion of cereals as feed in developing countries and increased share of cereals in world trade.

Rice

Rice is the most important tropical cereal and supplies a quarter of the entire caloric intake of the human race. About 90% of its area and consumption is in South and Southeast Asia, which support a major part of the world population. Rice belongs to the genus Oryza and there are two main cultigens, i.e., sativa in Asia and glaberrima in Africa. Rice is a semi aquatic graminaceous crop having great deiversity as it is grown in complex range of environments, i.e., from uplands at altitude of 3000 m to rainfed lowland irrigated, tidal swamp, and deepwater areas. Besides these two species, aquatic rice species, i.e., Zizania aquatica and Z. palustris, are endemic to North America, where it is the staple food of Indians.

Origin

The place of major diversity where rice might have domesticated is roughly the east west belt along the Himalayas and adjoining Asia mainland (from Assam, Bangladesh, Burma, Thailand, southern China, and northeren Vietnam). The archaeological evidence

suggests that Asian rice culture was established around 7000 years ago. In India carbonized grains excavated from Hastinapur (New Delhi) suggest that it was in cultivation during 1100-800 BC.

Evolutionary history

The evidences from diverse disciplines including biosystematic and paleogeology suggest that the genus Oryza arose from a common ancestor. The evolutionary path was from wild perennial to wild annual to cultivated annual, and the closely related wild relatives contributed differentiation of two cultigens. In oryza sativa, the evolution of different geographical races, i.e., japonica, javanica, and indica (the latter forming aman, aus, and indica types in the Ganges belt) took place assisted strongly by human selecton. There is general agreement that in both Asia and Africa elongation and floating ability in two cultigens was derived from their wild relatives. In rice, change might have occurred in the following sequence: Perennial->climatic stress->seasonal->human selection-> cultivated rice.

Agri-history of Cotton in India : An Overview

The antiquity of cotton in the Indian subcontinent has been traced to the 4th millenium BC. The fabrics dated approximately 3000 BC , recovered from the Mohenjo-daro excavations in Sind (Pakistan), were identified to have originated from cotton plants, closely related to the Gossypium arboreum species. The lint-bearing species of the genus Gossypium, the true cottons, are four, out of which the diploid (2n=26) species G. arboreum and G. herbaceum are indigenous in Asia and Africa. The history of introduction into India of the new world cottons (tetraploid species of G. hirsutum and G. barbadense with 2n=52) dates back to the 18th century AD. By the last decade of the 20th century, India had gained a pride of place in the global cotton statistics with the largest cropped area of 8.9 million in 1996-97, growing the most diverse cultivars in terms of botanical species and composition, producing the widest range of cotton fiber quality suitable for spinning 6‘s to 120‘s counts yarn, and supporting the largest agrobased national industry of the country.

Origin of the indigenous cottons

The cotton textiles of the Harappan civilization (2300-1750BC) were produced by sophisticated textile craftsmanship. Thus at the earliest agricultural levels yet discovered, true cottons were already present in the Indian subcontinent. Wild and weedy types have been found to be associated with primitive cultivated types in both the old world species of G. herbaceum and G. arboreum. Species of G. herbaceum, have been found from the coastal strip northwest of Karachi (Pakistan), through northern Baluchistan to south Yemen, Ethiopia, and Sudan and even in West Africa south of the Sahara. Species of G. arboreum.

have been recorded by in Kathiawar, Gujarat, Khandesh, and the Deccan in India. It seems likely that it was in Gujarat (India) or Sind (Pakistan) that G. arboreum cottons were first brought into cultivation (Hutchinson, 1971). It may further be surmised that the differentiation of the three perennial races of G. arboreum, namely burmanicum of northeastern India, indicum of western India and the Penninsula, and sudanense of northern Africa, ante-dated domestication and that each contributed separately to the cultivated cottons in Asia and Africa.

Agri-history of cotton production development

Until the middle of the 18th century, only indigenous arboreum and herbaceum varieties of cotton were grown in different regions of the country. Due to the human skills and dexterity of the local artisans, very fine yarns were produced by them, from even the short staple and coarse cottons grown in India. In 1788, the Governor General (at Calcutta) was requested by London to encourage growth and improvement of Indian cottons to meet the requirements of the Lancashire textile industry. The figures for exact area under indigenous cottons and production in India during this period are not available, although it is reported that the local production had stabilized by 1900AD.

Sugarcane

The origin of sugarcane was India. The species *Saccharum officinarum* was first domesticated in India and the spread to other countries by Arab merchants. Evidences revealed that 3000-7000 years ago, Atarna veda indicated that sugarcane originated from the area Sakkaram and then later it was indicated as sakkra in Sanskirit. Earlier indications in Kautilya Artha Sastra also mentioned about the cowdung sett treatment for sugarcane.

Crops introduced by Britishers

Pseudo cereals Avena sativa (oat);**Grain legumes** Castanospermum australe (black bean), Pisum sativum (pea); Fiber crops Gossypium barbadense (cotton);**Vegetables** Allium tuberosum (leek), Asparagus racemosus (satawar), Beta vulgaris (beet root), Brassica oleracea var. botrytis (cauliflower), Capsicum frutescens (sweet pepper), Cichorium intybus (chicory), Cucurbita maxima (squash), Daucas carota (carrot, orange type), Lactuca sativa (lettuce), Lycopersicon esculentum (tomato), Pisum sativum (sweet pea); **Fruits** Averrohoa carambola (carambola), Carica papaya (papaya), Fragaria ananassa (strawberry), Garcinia mangostana (mangosteen), Manihot esculenta (cassava), Malus pumila (apple), Prunus armeniaca (apricot), Prunus avium (cherry), Prunus communis syn. P. domestica (plum), Prunus persica (peach), pyrus communis (pear), Ribes rubrum (red currant) **Medicinal**

Cinchona officinalis (quinine), Origanum vulgare (majoram), aromatic plants Papaver somniferum (opium poppy), Pelargonium capaitatium (Geranium), Salvia officinalis (sage), Thymus vulgaris (thyme), Vanilla aromatica (vanilla)

Crops introduced from West and Central Asia by Mughals or Arabs

Allium cepa (onion), Allium sativum (garlic), Brassica rapa (turmip), Brassica oleracea var. capitata (cabbage), Coriandrum sativum (coriander), Cucumis melo (sweet muskmelon), Daucas carota (carrot, black & red type), Phoenix dactylifera (date palm), Pisum sativum (pea), Syzygium aromaticum (clove), Vitis vinifera (grape)

Crops introduced by Spaniards

Phaseolus vulgaris (French bean)

Crops introduced from China

Aleurites fordii (tung-oil), Glycine max (soyabean), Eriobotrya japonica (loquat), Juglans regia (walnut), Litchi chinensis (litchi), Sapium sebiferum (tallow-tree)

Crops introduced from Latin America

Hevea brasiliensis (Rubber), Ananas comosus (pineapple)

Crops introduced from Southeast Asia and Pacific islands

Arenga pinnata (sugar-palm), Artocarpus communis (breadfruit), Citrus decumanus (pomelo), Citrus paradisi (grapefruit), Durio zibethinus (durian) and Metroxylon sagus (sago)

Some recent introductions

Humulus lupulus (hops), Helianthus annuus (sunflower), Simarouba glauca (simarouba), Cyphomandra betacea (tree tomato), Carya illinoensis (pecan nut), Corylus avellana (hazel nut), Macadamia tetraphylla (macadamia nut), Parthenium argentatum (guayule), and Mentha arvensis (spearmint, USA) Acacia senegal (Australia), Acacia mangium (Australia) and Actinidia chinensis (kiwifruit, New Zealand)

7. Agriculture scope

Scope of Indian Agriculture

Agriculture: - The term agriculture is derived from two Latin words **ager** or **agri** meaning **soil** and **cultura** meaning **cultivation**. Agriculture is a broad term including all aspects of crop production, livestock farming, fisheries, forestry etc.

Agriculture is a branch of applied science. It is the art of farming including the work of cultivating the soil for producing crops and raising livestock. There are three main spheres of agriculture as under;

Geoponic:- meaning cultivation in earth,

Hydroponic:- meaning cultivation in water and

Aeroponic:- meaning cultivation in air.

AGRICULTURE is defined in the Agriculture ACT, 1947, as including 'horticulture, fruit growing, seed growing, dairy farming and livestock breeding and keeping, the use of land as grazing land, meadow land, osier land, market gardens and nursery grounds, and the use of land for woodlands where that use ancillary to the farming of land for Agricultural purposes".

Agriculture is defined as an art, science and business of producing crops and livestock for economic purposes

Agriculture is a productive unit where the gifts of nature like land, light, water and temperature are integrated into a single primary unit i.e **crop plant** which is indispensable for human beings. The secondary productive units of agriculture are **animals** including **livestock, birds and insects** which feed on the primary units and provide concentrated products such as **meat, milk, hide, wool, eggs, honey, silk and lac.**

Agriculture is considered as mother of all agro-based industries because the development and functioning of all such industries is governed by the raw material supplied from agriculture sector E.g. Textile, Oil, Sugar, Dairy and Canning industries are directly governed by cotton, oilseeds, sugarcane, milk and fruits production, respectively.

The important cultural energies utilized for the production and protection of agricultural commodities are;-

Natural resources:-

Agriculture implies the effective use of land, water, light and other resources of environment through the production of field crops, forage crops, horticultural crops, farm animals, fisheries and forestry.

Added resources:-

1. Irrigation and drainage
2. Organic, biological and mineral fertilizers, chemicals
3. Farm equipments and draft power.

These are used to maximize the productivity per **unit time, water, land, labour and rupee invested.**

The word **AGRICULTURE** thus may be expanded as **A**ctivities on the **G**round for **R**aising **I**ntended **C**rops for **U**plifting **L**ivelihood **T**hrough the **U**se of **R**echargeable **E**nergies.

REVOLUTIONS IN AGRICULTURE

Revolution	Concerned with	Achievements
Green revolution	**Food grain production**	Food grain production increased from 51 million tones at independence to 223 million tones in(2006 - 07), 4.5 times increase.
White revolution	**Milk production**	Milk production increased from 17 million tones at independence to 69 million tones, four times (1997-98).
Yellow revolution	**Oilseeds production**	Oil seed production increased from 5 million tones to 25 million tones since independence, 5 times increase
Blue revolution	**Fish production**	Fish production increased from 0.75 million tones to nearly 5.0 million tones during the last five decades.

Similarly, the egg production increased from 2 billion at independence to 28 billion, sugarcane production from 57 million tones to 276 million tones, cotton production from 3 million bales to 14 million bales which shows our sign of progress.

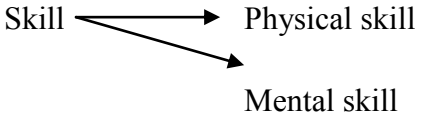
India is the largest producer of fruits in the world. India is the second largest producer of milk and vegetable.

In future, agriculture development in India would be guided not only by the compulsion of improving food and nutritional security, but also by the concerns for environmental protection, sustainability and profitability. By following the **General Agreement on Trade and Tariff (GATT)** and the liberalization process, globalization of markets would call for competitiveness and efficiency of agricultural production. Agricultural will face challenging situations on the ecological, global climate, economic equity, energy and employment fronts.

Agriculture as an art, science and business and Branches of agriculture

Agriculture as an art:- Learning by doing and gaining experience. Art is concerned with skill and experience. It is inherited by seeing parents or elders through experience. E.g. art of walking of a child.

Skill of agriculture is purely derived by physical work.



Agriculture **primarily requires physical skill** and **secondarily mental skill.** Physical skill is inherited by doing physical work with perfect execution. e.g. Opening a straight furrow, broadcasting/sowing seeds, levelling the field, top dressing of fertilizer, weeding, harvesting crop etc.

Art of agricultural requires secondarily **mental skill.** it is related with **decision making.** e.g. Selection of crops for a particular area is a skill season, right time of sowing the crop after onset of monsoon.

Agriculture as a Science:-

- Science is systematic study of happenings of any thing
- Scientific technology helps in getting maximum output, science helps to select a crop suitable to seasons at the appropriate time
- Part of science is inherited by farmers
- Science of agricultural tries to give reasons. Yield increase is due to application fertilizer. Yield reduction also results due to pest and disease attack etc.
- Farmers will become scientists if more sophisticated methods are given. Experience makes them scientists
- Science of agriculture requires **primarily mental skill** and **secondarily physical skill**

Agriculture as Business

- Nowadays, it is purely business oriented.
- The market price of agricultural produce is governs by total production of a particular commodity. It follows the economic principle of demand and supply.

- In agriculture business, quantity is ignored and profit is more. The farmers try to get more profit per rupee invested.

  E.g. in Punjab, rice is produced during *Kharif* season for profit and commercial reason

- Business of agriculture is purely economic

No.	Agriculture	Industry
a)	Resources are self generated	Depends on raw materials
b)	Direct producer	Indirect producer
c)	Subjected to natural calamities	Protected from natural calamities
d)	Production is not under control	Production is under control
e)	All the process is carried out by single person or family	There are separate units and subunits
f)	Owner himself is the labour	Owner as a labour is less in industry

BRANCHES OF AGRICULTURE

Seven branches as under

1) Agronomy: – It deals with the production of various crops which includes food crops, fodder crops, fibre crops, sugar, oil seeds, etc. The aim is to have better food production and how to control the diseases and pest.

2) Horticulture: – Branch of agriculture deals with the production of flowers, fruits, vegetables, ornamental plants, spices, condiments (includes narcotic crops – opium, etc. which has medicinal value) and beverages.

3) Forestry: – It deals with production of large scale cultivation of perennial trees for supplying wood, timber, rubber, etc. and also raw materials for industries.

4) Animal Husbandry: – The animals are being produced, maintained, etc. Maintenance of various types of livestock for direct energy (work energy). Husbandry is common for both crop and animals. The objective is to get maximum output by feeding, rearing, etc. The arrangement of crops is done to get minimum requirement of light or air. This arrangement is called geometry. Husbandry is for direct and indirect energy.

5) Fishery Science: – It is for marine fish and inland fishes including shrimps and prawns.

6) Agricultural Engineering: – It is an important component for crop production and horticulture particularly to provide tools and implements. It is aiming to produce modified tools to facilitate proper animal husbandry and crop production tools, implements and machinery in animal production.

7) Home Science: – Application and utilization of agricultural produces in a better manner. When utilization is enhanced production is also enhanced. E.g. a crop once in use in south was found that it had many uses now.

On integration, all the seven branches, **first three is grouped as for crop production**, **next two animal management** and **last two alive agriculture branches**.

Land utilization statistics

Sr. No.	Particulars	India	Gujarat
1.	Geographical location	$8^0.4'$ - $37^0.6'$ N latitude and $68^0.7'$ - $97^0.25'$ E longitude	$21^0.1'$ - $24^0.7'$ N latitude and $68^0.4'$ - $74^0.5'$ E longitude
2.	Total geographical area	328.848 million ha	19.60 million ha
3.	Total reporting area	304.300 million ha	18.82 million ha
4.	Area under cultivation	143.000 million ha	9.42 million ha
5.	Total cropped area	179.750 million ha	10.16 million ha
6.	Area sown more than once	36.750 million ha	0.74 million ha
7.	Area not available for cultivation	161.300 million ha	2.61 million ha
8.	Area under forest	66.400 million ha	1.88 million ha
9.	Length of Sea coast	7516.5 km	1600 km

Agricultural trade

Agricultural Export and Import (US dollars)

Export				Import			
Commodity	13-14	14-15	15-16	Commodity	13-14	14-15	15-16
Rice	6.2	7.8	7.9	Pulses	2.4	1.8	2.8
Meat and meat preparations	3.3	4.5	4.9	Cashew	1.0	0.8	1.1
Processed foods	2.8	2.7	2.7	Vegetable oils	9.9	7.2	10.6
Spices	2.8	2.5	2.4	Fresh fruits	1.1	1.3	1.6
Oil meals	3.0	2.8	1.3	Spices	0.5	0.6	0.7
Sugar	1.6	1.2	0.9	Sugar	0.6	0.4	0.6
Wheat	1.9	1.6	0.8	Cocoa products	0.2	0.2	0.3
Pulses	0.2	0.3	0.2	Natural Rubber	0.8	0.9	0.8
Agriculture exports	32.0	33.0	30.1	Agriculture Imports	16.8	14.9	15.9

Food grain production trends in India

India is estimated to produce 273.38 million tonnes (MT) of foodgrain in the 2016-17 crop year (July-June) over 8 MT more than the previous record of 265.04 MT in 2013-14. Anticipating good monsoon this year too, the ministry had last month set a target of foodgrain

production at 273 MT for the 2017-18 crop year and expressed confidence of maintaining farm sector growth rate of over 4% during the period.

Table 1: Production of Foodgrains and Other major Crops

Crop	2004-05	2010-11	2011-12	2012-13	2013-14
Rice	83.1	96.0	105.3	105.2	106.7
Wheat	68.6	86.9	94.9	93.5	95.9
Coarse Cereals	33.5	43.4	42.0	40.0	43.3
Pulses	13.1	18.2	17.1	18.3	19.3
Total Food Grain	198.4	244.5	259.3	257.1	265.0
Oilseeds (lakh tonnes)	243.5	324.8	298.0	309.4	327.5
Sugacane (lakh tonnes)	2370.9	3423.8	3610.4	3412.0	3521.4
Cotton (Lakh bales)	164.3	330.0	352.0	342.2	359.0

Table 2:Production of Milk, Eggs, Wool, Meat and Fish- All India

Year	Milk	Eggs	Wool	Meat	Fish
	(Million Tonnes)	(Million Nos.)	(Million Kgs.)	(Million Tonnes)	(000' Tonnes)
1950-51	17	1832	27.5	-	752
1980-81	31.6	10060	32	-	2442
1990-91	53.9	21101	41.2	-	3836
2000-2001	80.6	36632	48.4	1.9	5656
2010-2011	121.8	63024	43	4.8	8231
2013-2014	137.7	74752	47.9	6.2	9574

8. Importance of agriculture and agriculture available in India

Development of Agricultural Departments, ICAR and SAUs in India

A fundamental department of agriculture in India was started in the year 1871. Although the chief function of the department named 'Department of Revenue, Agriculture and Commerce' remained revenue and there was no work on agricultural development. Primarily, the department was established by the Government with a view to supply cotton to the textile industries of Manchester, and not to feed the famine- ravished India. Based on the reports of the Famine Commissions of 1880, 1898 and 1900, the Government of India (GoI) was determined to set up a central 'Department of Agriculture' controlled by the Imperial Secretariat and agriculture departments were to be set up in the provinces to primarily look after agricultural enquiry, agricultural development and famine relief in the country. However, the key duty of the agriculture departments both in the centre and the provinces lingered on famine relief. In 1892, an agricultural chemist and an assistant chemist were allotted to look after research and teaching in India, which manifested the first scientific staff in the Department of Revenue and Agriculture. Eventually, in 1901, an Inspector General of Agriculture was appointed to advise the imperial and the provincial governments on agricultural matters. An imperial mycologist was appointed in the same year, and an entomologist was appointed in 1903.

During the severe famines of 1899–1900, Lord Curzon, the then Viceroy of India, was convinced that the GoI must urgently concentrate on the agricultural sector to overcome the damages caused by frequent famines. As a consequence, Agriculture Research Institute (now the Indian Agricultural Research Institute (IARI), together with a college for advanced agriculture training, was established at Pusa in the year 1905 and its director was the agriculture adviser to the GoI till 1929. Today, IARI is one of the premier national institutes for agricultural research, education and extension in India. The Agricultural School at Saidapet, Chennai, which was established as early as 1868, was later relocated to Coimbatore during 1906. Likewise, a branch for teaching agriculture in the College of Science at Pune (established in 1879) was subsequently developed into a separate College of Agriculture in 1907. Similar agricultural colleges were established at Kanpur, Sabour, Nagpur and Lyallpur, now in Pakistan, between 1901 and 1905.

An All-India Board of Agriculture was established in 1905 with a view to bring the provincial governments more in touch with one another and making suitable

recommendations to the GoI. The Indian Agriculture Service was constituted in 1906. Establishment of the Imperial Council of Agricultural Research (the present-day ICAR). The Royal Commission on Agriculture (Linlithgow Commission), which was appointed in the year 1926, authoritatively reviewed the position of agriculture in India and reported the same in 1928. According to the proposal of the Royal Commission on Agriculture, the GoI, Department of Education, Health and Lands set-up the Imperial Council of Agricultural Research (now ICAR) on 16 July 1929.

The Commodity Committee

Several semi-autonomous Central Commodity Committees were set up by the Ministry of Food and Agriculture. The Indian Central Cotton Committee was the first one to be established in 1921 on the recommendation of the Indian Cotton Committee (1917–18). The chief function of the Central Cotton Committee was cotton improvement with special focus on the development of improved methods of growing and marketing cotton. The Committee's support led to the development of 70 improved varieties and considerably improved fibre quality.

The achievement by the Indian Central Cotton Committee led to the setting up of commodity committees on crops such as lac, jute, sugarcane, tobacco, coconut, oilseeds, spices, cashewnut and arecanut. These apprehensions led to the formulation of the Project for Intensification of Regional Research on Cotton, Oilseeds and Millets (PIRRCOM), which was the first step in the country towards coordinated approach to agricultural research. The Central Commodity Committees were abolished in 1965 and the research institutes under their control were transferred to ICAR. Plantation research in colonial India Though the experimental farms were established in 1884, the provincial agricultural departments could seldom go beyond the collection of revenue data and famine relief operations

PIRRCOM

With the initiatives for agricultural research development, there was a need to coordinate the research on various crops, especially cotton, oilseeds and millets. Moreover, a need was felt to conduct research work in different agro- climatic regions of the country. The first coordinated research work on regional basis was initiated in 1956 in the form of a joint venture by ICAR and the Indian Central Commodity Committees on Oilseeds and Cotton. Eventually, 17 centres were established across the country to perform research on cotton (Gossypium species), castor (Ricinus communis), groundnut (Arachis hypogaea), taramira (Eruca vesicaria), jowar (Sorghum bicolor), bajra (Pennisetum glaucum), etc. A regional

research station with of full-fledged sections of plant breeding and genetics, agronomy, agricultural chemistry and soil science, plant pathology and entomology was established.

Initiation of All-India Coordinated Research Projects

The conception of coordinated projects was first initiated for hybrid maize. It was under the United States Agency for International Development (USAID). The Ministry of Food and Agriculture under the GoI, signed an agreement with the Rockefeller Foundation in 1956, according to which the latter was to assist in the development of: (i) The postgraduate school of IARI, New Delhi, and (ii) Research programmes on the improvement of some crops (maize, jowar and bajra, initially). The coordinated maize project in India had proven to be the defining moment in research planning in agriculture in the country. As a result of the coordinated project, new high-yielding maize hybrids became available by 1961. Encouraged by the success of the maize project, in 1965 ICAR decided to initiate coordinated projects on other crops as well as in other areas of research, e.g. animal husbandry, soil sciences, etc. Seventy coordinated projects on various subjects were launched within 3 years of this decision and these accounted for 40% of the total expenditure for agriculture in the Fourth Five-Year Plan. However, the advancement of the coordinated projects was critically analysed in the Fifth Five-Year Plan. Accordingly, some projects were terminated, some were merged with other projects, some were elevated to the level of Project Directorates and some projects were changed to Coordinated Programmes. As a result, the number of coordinated projects decreased to 49 in the Fifth Five- Year Plan.

Reorganization of ICAR

In 1963, the Ministry of Food and Agriculture appointed the Agricultural Review Team headed by Marion W. Parker of USDA (United States Department of Agriculture), to scrutinize the organization of agricultural research in India. The team submitted its report in March 1964 and based on the recommendation of the team, ICAR was reorganized in 1966 and made an entirely autonomous organization. The ICAR was proffered the control for various research organizations under the Department of Food and Agriculture and under the Central Commodity Committees. Eventually, a policy was formulated suggesting that an agricultural scientist would be appointed as the chief executive of ICAR with the designation of Director General. Accordingly, B. P. Pal was appointed as the first Director General of ICAR in May 1965. In June 1972, the GoI appointed a committee headed by P. B. Gajendragadkar (retired Chief Justice of India) to review the enrollment and personnel policies of ICAR and its institutes, and to recommend actions for the enhancement of the same. The committee submitted its report in January 1973. A Department of Agricultural

Research and Education was created in the Ministry of Food and Agriculture in December 1973 according to the recommendations made by the committee. The Director General, ICAR was made secretary to the new department. The Minister of Agriculture was designated as the President of the Council, while the Director General of ICAR was made the Chairman of the Governing Body of the Council. Under the Agricultural Scientists' Recruitment Board (ASRB), an Agricultural Research Service (ARS) was initiated for the recruitment of scientific personnel.

Development of agricultural universities

One of the important and premier institutes of the pre-independence era was the Imperial Agricultural Research Institute established at Pusa in 1905. Eventually, IARI has become one of the premier institutes for agricultural research, education and extension in the country. During the years 1948–49, the University Education Commission headed by S. Radhakrishnan, suggested that the country should focus on the establishment of rural universities. H. S. Singh and A. N. Jha (Chief Secretary and Development Commissioner, Uttar Pradesh (UP) visited Land-Grant Universities of United States in 1950 and after coming back, advised the then Chief Minister of UP, Pandit Govind Ballabh Pant, to set up such a university in the state. The Chief Minister accepted their recommendation. This event may be regarded as the one which led to the initiation of agricultural universities in the country. In 1955, the first Joint Indo-American Team was set up. The team suggested the founding of rural universities in each of the states in India. Accordingly, the team identified UP (Tarai), West Bengal (Haringhatta), Bihar (Patna), Odisha (Bhubaneshwar), Travancore-Cochin and Mumbai (Anand, now in Gujarat) to be apposite for starting such universities.

In 1956, a blueprint for agricultural universities was prepared and this provided the root for the proposal by the Government of UP to the Central Government (in September 1956) for starting an agricultural university near Rudrapur in the Tarai region of UP. The Central Government also agreed to the proposal on an experimental basis. In 1959, the second Joint Indo-American Team was setup, which submitted its report in 1960. The Team suggested that the agricultural universities should be autonomous; should consist of colleges of agriculture like veterinary, animal husbandry, home science, technology and basic sciences under them; should have interdisciplinary teaching programme; and should integrate teaching, research and extension. GoI appointed a committee, headed by R. W. Cummings, for providing a model for the essential legislation by the states for the establishment of agricultural universities. The committee submitted its report in 1962 and on the basis of this report, ICAR prepared the model act for the development of agricultural universities. During

the period of the Fourth Five-Year Plan between the years 1960 and 1965, seven agricultural universities were established in UP, Odisha, Rajasthan, Punjab, Andhra Pradesh, Madhya Pradesh and Karnataka. The Review Committee on Agriculture Universities (1977–78), headed by M. S. Randhawa, made many useful recommendations for the development of agricultural universities. It noted that the quality of leadership and financial support from the state were cru-cial factors in the development of agricultural universi-ties. The committee suggested, among other things, that the Director General, ICAR, and Chairman, University Grants Commission, should be members of the selection committee that appoints Vice-Chancellors for agricultural universities. The agricultural universities have contributed a great extent to agricultural education, research and development in the country. Many improved varieties of crops, feed and animal stocks have been developed in the agriculture universities. In other words, it could be concluded that the ICAR is identical to agricultural research and education in the country. The role played by the council in the development of agricultural research and education has been quite extraordinary.

Important State, National and International Institutes

1.	AICRP on Nematodes, New Delhi
2.	AICRP on Maize, New Delhi
3.	AICRP Rice, Hyderabad
4.	AICRP on Chickpea, Kanpur
5.	AICRP on MULLARP, Kanpur
6.	AICRP on Pigeon Pea, Kanpur
7.	AICRP on Arid Legumes, Kanpur
8.	AICRP on Wheat & Barley Improvement Project, Karnal
9.	AICRP Sorghum, Hyderabad
10.	AICRP on Pearl Millets, Jodhpur
11.	AICRP on Small Millets, Bangalore
12.	AICRP on Sugarcane, Lucknow
13.	AICRP on Cotton, Coimbatore
14.	AICRP on Groundnut, Junagarh
15.	AICRP on Soybean, Indore
16.	AICRP on Rapeseed & Mustard, Bharatpur
17.	AICRP on Sunflower, Safflower, Castor, Hyderabad
18.	AICRP on Linseed, Kanpur
19.	AICRP on Sesame and Niger, Jabalpur
20.	AICRP on IPM and Biocontrol, Bangalore
21.	AICRP on Honey Bee Research & Training, Hisar
22.	AICRP -NSP(Crops), Mau
23.	AICRP on Forage Crops, Jhansi
24.	AICRP on Fruits, Bangaluru
25.	AICRP Arid Zone Fruits, Bikaner
26.	AICRP Mushroom, Solan

27.	AICRP Vegetables including NSP vegetable, Varanasi
28	AICRP Potato, Shimla
29.	AICRP Tuber Crops, Thiruvananthapuram
30.	AICRP Palms, Kasaragod
31.	AICRP Cashew, Puttur
32.	AICRP Spices, Calicut
33.	AICRP on Medicinal and Aromatic Plants including Betelvine, Anand
34.	AICRP on Floriculture, New Delhi
35.	AICRP in Micro Secondary & Pollutant Elements in Soils and Plants, Bhopal
36.	lAICRP on Soil Test with Crop Response, Bhopal
37.	AICRP on Long Term Fertilizer Experiments, Bhopal
38.	AICRP on Salt Affected Soils & Use of Saline Water in Agriculture, Karnal
39.	AICRP on Water Management Research, Bhubaneshwar
40.	AICRP on Ground Water Utilisation, Bhubaneshwar
41.	AICRP Dryland Agriculture, Hyderabad
42.	AICRP on Agrometeorology, Hyderabad including Network on Impact adaptation & Vulnerability of Indian Agri. to Climate Change
43.	AICRP Integrated Farming System Research, Modipuram including Network Organic Farming
44.	AICRP Weed Control, Jabalpur
45.	AICRP on Agroforestry, Jhansi
46.	AICRP on Farm Implements & Machinery, Bhopal
47.	All India Coordinated Research Project on Ergonomics and Safety in Agriculture
48.	AICRP on Energy in Agriculture and Agro Based Indus.,Bhopal
49.	AICRP on Utilization of Animal Energy (UAE), Bhopal
50.	AICRP on Plasticulture Engineering and Technologies, Ludhiana
51.	AICRP on PHT, Ludhiana
52.	AICRP on Goat Improvement, Mathura
53.	AICRP- Improvement of Feed Sources & Nutrient Utilisation for raising animal production, Bangalore
54.	AICRP on Cattle Research, Meerut
55.	AICRP on Poultry, Hyderabad
56.	AICRP-Pig, Izzatnagar
57.	AICRP Foot and Mouth Disease, Mukteshwar
58.	AICRP ADMAS, Bangalore
59.	AICRP on Home Science, Bhubaneshwar

Network Projects

1	All India Network Project on Pesticides Residues, New Delhi
2	All India Network Project on Underutilised Crops, New Delhi
3	All India Network Project on Tobacco, Rajahmundry
4	All India Network Project on Soil Arthropod Pests, Durgapura
5	Network on Agricultural Acarology, Bangalore
6	Network on Economic Ornithology, Hyderabad
7	All India Network Project on Rodent Control, Jodhpur
8	All India Network Project on Jute and Allied Fibres, Barrackpore
9	Network project on Improvement of Onion & Garlic, Pune

10	Network Bio-fertilizers, Bhopal
11	Network Project on Harvest & Post Harvest and Value Addition to Natural Resins & Gums, Ranchi
12	Network project on Animal Genetic Resources, Karnal
13	Network Project on R&D Support for Process Upgradation of Indigenous Milk products for industrial application Karnal
14	Network Programme on Sheep Improvement, Avikanagar
15	Network Project on Buffaloes Improvement, Hisar
16	Network on Gastro Intestinal Parasitism, Izatnagar
17	Network on Haemorrhagic Septicaemia, Izatnagar
18	Network Programme Blue Tongue Disease, Izatnagar
19	Network Project on Conservation of Lac Insect Genetic Resources, Ranchi
20	Network Project on Agricultural Bioinformatics and Computational Biology, New Delhi

Deemed Universities

1.	ICAR-Indian Agricultural Research Institute, New Delhi
2.	ICAR-National Dairy Research Institute, Karnal
3.	ICAR-Indian Veterinary Research Institute, Izatnagar
4.	ICAR-Central Institute on Fisheries Education, Mumbai

Institutions

1.	ICAR-Central Island Agricultural Research Institute , Port Blair
2.	ICAR-Central Arid Zone Research Institute, Jodhpur
3.	ICAR-Central Avian Research Institute, Izatnagar
4.	ICAR-Central Inland Fisheries Research Institute, Barrackpore
5.	ICAR-Central Institute Brackishwater Aquaculture, Chennai
6.	ICAR-Central Institute for Research on Buffaloes, Hissar
7.	ICAR-Central Institute for Research on Goats, Makhdoom
8.	ICAR-Central Institute of Agricultural Engineering, Bhopal
9.	ICAR-Central Institute for Arid Horticulture, Bikaner
10.	ICAR-Central Institute of Cotton Research, Nagpur
11.	ICAR-Central Institute of Fisheries Technology, Cochin
12.	ICAR-Central Institute of Freshwater Aquaculture, Bhubneshwar
13.	ICAR-Central Institute of Research on Cotton Technology, Mumbai
14.	ICAR-Central Institute of Sub Tropical Horticulture, Lucknow
15.	ICAR-Central Institute of Temperate Horticulture, Srinagar
16.	ICAR-Central Institute on Post harvest Engineering and Technology, Ludhiana
17.	ICAR-Central Marine Fisheries Research Institute, Kochi
18.	ICAR-Central Plantation Crops Research Institute, Kasargod
19.	ICAR-Central Potato Research Institute, Shimla
20.	ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore
21.	ICAR-Central Research Institute of Dryland Agriculture, Hyderabad
22.	ICAR-National Rice Research Institute, Cuttack
23.	ICAR-Central Sheep and Wool Research Institute, Avikanagar, Rajasthan
24.	ICAR- Indian Institute of Soil and Water Conservation, Dehradun

25.	ICAR-Central Soil Salinity Research Institute, Karnal
26.	ICAR-Central Tobacco Research Institute, Rajahmundry
27.	ICAR-Central Tuber Crops Research Institute, Trivandrum
28.	ICAR-ICAR Research Complex for Eastern Region, Patna
29.	ICAR-ICAR Research Complex for NEH Region, Barapani
30.	ICAR-Central Coastal Agricultural Research Institute, Ela, Old Goa, Goa
31.	ICAR-Indian Agricultural Statistics Research Institute, New Delhi
32.	ICAR-Indian Grassland and Fodder Research Institute, Jhansi
33.	ICAR-Indian Institute of Agricultural Biotechnology, Ranchi
34.	ICAR-Indian Institute of Horticultural Research, Bengaluru
35.	ICAR-Indian Institute of Natural Resins and Gums, Ranchi
36.	ICAR-Indian Institute of Pulses Research, Kanpur
37.	ICAR-Indian Institute of Soil Sciences, Bhopal
38.	ICAR-Indian Institute of Spices Research, Calicut
39.	ICAR-Indian Institute of Sugarcane Research, Lucknow
40.	ICAR-Indian Institute of Vegetable Research, Varanasi
41.	ICAR-National Academy of Agricultural Research & Management, Hyderabad
42.	ICAR-National Institute of Biotic Stresses Management, Raipur
43.	ICAR-National Institue of Abiotic Stress Management, Malegaon, Maharashtra
44.	ICAR-National Institute of Animal Nutrition and Physiology, Bengaluru
45.	ICAR-National Institute of Research on Jute & Allied Fibre Technology, Kolkata
46.	ICAR-National Institute of Veterinary Epidemiology and Disease Informatics, Hebbal, Bengaluru
47.	ICAR-Sugarcane Breeding Institute, Coimbatore
48.	ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora
49.	ICAR-Central Institute for Research on Cattle, Meerut, Uttar Pradesh
50.	ICAR-National Institute of High Security Animal Diseases, Bhopal
51.	ICAR-Indian Institute of Maize Research,New Delhi
52.	ICAR- Central Agroforestry Research Institute , Jhansi
53.	ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi
54.	ICAR- Indian Institute of Wheat and Barley Research, Karnal
55.	ICAR- Indian Institute of Farming Systems Research, Modipuram
56.	ICAR- Indian Institute of Millets Research, Hyderabad
57.	ICAR- Indian Institute of Oilseeds Research, Hyderabad
58.	ICAR- Indian Institute of Oil Palm Research, Pedavegi, West Godawari
59.	ICAR- Indian Institute of Water Management, Bhubaneshwar
60.	ICAR-Indian Institute of Rice Research, Hyderabad
61.	ICAR- Central Institute for Women in Agriculture, Bhubaneshwar
62.	ICAR-Central Citrus Research Institute, Nagpur
63.	ICAR-Indian Institute of Seed Research, Mau
64.	ICAR-Indian Agricultural Research Institute, , Hazaribag , Jharkhand

National Research Centres

1.	ICAR-National Research Centre for Banana, Trichi
2.	ICAR-National Research Centre for Grapes, Pune
3.	ICAR-National Research Centre for Litchi, Muzaffarpur
4.	ICAR-National Research Centre for Pomegranate, Solapur

5.	ICAR-National Research Centre on Camel, Bikaner
6.	ICAR-National Research Centre on Equines, Hisar
7.	ICAR-National Research Centre on Meat, Hyderabad
8..	ICAR-National Research Centre on Mithun, Medziphema, Nagaland
9.	ICAR-National Research Centre on Orchids, Pakyong, Sikkim
10.	ICAR-National Research Centre on Pig, Guwahati
11.	ICAR-National Research Centre on Plant Biotechnology, New Delhi
12.	ICAR-National Research Centre on Seed Spices, Ajmer
13.	ICAR-National Research Centre on Yak, West Kemang
14.	ICAR-National Centre for Integrated Pest Management, New Delhi
15.	National Research Centre on Integrated Farming (ICAR-NRCIF),Motihari

National Bureaux

1.	ICAR-National Bureau of Plant Genetics Resources, New Delhi
2.	ICAR-National Bureau of Agriculturally Important Micro-organisms, Mau, Uttar Pradesh
3.	ICAR-National Bureau of Agricultural Insect Resources, Bengaluru
4.	ICAR-National Bureau of Soil Survey and Land Use Planning, Nagpur
5.	ICAR-National Bureau of Animal Genetic Resources, Karnal
6.	ICAR-National Bureau of Fish Genetic Resources, Lucknow

Directorates/Project Directorates

1.	ICAR-Directorate of Groundnut Research, Junagarh
2.	ICAR-Directorate of Soybean Research, Indore
3.	ICAR-Directorate of Rapeseed & Mustard Research, Bharatpur
4.	ICAR-Directorate of Mushroom Research, Solan
5.	ICAR-Directorate on Onion and Garlic Research, Pune
6.	ICAR-Directorate of Cashew Research, Puttur
7..	ICAR-Directorate of Medicinal and Aromatic Plants Research, Anand
8.	ICAR-Directorate of Floricultural Research, Pune, Maharashtra
9.	ICAR-Directorate of Weed Research, Jabalpur
10.	ICAR-Project Directorate on Foot & Mouth Disease, Mukteshwar
11.	ICAR-Directorate of Poultry Research, Hyderabad
12.	ICAR-Directorate of Knowledge Management in Agriculture (DKMA), New Delhi
13.	ICAR-Directorate of Cold Water Fisheries Research, Bhimtal, Nainital

Agricultural Universities

1	Acharya NG Ranga Agricultural University, Hyderabad, Andhra Pradesh
2	Agriculture University, Jodhpur
3	Agriculture University, Kota
4	Anand Agricultural University, Anand, Gujarat
5	Assam Agricultural University, Jorhat, Assam
6	Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal
7	Bihar Agricultural University, Sabour, Bhagalpur, Bihar
8	Birsa Agricultural University, Ranchi, Jharkhand

9	Central Agricultural University, Imphal, Manipur
10	Chandra Shekar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh
11	Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana
12	CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh
13	Chhattisgarh Kamdhenu Vishwavidyalaya, Durg, Chhattisgarh
14	Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli Distt, Ratnagiri, Maharashtra
15	Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra
16	Dr Yashwant Singh Parmar Univ of Horticulture & Forestry, Nauni, Himachal Pradesh
17	Dr YSR Horticultural University, West Godavari Dist., Tadepalligudem, Andhra Pradesh
18	Govind Ballabh Pant University of Agriculture & Technology, Pantnagar, Uttaranchal
19	Guru Angad Dev Veterinary and Animal Science University, Ludhiana, Punjab
20	Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh
21	Jawaharlal Nehru Krishi Viswavidyalaya, Jabalpur, Madhya Pradesh
22	Junagadh Agricultural University, Junagadh, Gujarat
23	Karnataka Veterinary, Animal and Fisheries Sciences University, Bidar, Karnataka
24	Kerala Agricultural University, Trichur, Kerala
25	Kerala University of Fisheries & Ocean Studies, Kochi, Kerala
26	Kerala Veterinary and Animal Sciences University, Thiruvananthapuram, Kerala
27	Lala Lajpat Rai University of Veterinary & Animal Sciences, Hisar, Haryana
28	Nanaji Deshmukh Veterinary Science University, Jabalpur, Madhya Pradesh
29	Maharana Pratap Univ. of Agriculture & Technology, Udaipur, Rajasthan
30	Maharashtra Animal Science & Fishery University, Nagpur, Maharashtra
31	Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra
32	Manyavar Shri Kanshiram Ji University of Agriculture and Technology, Banda, Uttar Pradesh
33	Narendra Deva University of Agriculture & Technology, Faizabad, Uttar Pradesh
34	Navsari Agricultural University, Navsari, Gujarat
35	Orissa Univ. of Agriculture & Technology, Bhubaneshwar, Orissa
36	Prof. Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad
37	Punjab Agricultural University, Ludhiana, Punjab
38	Rajasthan University of Veterinary and Animal Sciences, Bikaner, Rajasthan,
39	Rajendra Agricultural University, Samastipur, Bihar
40	Rajmata Vijayraje Sciendia Krishi Vishwa Vidyalaya, Gwalior, MP
41	Rani Laxmi Bai Central Agricultural University, Jhansi, Uttar Pradesh
42	Sardar Vallabhbhai Patel University of Agriculture and Technology, Modipuram, Meerut, Uttar Pradesh
43	Sardarkrushinagar-Dantiwada Agricultural University, Distt Banaskantha, Gujarat
44	Sher-E-Kashmir Univ of Agricultural Sciences & Technology, Jammu, J&K
45	Sher-E-Kashmir Univ of Agricultural Sciences & Technology of Kashmir, Shrinagar, Jammu & Kashmir
46	Sri Karan Narendra Agriculture University, Jobner
47	Sri Venkateswara Veterinary University, Tirupati
48	Swami Keshwanand Rajasthan Agricultural University, Bikaner,Rajasthan
49	Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu
50	Tamil Nadu Fisheries University, Nagapattinam, Tamil Nadu
51	Tamil Nadu Veterinary & Animal Science University, Chennai, Tamilnadu
52	University of Agricultural Sciences, Bengaluru, Karnataka
53	University of Agricultural Sciences, Dharwad, Karnataka
54	University of Agricultural Sciences, Shimoga, Karnataka

55	University of Horticultural Sciences, Bagalkot, Karnataka
56	University of Agricultural Sciences, Raichur, Karnataka
57	UP Pandit Deen Dayal Upadhaya Pashu Chikitsa Vigyan Vishwa Vidhyalaya evam Go Anusandhan Sansthan, Mathura, Uttar Pradesh
58	Uttarakhand University of Horticulture and Forestry, Pauri Garhwal, Uttarakhand
59	Uttar Banga Krishi Viswavidyalaya, Coach Bihar,West Bengal
60	Vasantrao Naik Marathwada Agricultural University, Parbhani, Maharashtra
61	West Bengal University of Animal & Fishery Sciences, Kolkata, West Bengal
62	Sri Konda Laxman Telangana State Horticultural University, Rajendra Nagar Campus, Hyderabad
63	Kamdhenu University, Gandhinagar, Gujarat

INTERNATIONAL ORGANIZATIONS OF CROP IMPROVEMENT

CIAT International Centre for Tropical Agriculture: Cali, Columbia

CIFOR Center for International Forestry Research: Jakarta, Indonesia

CIMMYT International Centre for Wheat and Maize Improvement: Baton, Mexico

CIP International Potato Centre: Lima, Peru

IBPGR International Board for Plant Genetic Resources: Rome, Italy

ICARDA International Centre for Agricultural Research in the Dry Areas: Beruit, Lebanon

ICGES International Centre for Genetic Engineering and Biotechnology: Triesta, Italy

ICRAF International Centre for Research in Agro forestry: Nairobi, Kenya

ICRISAT International Crops Research Institute for the Semi-Arid Tropics: Hyderabad, India

IFPRI International Food Policy Research Institute: Washington, USA

IITA International Institute of Tropical Agriculture: Ibadan, Nigeria

IIMI International Irrigation Management Institute: Colombo, Srilanka

ILRI International Livestock Research Institute: Nairobi, Kenya

INSFFER International Network on Soil Fertility and Fertilizer Evaluation on Rice: New Delhi, India

IPGRI International Plant Genetic Resource Institute: Rome, Italy

ISNAR International Service for National Agricultural Research: Netherlands

IRRI International Rice Research Institute: Manila, Phillipines

IWMI International Water Management Institute: Columbo, Sri Lanka

WFC World Fish Centre : Bayan Lepas, Malaysia

WARDAWest African Rice Development Association: Monrovia, Liberia

9. Crop significance and classification

A **crop** is "a plant or animal or plant or animal product that can be grown and harvested extensively for profit or subsistence." Crop may refer either to the harvested parts or to the harvest in a more refined state (husked, shelled, etc.). Most crops are cultivated in agriculture or aquaculture. Most crops are harvested as food for humans or livestock (fodder crops). Some crops are gathered from the wild (including intensive gathering, e.g. ginseng).

Important non-food crops include horticulture, floriculture and industrial crops. Horticulture crops include plants used for other crops (e.g. fruit trees). Floriculture crops include bedding plants, houseplants, flowering garden and pot plants, cut cultivated greens, and cut flowers. Industrial crops are produced for clothing (fiber crops), biofuel (energy crops, algae fuel), or medicine (medicinal plants). Animals and microbes (fungi, bacteria or viruses) are rarely referred to as crops. Animals raised for human or animal consumption are referred to as livestock and microbes as microbiological cultures. Microbes are not typically grown for food itself, but are rather used to alter food

Classification of Crop Plants

Importance of classifying the Crop Plants:

1. To get acquainted with crops.
2. To understand the requirement of soil & water different crops.
3. To know adaptability of crops.
4. To know the growing habit of crops.
5. To understand climatic requirement of different crops.
6. To know the economic produce of the crop plant & its use.
7. To know the growing season of the crop
8. Overall to know the actual condition required to the cultivation of plant.

Classification based on climate:

1. Tropical: Crops grow well in warm & hot climate. E.g. Rice, sugarcane, Jowar etc

2. Temperate: Crops grow well in cool climate. E.g. Wheat, Oats, Gram, Potato etc.

Classification Based on growing season:

1. **Kharif/Rainy/Monsoon crops:** The crops grown in monsoon months from June to Oct-Nov, Require warm, wet weather at major period of crop growth, also required short day length for flowering. E.g. Cotton, Rice, Jowar, bajara.
2. **Rabi/winter/cold seasons crops:** require winter season to grow well from Oct to March month. Crops grow well in cold and dry weather. Require longer day length for flowering. E.g. Wheat, gram, sunflower etc.

3. Summer/Zaid crops: crops grown in summer month from March to June. Require warm day weather for major growth period and longer ay length for flowering. E.g. Groundnuts, Watermelon, Pumpkins, Gourds.

Use/Agronomic classification:

1. **Grain crops:** may be cereals as millets cereals are the cultivated grasses grown for their edible starchy grains. The larger grain used as staple food is cereals. E.g. rice, Jowar, wheat, maize, barley, and millets are the small grained cereals which are of minor importance as food. E.g. Bajara.
2. **Pulse/legume crops:** seeds of leguminous crops plant used as food. On splitting they produced dal which is rich in protein. E.g. green gram, black gram, soybean, pea, cowpea etc.
3. **Oil seeds crops:** crop seeds are rich in fatty acids, are used to extract vegetable oil to meet various requirements. E.g. Groundnut, Mustard, Sunflower, Sesamum, linseed etc.
4. **Forage Crop:** It refers to vegetative matter fresh as preserved utilized as food for animals. Crop cultivated & used for fickler, hay, silage. Ex- sorghum, elephant grass, guinea grass, berseem & other pulse bajara etc.
5. **Fiber crops:** crown for fiber yield. Fiber may be obtained from seed. E.g. Cotton, steam, jute, Mesta, sun hemp, flax.
6. **Roots crops:** Roots are the economic produce in root crop. E.g. sweet, potato, sugar beet, carrot, turnip etc.
7. **Tuber crop**: crop whose edible portion is not a root but a short thickened underground stem. E.g. Potato, elephant, yam.
8. **Sugar crops:** the two important crops are sugarcane and sugar beet cultivated for production for sugar.
9. **Starch crops:** grown for the production of starch. E.g. tapioca, potato, sweet potato.
10. **Dreg crop:** used for preparation for medicines. E.g. tobacco, mint, pyrethrum.
11. **Spices & condiments/spices crops:** crop plants as their products are used to flavor taste and sometime color the fresh preserved food. E.g. ginger, garlic, chili, cumin onion, coriander, cardamom, pepper, turmeric etc.
12. **Vegetables crops:** may be leafy as fruity vegetables. E.g. Palak, mentha, Brinjal, tomato.

13. **Green manure crop:** grown and incorporated into soil to increase fertility of soil. E.g. sun hemp.
14. **Medicinal & aromatic crops:** Medicinal plants includes cinchona, isabgoli, opium poppy, senna, belladonna, rauwolfra, iycorice and aromatic plants such as lemon grass, citronella grass, palmorsa, Japanese mint, peppermint, rose geranicem, jasmine, henna etc.

Classification based on life of crops/duration of crops:

1. **Seasonal crops:** A crop completes its life cycle in one season- Kharif, Rabi. summer. E.g. rice, jowar, wheat etc.
2. **Two seasonal crops:** crops complete its life in two seasons. E.g. Cotton, turmeric, ginger.
3. **Annual crops:** Crops require one full year to complete its life in cycle. E.g. sugarcane.
4. **Biennial crops:** which grows in one year and flowers, fructifies & perishes the next year E.g. Banana, Papaya.
5. **Perennial crops:** crops live for several years. E.g. Fruit crops, mango, guava etc.

Classification based on cultural method/water:

1. Rain fed: crops grow only on rain water. E.g. Jowar, Bajara, Mung etc.
2. Irrigated crops: Crops grows with the help of irrigation water. E.g. Chili, sugarcane, Banana, papaya etc.

Classification based on root system:

1. **Tap root system:** The main root goes deep into the soil. E.g. Tur, Grape, Cotton etc.
2. **Adventitious/Fiber rooted:** The crops whose roots are fibrous shallow & spreading into the soil. E.g. Cereal crops, wheat, rice etc.

Classification based on economic importance:

1. **Cash crop:** Grown for earning money. E.g. Sugarcane, cotton.
2. **Food crops:** Grown for raising food grain for the population and & fodder for cattle. E.g. Jowar, wheat, rice etc.

Classification based on No. of cotyledons:

1. **Monocots or monocotyledons:** Having one cotyledon in the seed. E.g. all cereals & Millets.
2. **Dicots or dicotyledonous:** Crops having two cotyledons in the seed. E.g. all legumes & pulses.

Classification based on photosynthesis' (Reduction of CO2/Dark reaction):

1. **C3 Plants:** Photo respiration is high in these plants C3 Plants have lower water use efficiency. The initial product of C assimilation in the three 'C' compounds. The enzyme involved in the primary carboxylation is ribulose-1,-Biophospate carboxylose. E.g. Rice, soybeans, wheat, barley cottons, potato.
2. **C4 plants:** The primary product of C fixation is four carbon compounds which may be malice acid or acerbic acid. The enzymes responsible for carboxylation are phosphoenol Pyruvic acid carboxylose which has high affinity for CO2 and capable of assimilation CO2 event at lower concentration, photorespiration is negligible. Photosynthetic rates are higher in C4 than C3 plants for the same amount of stomatal opening. These are said to be drought resistant & they are able to grow better even under moisture stress. C4 plants translate photosynthates rapidly. E.g. Sorghum, Maize, napter grass, sesame etc.
3. **Cam plants**: (Cassulacean acid metabolism plants) the stomata open at night and large amount of CO2 is fixed as a malice acid which is stored in vacuoles. During day stomata are closed. There is no possibility of CO2 entry. CO2 which is stored as malice acid is broken down & released as CO2. In these plants there is negligible transpiration. C4 & cam plant have high water use efficiency. These are highly drought resistant. E.g. Pineapple, sisal & agave.

Classification based on length of photoperiod required for floral initiation:

Most plants are influenced by relative length of the day & night, especially for floral initiation, the effect on plant is known as photoperiodism depending on the length of photoperiod required for floral ignition, plants are classified as:

1. Short-day plants: Flower initiation takes plate when days are short less then ten hours. E.g. rice, Jowar, green gram, black gram etc.

2. Long day's plants: require long days are more than ten hours for floral ignition. E.g. Wheat, Barley,

3. Day neutral plants: Photoperiod does not have much influence for phase change for these plants. E.g. Cotton, sunflower. The rate of the flowering initiation depends on how short or long is photoperiod. Shorter the days, more rapid initiation of flowering in short days plants. Longer the days more rapid are the initiation of flowering in long days plants.

10. National agricultural setup in India

ICAR

The Indian Council of Agricultural Research (ICAR) is an autonomous organization under the Department of Agricultural Research and Education (DARE), Ministry of Agriculture and Farmers Welfare, Government of India. Formerly known as Imperial Council of Agricultural Research, it was **established on 16 July 1929** as a registered society under the Societies Registration Act, 1860 in pursuance of the report of the Royal Commission on Agriculture. The ICAR has its headquarters at New Delhi. With **101 ICAR institutes** and **63 agricultural universities** spread across the country this is one of the largest national agricultural systems in the world.

The ICAR has played a pioneering role in ushering Green Revolution and subsequent developments in agriculture in India through its research and technology development that has **enabled the country to increase the production of food grains by 5 times**, **horticultural crops by 9.5 times**, **fish by 12.5 times** , **milk 7.8 times** and **eggs 39 times** since 1951 to 2014, thus making a visible impact on the national food and nutritional security.

As of June 2017 ICAR has following institutions

- Four Deemed Universities
- 64 ICAR Institutions
- Six National Bureaux
- 13 Project Directorates
- 15 National Research Centres
- 138 Substations of ICAR Institutes
- 59 AICRPs (All India Coordinated Research Projects)
- 10 Other Projects
- 19 Network Projects
- Eight Zonal Project Directorates
- 665 Krishi Vigyan Kendras (KVKs) (660 as of 2017)

Milestones

- Initiation of the first All-India Co-ordinated Research Project on Maize in 1957
- Status of Deemed University accorded to IARI in 1958

- Establishment of the first State Agricultural University on land grant pattern at Pantnagar in 1960
- Placement of different agricultural research institutes under the purview of ICAR in 1966
- Creation of Department of Agricultural Research and Education (DARE) in the Ministry of Agriculture in 1973
- Opening of first Krishi Vigyan Kendra (KVK) at Puducherry (Pondicherry) in 1974
- Establishment of Agricultural Research Service and Agricultural Scientists' Recruitment Board in 1975
- Launching of Lab-to-Land Programme and the National Agricultural Research Project (NARP) in 1979
- Initiation of Institution-Village Linkage Programme (IVLP) in 1995
- Establishment of National Gene Bank at New Delhi in 1996
- The ICAR was bestowed with the King Baudouin Award in 1989 for its valuable contribution in ushering in the Green Revolution. Again awarded King Baudouin Award in 2004 for research and development efforts made under partnership in Rice Wheat Consortium.
- Launching of National Agricultural Technology Project (NATP) in 1998 and National Agricultural Innovation Project (NAIP) in 2005
- As of July, 2006 it has developed a vaccine against bird flu. The vaccine was developed at the High Security Animal Disease Laboratory, Bhopal, the only facility in the country to conduct tests for the H5N1 variant of bird flu. It was entrusted with the task of developing a vaccine by the ICAR after the Avian Influenza outbreak in February. The ICAR was provided Rs. 8 crore for the purpose.
- 2009: In December 2009, it announced that it was considering a policy to provide open access to its research.
- 2010: In March 2010, ICAR made its two flagship journals (Indian Journal of Agricultural Sciences and Indian Journal of Animal Sciences) as Open Access Journals.
- 2013: On 13 September 2013, it announced the Open Access Policy and committed for making all the public funded scholarly research outputs openly available via open access repositories.
- ICAR scientists were the first in the world to sequence the pigeon pea genome. it was a purely indigenous effort by 31 scientists led by Nagendra Kumar Singh of NRCPB.

Mandate

- Plan, Undertake, Coordinate and Promote Research and Technology Development for Sustainable Agriculture.
- Aid, Impart and Coordinate Agricultural Education to enable Quality Human Resource Development.
- Frontline Extension for technology application, adoption, knowledge management and capacity development for agri-based rural development.

- Policy, Cooperation and Consultancy in Agricultural Research, Education & Extension.

Organization

- Union Minister of Agriculture is the ex-officio President of the ICAR Society
- Secretary, Department of Agricultural Research and Education, Ministry of Agriculture, Government of India and Director General, ICAR is the Principal Executive Officer of the Council
- Governing Body is the policy-making authority
- Agricultural Scientists' Recruitment Board
- Deputy Directors-General (8)
- Additional Secretary (DARE) and Secretary (ICAR)
- Additional Secretary and Financial Advisor
- Assistant Directors-General (24)
- National Director, National Agricultural Innovation Project
- Directorate of Knowledge Management in Agriculture

ICAR Awards 2016

The Indian Council of Agricultural Research, New Delhi announces the following ICAR Awards:

1. **ICAR Challenge Award**

   To find a solution for any immediate or long-standing problem, or limitation in agriculture, which is coming in the way of agricultural development and/ or enhancing productivity in any major agricultural, horticultural or animal/fish product, ICAR has instituted a Challenge Award.

2. **Sardar Patel Outstanding ICAR Institution Award**

   In order to recognize outstanding performance by the ICAR institutes, DUs of ICAR, CAU and State Agricultural Universities

3. **Chaudhary Devi Lal Outstanding All India Coordinated Research Project Award**

   In order to recognize outstanding performance of the AICRP and its cooperating centers and to provide incentive for outstanding performance in terms of linkages and research output and its impact.

4. **Jawaharlal Nehru Award for P.G. Outstanding Doctoral Thesis Research in Agricultural and Allied Sciences**

In order to promote high quality doctoral thesis research in priority/frontier areas of agriculture and allied sciences, ICAR has instituted **18** awards of Rs. **50,000/-** in cash plus a citation and silver medal (gold polished) each to be awarded annually for the outstanding original research work in agriculture and allied sciences.

5. **Panjabrao Deshmukh Outstanding Woman Scientist Award**

All women scientists engaged in research in agricultural and allied subjects /extension in a recognized institutions are eligible for this award.

6. **Vasantrao Naik Award for Outstanding Research Application in Dry Land Farming Systems**

In order to promote outstanding research and application in priority aspects of dry land farming systems & water conservation.

7. **Jagjivan Ram Abhinav Kisan Puruskar /Jagjivan Ram Innovative Farmer Award (National/Zonal)**

In order to recognize the outstanding contributions of innovative farmers for initiatives in development adoption, modification and dissemination of improved technology and practices for increased income with sustainability, following national and zonal awards are announced: **(i) National:** One annual national award **(ii)Zonal:** Eight annual awards

8. **N.G. Ranga Farmer Award for Diversified Agriculture**

In order to recognize outstanding contribution of innovative farmers for diversified agriculture, one annual award of **Rs 1.00 lakh** in any of the areas of Diversified Agriculture is given by ICAR.

9. **Pandit Deen Dayal Upadhyay Antyodaya Krishi Puruskar (National & Zonal)**

In order to recognize the contributions of marginal, small and landless farmers for developing sustainable integrated models of farming, the ICAR has instituted **Pandit Deen Dayal Upadhyay Antyodaya Krishi Puruskar (National & Zonal)** annually.

10. **Haldhar Organic Farmer Award**

In order to recognize outstanding contribution of organic farmers ICAR has instituted an award titled **Haldhar Organic Farmer Award**

11. **Chaudhary Charan Singh Award for Excellence in Journalism in Agricultural Research and Development**

    Journalists for Print Media [Hindi Journalism/ English Journalism/ Journalism in Regional languages (four awards)] and Electronic media (two awards).

12. **Fakhruddin Ali Ahmed Award for Outstanding Research in Tribal Farming Systems**

    The award is primarily meant for any person or team (with two or three associates, if any) engaged in applied research and its applications in tribal areas of the country aimed at improving the biological resources and livelihoods or in original work directly applicable to tribal farming system.

13. **Bharat Ratna Dr C. Subramaniam Award for Outstanding Teachers 2016**

    In order to provide recognition to outstanding teachers and to promote quality teaching in the field of Agriculture, four outstanding teacher awards are given annually.

14. **Pandit Deen Dayal Upadhyay Krishi Vigyan Protshahan Puraskar (National & Zonal) 2017**

    These awards promote healthy competition among Krishi Vigyan Kendras (KVKs) at Zonal and National Level for application of science and technology in agriculture.

15. **Dr Rajendra Prasad Puruskar for technical books in Hindi in Agricultural and Allied Sciences 2016**

    These awards recognize to authors of original Hindi Technical books in agriculture and allied sciences & incentivize Indian writers to write original standard works in agricultural and allied sciences in Hindi. The award is meant for individuals as well as teams of authors.

16. **Lal Bahadur Shastri Outstanding Young Scientist Award 2016**

    In order to recognize the talented young scientists who have shown extraordinary originality and dedication in their research programmes, four individual awards are to be given annually.

17. **Rafi Ahmed Kidwai Award for Outstanding Research in Agricultural Sciences 2016**

In order to recognize outstanding research in agricultural and allied sciences & provide incentives for excellence in agricultural research, this award is to be given to agricultural scientists for outstanding contribution in specified areas. A total of four awards are provided under the award.

18. **Swami Sahajanand Saraswati Outstanding Extension Scientist Award 2016**

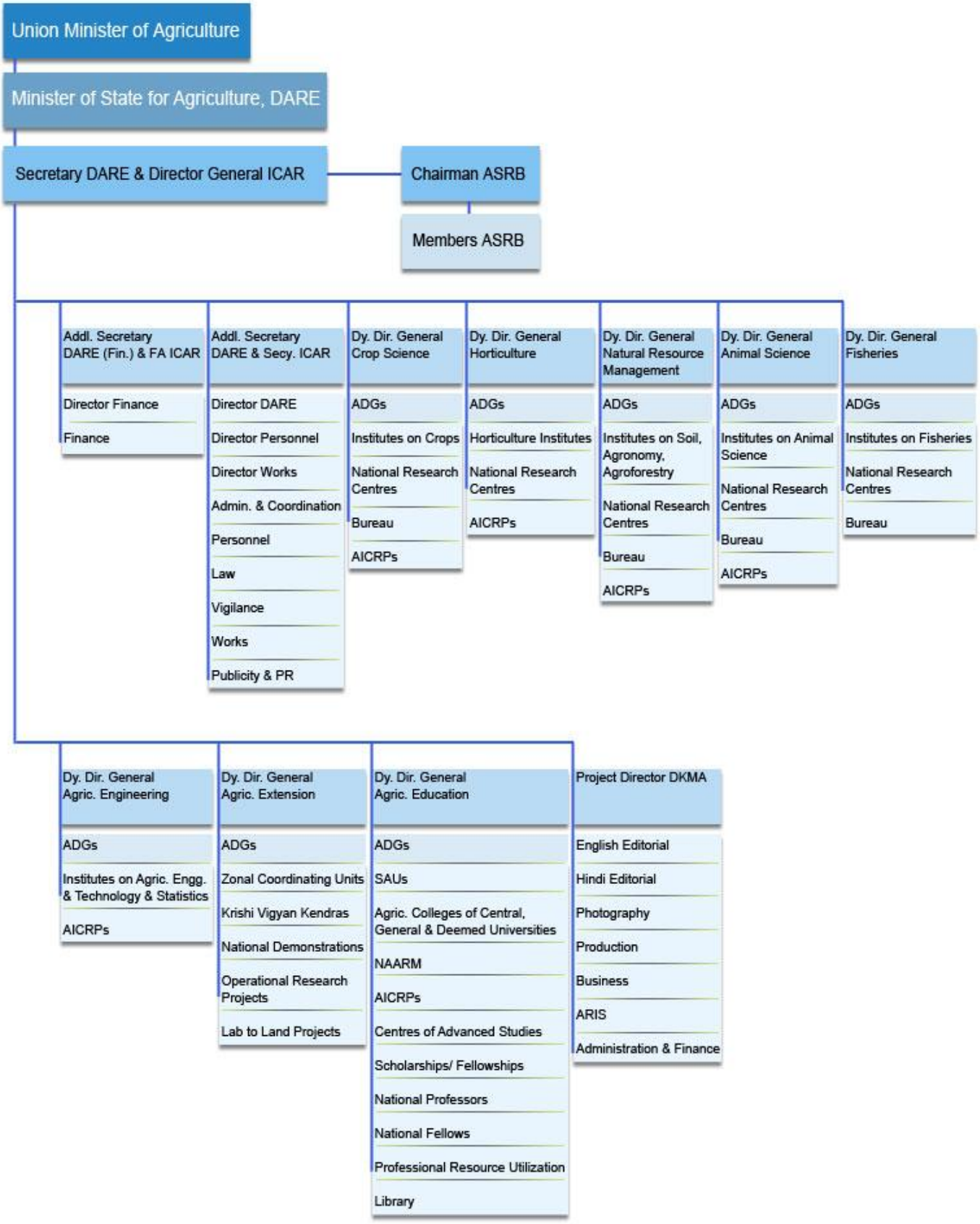
The award is exclusively meant for individual extension scientist/teacher for excellence in agricultural extension methodology and education work. Two individual awards have been provided.

19. **NASI-ICAR Award For Innovation and Research on Farm Implements -2016**

In order to reduce drudgery of farm women by development of farm implements and to encourage researchers and innovators to develop farm implements for farm women, ICAR and NASI have instituted the **NASI-ICAR Award For Innovation and Research on Farm Implements.**

20. **Hari Om Ashram Trust Award for the biennium 2014-2015**

In order to recognize the outstanding research on long term problem in agricultural and allied sciences, four individual awards have been instituted.


Union Minister of Agriculture
Minister of State for Agriculture, DARE
Secretary DARE & Director General ICAR
Chairman ASRB
Members ASRB
Addl. Secretary DARE (Fin.) & FA ICAR
Director Finance
Finance
Addl. Secretary DARE & Secy. ICAR
Director DARE
Director Personnel
Director Works
Admin. & Coordination
Personnel
Law
Vigilance
Works
Publicity & PR
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Institutes on Crops
National Research Centres
Bureau
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Horticulture Institutes
National Research Centres
AICRPs
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National Research Centres
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Dy. Dir. General Fisheries
ADGs
Institutes on Fisheries
National Research Centres
Bureau
Dy. Dir. General Agric. Engineering
ADGs
Institutes on Agric. Engg. & Technology & Statistics
AICRPs
Dy. Dir. General Agric. Extension
ADGs
Zonal Coordinating Units
Krishi Vigyan Kendras
National Demonstrations
Operational Research Projects
Lab to Land Projects
Dy. Dir. General Agric. Education
ADGs
SAUs
Agric. Colleges of Central, General & Deemed Universities
NAARM
AICRPs
Centres of Advanced Studies
Scholarships/ Fellowships
National Professors
National Fellows
Professional Resource Utilization
Library
Project Director DKMA
English Editorial
Hindi Editorial
Photography
Production
Business
ARIS
Administration & Finance

State Agricultural Universities

Agricultural Universities or 'AUs' are mostly public universities in India that are engaged in teaching, research and extension in agriculture and related disciplines. In India, agricultural education has evolved into a large and distinct domain, often separately from other areas of higher education. Many of these universities are member of a registered society, the Indian Agricultural Universities Association. Indian Council of Agricultural Research is the main regulatory authority of agricultural education in India, while the disciplines of veterinary medicine and forestry are regulated by the Veterinary Council of India and Indian Council of Forestry Research and Education respectively. A SAU is usually a university established by an act of state legislature with a dedicated mandate of teaching, research and extension in agriculture and related disciplines.

Deemed universities

Deemed universities are not established by an act of independent legislation, but declared to function as universities by Government of India under Section 3 of the University Grants Commission Act 1956. As per this section, "The Central Government may, on the advice of the Commission, declare by notification in the Official Gazette, that any institution for higher education, other than a University, shall be deemed to be a University for the purposes of this Act, and on such a declaration being made, all the provisions of this Act shall apply to such institution as if it were a University within the meaning of clause (f) of section 2". Thus, the provision of deemed universities enables the central government to incorporate an agricultural university without the need of Parliamentary legislation, thus circumventing the complexities of federal division for legislative powers, which has put agriculture in the state list.

Central agricultural universities

There are currently 3 central agriculture university in India, and they are

- Central Agricultural University Imphal
- Rani Laxmibai Central Agricultural University Jhansi
- Dr. Rajendra Prasad Central Agriculture University, Samasthipur Bihar

Upcoming or proposed central agricultural university

- Punjab Agricultural University, Ludhiana
- Govind Ballabh Pant University of Agriculture and Technology, Pantnagar

The Central Agricultural University was established by an act of Parliament, the Central Agricultural University Act 1992 (No.40 of 1992). The Act came into effect on 26 January 1993 with the issue of necessary notification by the Department of Agricultural Research and Education (DARE), Government of India. The university became functional with the joining of the first vice-chancellor on 13 September 1993.

Other universities involved in agricultural education

Central universities

Central universities, including Banaras Hindu University, Aligarh Muslim University, Visva-Bharati University, Hemwati Nandan Bahuguna Garhwal University, Nagaland University and Sikkim University have distinct faculties in agriculture. A few central universities also have affiliated agricultural colleges.

State universities

Bundelkhand University, Lucknow University, Kanpur University, Gorakhpur University, Meerut University, Calcutta University and many other state universities have distinct agriculture faculties. Most of these have a number of affiliated agriculture colleges.

Institute of national importance

IIT Kharagpur has a very strong programme in agricultural engineering, while IIM A and IIM Lucknow have leading programmes in agribusiness. Central Food Technological Research Institute under AcSIR is the premier institute in food technology.

Private universities

Amity University has a programme in organic farming

Annamalai University offers Undergraduate, Postgraduate and Diploma courses through Faculty of Agriculture

Rai Technology University offers B.Sc and M.Sc programs in Ag riculture through its School of Agricultural Sciences and Forestry

Ministry of Agriculture & Farmers Welfare

The Ministry of Agriculture and Farmers Welfare (formerly Ministry of Agriculture), a branch of the Government of India, is the apex body for formulation and administration of the rules and regulations and laws related to agriculture in India. The 3 broad areas of scope

for the Ministry are agriculture, food processing and co-operation. The agriculture ministry is headed by Minister of Agriculture Radha Mohan Singh. S S Ahluwalia, Sudarshan Bhagat & Parshottam Rupalai are the Ministers of State. The combined efforts of Central Government, State Governments and the farming community have succeeded in achieving record production of 244.78 million tonnes of foodgrains during 2010-11.

Origins

Department of Revenue and Agriculture and Commerce was set up in June 1871 to deal with all the agricultural matters in India. Until this ministry was established, matters related to agriculture were within the portfolio of the Home Department. In 1881, Department of Revenue & Agriculture was set up to deal with combined portfolios of education, health, agriculture, revenue. However, In 1947, Department of Agriculture was redesignated as Ministry of Agriculture.

Structure & Departments

The Ministry of Agriculture and farmers Welfare consists of the following three Departments.

- Department of Agriculture, Co-operation and Farmers Welfare.
- Department of Agriculture Research and Education.
- Department of Animal Husbandry, Dairying and Fisheries.

A leading program of the Ministry is the Rashtriya Krishi Vikas Yojana, which was launched in 2007 on the recommendations of the National Development Council of India. This program sought to improve the overall state of agriculture in India by providing stronger planning, better co-ordination and greater funding to improve productivity and overall output. The total budget for this program in 2009-10 was just over INR 38,000 crore.

11. Current scenario of Indian agriculture

1. Organic Farming

Organic farming is an alternative agricultural system which originated early in the 20th century in reaction to rapidly changing farming practices. It relies on fertilizers of organic origin such as compost, manure, green manure, and bone meal and places emphasis on techniques such as crop rotation and companion planting. Biological pest control, mixed cropping and the fostering of insect predators are encouraged. In general, organic standards are designed to allow the use of naturally occurring substances while prohibiting or strictly limiting synthetic substances. For instance, naturally occurring pesticides such as pyrethrin and rotenone are permitted, while synthetic fertilizers and pesticides are generally prohibited. Synthetic substances that are allowed include, for example, copper sulfate, elemental sulfur and Ivermectin. Genetically modified organisms, nanomaterials, human sewage sludge, plant growth regulators, hormones, and antibiotic use in livestock husbandry are prohibited. Organic agricultural methods are internationally regulated and legally enforced by many nations, based in large part on the standards set by the International Federation of Organic Agriculture Movements (IFOAM), an international umbrella organization for organic farming organizations established in 1972.

"Organic agriculture can be defined as: an integrated farming system that strives for sustainability, the enhancement of soil fertility and biological diversity whilst, with rare exceptions, prohibiting synthetic pesticides, antibiotics, synthetic fertilizers, genetically modified organisms, and growth hormones".

2. Farming system, Definition

Farming system is a resource management strategy to achieve economic and sustained agricultural production to meet diverse requirements of farm livelihood while preserving resource base and maintaining a high level of environment quality (Lal and Miller 1990).

Key principles

• ***Cyclic*** The farming system is essentially cyclic (organic resources – livestock – land – crops). Therefore, management decisions related to one component may affect the others.

• ***Rational*** Using crop residues more rationally is an important route out of poverty. For resource-poor farmers, the correct management of crop residues, together with an optimal allocation of scarce resources, leads to sustainable production.

• ***Ecologically sustainable*** Combining ecological sustainability and economic viability, the integrated livestock-farming system maintains and improves agricultural productivity while also reducing negative environmental impacts.

Benefits or Advantages of Integrated Farming System

1) Productivity
2) Profitability
3) Potentiality or Sustainability
4) Balanced Food
5) Environmental Safety
6) Recycling
7) Income Rounds the year
8) Adoption of New Technology
9) Saving Energy
10) Meeting Fodder crisis
11) Solving Fuel and Timber Crisis
12) Employment Generation
13) Agro – industries
14) Increasing Input Efficiency

3. Precision Farming

Precision agriculture (**PA**) or **satellite farming** or **site specific crop management** (**SSCM**) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops.

Precision agriculture aims to optimize field-level management with regard to:

- Crop science: matching farming practices closely to crop needs (e.g. fertilizer inputs);
- Environmental protection: reducing environmental risks (e.g. limiting leaching of nitrogen);
- Economics: boosting competitiveness through more efficient practices (e.g. improved management of fertilizer usage and other inputs).

Precision agriculture also provides farmers with a wealth of information to:

- build up a record of their farm;
- improve decision-making;
- foster greater traceability
- enhance marketing of farm products
- improve lease arrangements and relationship with landlords
- enhance the inherent quality of farm products (e.g. protein level in bread-flour wheat)

Emerging technologies

Robots

Self-steering tractors have existed for some time now, as John Deere equipment works like a plane on autopilot. Technology is advancing towards driverless machinery programmed by GPS to spread fertilizer or plow land. Agricultural robots, also known as AgBots, already exist, but advanced harvesting robots are being developed to identify ripe fruits, adjust to their shape and size, and carefully pluck them from branches.

Drones and satellite imagery

Advances in drone and satellite technology benefits precision farming because drones take high quality images, while satellites capture the bigger picture. Light aircraft pilots can combine aerial photography with data from satellite records to predict future yields based on the current level of field biomass. Aggregated images can create contour maps to track where water flows, determine variable-rate seeding, and create yield maps of areas that were more or less productive.

The Internet of things

The Internet of things is the network of physical objects outfitted with electronics that enable data collection and aggregation. For example, farmers can spectroscopically measure nitrogen, phosphorus, and potassium in liquid manure, which is notoriously inconsistent.[21] They can then scan the ground to see where cows have already urinated and apply fertilizer to only the spots that need it. This cuts fertilizer use by up to 30%.

4. Micro irrigation

Definition of Micro Irrigation:

It can be defined as the application of water at low volume and frequent interval under low pressure to plant root zone.

Besides the land, water also an important factor in the progress of Agriculture. In vast country like India with a geographical area of 328 million hectares less than 45% area is cultivated of this cultivated area only 35% i.e. 65 million ha gets irrigation. This could be

achieved by introducing advanced and sophisticated methods of irrigation viz. drip irrigation, sprinkler, etc.

Micro-sprayers/sprinklers is installed on a stake, wetting foliage and a larger surface area of 4-6 feet.

Micro-bubblers are installed on short stakes, have solid spray and used to establish and maintain larger plants and have less evaporation than micro-sprayers/sprinklers.

Drippers apply water directly to the soil resulting in minimal evaporation, attach to a distribution tube or spaghetti tubing and are used for widely spaced plants or containers.

Drip tubing contains factory installed emitters inside the tubing that are pressure compensating,
and has fewer parts/pieces than other types of microirrigation.

5. Conservation Agriculture

Definition of Conservation Agriculture

It is a way of farming that conserves, improves and makes more efficient use of natural resources through integrated management of available resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustain agricultural production. It can also be referred to as resource efficient agriculture.

Conservation agriculture has three basic principles:

1. Disturb the soil as little as possible: farmers plough and hoe to improve the soil structure and control weeds. But in the long term, they actually destroy the soil structure and contribute to declining soil fertility.
2. Mulching: cover crops protect the soil from erosion and limit weed growth throughout the year.
3. Mix and rotate crops with legume based cropping system

6. Nanotechnology

It deals with the physical, chemical, and biological properties of matter considered at nanoscale (1–100 nm) and their implications for the welfare of human beings. Nanomaterial is an ingredient containing particles with at least one dimension that approximately measures 1–100 nm. It has the ability to control and/or manufacture matter at this scale which results in

the development of innovative and novel properties like increase in the surface area of the particles that can be utilized to address numerous technical and societal issues

Table 1: Classification of nanomaterials.

Categories of nanomaterials	**Description**
Nanoparticles	Submicron or even ultramicron size particles obtainable as high performance radiant resistant materials, magnetic materials, solar battery materials, packaging materials, and magnetic fluid materials
Nanotubes and nanofibers	Nanometer size long linear material, optical materials, micro conductors, microfibers, nanotubes of PEEK, PET and PTFE
Nanofilm	Films utilized as gas catalyst materials
Nanoblock	Nanometer crystalline materials produced by substantial accuracy, developing controlled crystallization or nanoparticles
Nanocomposites	Composite nanomaterials, which use nanosize reinforcements instead of conventional fibers or particulates
Nanocrystalline solids	Polycrystals with the size of 1 to 10 nm and 50% or more of solid consists of inherent interface between crystals and different orientations. The clusters that formed through homogenous nucleation and grow by coalescence and incorporation of atoms

Table 2: Commercial uses of nanoparticles

Type of product	Product name & manufacturer	Nano content	Purpose
Nano-agrochemicals			
Super" combined fertilizer and pesticide	Pakistan-US Science and Technology Cooperative Program	Nano-clay capsule contains growth stimulants and biocontrol agents	Slow release of active ingredients, Reducing application rates
Herbicide	Tamil Nadu Agricultural University (India) and Technologico de Monterry (Mexico)	Nano-formulated	Designed to attack the seed coat of weeds, destroy soil seed banks and prevent weed germination
Pesticides, including herbicides	Australian Common wealth Scientific and Industrial Research Organization	Nano-encapsulated active ingredients	Very small size of nanocapsules increases their potency and may enable targeted release of active ingredients
Nano-materials			
Nutritional supplement	Nanoceuticals „mycrohydrin" powder, RBC Life sciences	Molecularcaes 1-5 nm diameter made from silica mineral hydride comple	Nano-sized mycrohydrin has increased potency and bioavailability. Exposure to moisture releases H- ions and acts as a powerful antioxidant.
Nutritional drink	Oat Chocolate Nutritional Drink Mix, Toddler Health	300nm particles of iron (SunActive Fe)	Nano-sized iron particles have increased reactivity and bioavailability.
Food packaging	Adhesive for McDonald"s burger containers, Ecosynthetix	50-150nm starch nanospheres	These nanoparticles have 400 times the surface area of natural starch particles. When used as an adhesive they require less water and thus less time and energy to dry.
Food additive	Aquasol preservative, AquaNova	Nanoscale micelle (capsule) of lipophilic or water insoluble substances	Surrounding active ingredients within soluble nanocapsulesb increases absorption within the body (including individual cell)
Plant growth treatment	Primo Maxx, Syngenta	100nm particle size emulsion	Nano-sized particles increases the potency of active ingredients, potentially reducing the quantity to be applied

Place of Indian Agriculture in Indian Economy

♣The agriculture sector employs nearly half of the workforce in the country. However, it contributes to 17.5 % of the GDP (at current prices in 2015-16).

♣Over the past few decades, the manufacturing and services sectors have increasingly contributed to the growth of the economy, while the agriculture sector‟s contribution has decreased from more than 50% of GDP in the 1950s to 15.4% in 2015-16.

♣ India‟s production of food grains has been increasing every year and India is among the top producers of several crops such as wheat, rice, pulses, sugarcane and cotton. It is the highest producer of milk and second highest producer of fruits and vegetables.

♣In 2013, India contributed 25% to the world‟s pulses production, the highest for any one country, 22% to the rice production and 13% to the wheat production. It also accounted for about 25% of the total quantity of cotton produced, besides being the second highest exporter of cotton for the past several years. However, the agricultural yield (quantity of a crop produced per unit of land) is found to be lower in the case of most crops, as compared to other top producing countries such as China, Brazil and the United States.

♣Agricultural growth has been fairly volatile over the past decade, ranging from 5.8% in 2005-06 to 0.4% in 2009-10 and -0.2% in 2014-15.

♣Total production of food grains increased from 51million tonnes in 1950-51 to 252 million tonnes in 2015-16.

♣According to the second advance estimate by the Ministry of Agriculture, food grains production is estimated to be 272 million tonnes in 2016-17.

♣The production of wheat and rice took off after the green revolution in the 1960s, and as of 2015-16, wheat and rice accounted for 78% of the food grains production in the country.

Importance Of Agriculture

Agriculture plays a crucial role in the life of an economy. It is the backbone of our economic system. Agriculture not only provides food and raw material but also employment opportunities to a very large proportion of population. The following facts clearly highlight the importance of agriculture in this country.

1. Source of Livelihood: In India the main occupation of our working population is agriculture. About 70 per cent of our population is directly engaged in agriculture. In advanced countries, this ratio is very small being 5 per cent in U.K., 4 per cent in USA., 16 per cent in Australia, 14 per cent in France, 21 per cent in Japan and 32 per cent in USSR.

2. Contribution to National Income: Agriculture is the premier source of our national income. According to National Income Committee and C.S.O., in 1960-61, 52 per cent of national

income was contributed by agriculture and allied occupations. This was further reduced to 28 per cent in 1999-2000.

3. Supply of Food and Fodder: Agriculture sector also provides fodder for livestock (35.33 crores). Cow and buffalo provide protective food in the form of milk and they also provide draught power for farm operations. Moreover, it also meets the food requirements of the people.

4. Importance in International Trade: It is the agricultural sector that feeds country's trade. Agricultural products like tea, sugar, rice, tobacco, spices etc. constitute the main items of exports of India. If the development process of agriculture is smooth, export increases and imports are reduced considerably.

5. Marketable Surplus: The development of agricultural sector leads to marketable surplus. As agricultural development takes place, output increases and marketable surplus expands. This can be sold to other countries.

6. Source of Raw Material: Agriculture has been the source of raw materials to the leading industries like cotton and jute textiles, sugar, tobacco, edible and non-edible oils etc. All these depend directly on agriculture. Apart from this, many others like processing of fruits and vegetables, dal milling, rice husking, gur making also depend on agriculture for their raw material.

7. Importance in Transport: Agriculture is the main support for railways and roadways which transport bulk of agricultural produce from farm to the mandies and factories. Internal trade is mostly in agricultural products. Besides, the finance of the govt, also, to the large extent, depends upon the prosperity of agricultural sector.

8. Contribution to Foreign Exchange Resources: Agricultural sector constitutes an important place in the country's export trade. According to an estimate, agricultural commodities like jute, tobacco, oilseeds, spices, raw cotton, tea and coffee accounted for about 18 per cent of the total value of exports in India.

9. Vast Employment Opportunities: The agricultural sector is significant as it provides greater employment opportunities in the construction of irrigation projects, drainage system and other such activities. With the fast growing population and high incidence of unemployment and disguised unemployment in backward countries, it is only agriculture sector which provides more employment chances to the labour force.

10. Source of Saving: Improvement in agriculture can go a long way in increasing savings. It is seen that rich farmers have started saving especially after green revolution in the country.

This surplus amount can be invested in agriculture sector for further; development of the sector.

11. Source of Government Income: In India, many state governments get sizeable revenue from the agriculture sector. Land revenue, agricultural income tax, irrigation tax and some other types of taxes are being levied on agriculture by the state governments.

12. Basis of Economic Development: The development of agriculture provides necessary capital for the development of other sectors like industry, transport and foreign trade. In fact, a balanced development of agriculture and industry is the need of the day.

Challenges

Three agriculture sector challenges will be important to India‟s overall development and the improved welfare of its rural poor:

1. Raising agricultural productivity per unit of land: Raising productivity per unit of land will need to be the main engine of agricultural growth as virtually all cultivable land is farmed. Water resources are also limited and water for irrigation must contend with increasing industrial and urban needs.

2. Reducing rural poverty through a socially inclusive strategy that comprises both agriculture as well as non-farm employment: Rural development must also benefit the poor, landless, women, scheduled castes and tribes. Moreover, there are strong regional disparities: the majority of India‟s poor are in rain-fed areas or in the Eastern Indo-Gangetic plains. Reaching such groups has not been easy. While progress has been made-the rural population classified as poor fell from nearly 40% in the early 1990s to below 30% by the mid-2000s (about a 1% fall per year) –there is a clear need for a faster reduction. Hence, poverty alleviation is a central pillar of the rural development efforts of the Government and the World Bank.

3. Ensuring that agricultural growth responds to food security needs: The sharp rise in food-grain

production during India‟s Green Revolution of the 1970s enabled the country to achieve self-sufficiency in food-grains and stave off the threat of famine. However agricultural growth in the 1990s and 2000s slowed down, averaging about 3.5% per annum, and cereal yields have increased by only 1.4% per annum in the 2000s. The slow-down in agricultural growth has become a major cause for concern.

Priority areas for support

1. Enhancing agricultural productivity, competitiveness, and rural growth Promoting new technologies and reforming agricultural research and extension
2. Improving Water Resources and Irrigation/Drainage Management:
3. Facilitating agricultural diversification to higher- value commodities:
4. Developing markets, agricultural creditand public expenditures:
5. Poverty alleviation and community actions
6. Sustaining the environment and future agricultural productivity

12. Indian agricultural concerns and prospects

A. Ill effects of Green Revolution

1. **Degradation of land:** Due to change in land use pattern and employing two and three crop rotation every year land quality has gone down and yield has sufferred.
2. **Degradation of land part:** Due to heavy chemical fertilizer inputs land has become hard and carbon material has gone down.
3. **Weeds have increased:** Due to heavy crop rotation pattern we do not give rest to land nor we have time to employ proper weed removal system which has increased weeds.
4. **Pest infestation has gone up:** Pests which we used to control by bio degradable methods have become resistant to many pesticides and now these chemical pesticides have become non effective.
5. **Loss of bio diversity:** Due to heavy use of chemical pesticides, insecticides and fertilizers we have lost many birds and friendly insects and this is a big loss in long term.
6. **Chemicals in water:** These chemicals which we have been using in our farms go down and contaminate ground water which effect our and our children health.
7. **Water table has gone down:** Water table has gone down due to lack of water harvesting systems and now we have to pull water from 300 to 400 ft. depth which was 40 to 50 feet earlier.
8. **Loss of old seeds:** We have started using new seeds and lost old once since new once give better yield but due to this we have lost many important genes in these seeds.

B. Soil retrogression and degradation

Soil retrogression and degradation are two regressive evolution processes associated with the loss of equilibrium of a stable soil. Retrogression is primarily due to soil erosion and corresponds to a phenomenon where succession reverts the land to its natural physical state. Degradation is an evolution, different from natural evolution, related to the local climate and vegetation. It is due to the replacement of primary plant communities (known as climax vegetation) by the secondary communities. This replacement modifies the humus composition and amount, and affects the formation of the soil. It is directly related to human activity.

Consequences of soil regression and degradation

- Yields impact: Recent increases in the human population have placed a great strain on the world's soil systems. Slight degradation refers to land where yield potential has been reduced by 10%, moderate degradation refers to a yield decrease from 10-50%. Severely degraded soils have lost more than 50% of their potential.
- Natural disasters: Natural disasters such as mud flows, floods are responsible for the death of many living beings each year.

- Deterioration of the water quality: Soils particles in surface waters are also accompanied by agricultural inputs and by some pollutants of industrial, urban and road origin.
- Biological diversity: soil degradation may involve perturbation of microbial communities, disappearance of the climax vegetation and decrease in animal habitat. Economic loss: the estimated costs for land degradation are US $40 billion per year.

Soil rebuilding and regeneration

Rebuilding is especially possible through the improvement of soil structure, addition of organic matter and limitation of runoff. However, these techniques will never totally succeed to restore a soil (and the fauna and flora associated to it) that took more than 1000 years to build up.

Soil regeneration is the reformation of degraded soil through biological, chemical, and or physical processes. Supplementing the farmer's usual practice with a single application of 200 kg bentonite per rai (6.26 rai = 1 hectare) resulted in an average yield increase of 73%.

C. Soil contamination

Soil contamination or soil pollution as part of land degradation is caused by the presence of Xeno Bionis (human-made) chemicals or other alteration in the natural soil environment. It is typically caused by industrial activity, agricultural chemicals, or improper disposal of waste. The most common chemicals involved are petroleum hydrocarbons, polynuclear aromatic hydrocarbons (such as naphthalene and benzo(a)pyrene), solvents, pesticides, lead, and other heavy metals. Contamination is correlated with the degree of industrialization and intensity of chemical usage.

Soil pollution can be caused by the following (non-exhaustive list)

- Oil drilling.
- Mining and activities by other heavy industries
- Accidental spills as may happen during activities, etc.
- Corrosion of underground storage tanks (including piping used to transmit the contents)
- Acid rain (in turn caused by air pollution)
- Intensive farming
- Agrochemicals, such as pesticides, herbicides and fertilizers
- Industrial accidents
- Road debris
- Drainage of contaminated surface water into the soil
- Waste disposal

There are several principal strategies for remediation:

- Excavate soil and take it to a disposal site away from ready pathways for human or sensitive ecosystem contact.
- Aeration of soils at the contaminated site (with attendant risk of creating air pollution)
- Thermal remediation by introduction of heat to raise subsurface temperatures sufficiently high to volatize chemical contaminants out of the soil for vapour extraction.
- Bioremediation, involving microbial digestion of certain organic chemicals with commercially available microflora.
- Containment of the soil contaminants (such as by capping or paving over in place).
- Phytoremediation, or using plants (such as willow) to extract heavy metals.
- Mycoremediation (Fungus) to metabolize contaminants and accumulate heavy metals.
- Remediation of oil contaminated sediments with self-collapsing air microbubbles

D. Water pollution

Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater). This form of environmental degradation occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds.

Causes

- Wide spectrum of chemicals, pathogens, and physical changes such as elevated temperature and discoloration.
- High concentrations of naturally occurring substances can have negative impacts on aquatic flora and fauna.
- Oxygen-depleting substances may be natural materials such as plant matter (e.g. leaves and grass) as well as man-made chemicals.
- Other natural and anthropogenic substances may cause turbidity (cloudiness) which blocks light and disrupts plant growth, and clogs the gills of some fish species.

Control

1. Sewage treatment
2. Industrial waste water treatment
3. Agricultural waste water treatment
4. Erosion and sediment control from construction sites
5. Control of urban runoff

E. Agricultural Labour Scarcity

Definition and Classification The 2001 census of India, has defined agriculture labourer as "A person who works on another person's land for wages in money or kind or share is regarded as an agricultural labourer. She or he has no risk in the cultivation, but merely works on another person's land for wages."

The agricultural labourers can be classified mainly into two categories:

1. Landless agricultural labourers:

i) Permanent labourers attached to cultivating households

ii) Casual labourers.

2. Very small cultivators whose main source of earnings is wage employment, due to their small and sub-marginal holdings.

Agriculture labour scarcity in India

Even though India has the second largest man-power in the world, all the sectors of the economy have been affected by the scarcity of labourers, the impact being felt more in the agricultural sector. Labourers constitute a vital input in agricultural production, but they are migrating to different parts of the country for earning better livelihood adding to the existing imbalance between labour demand and supply of labourers.

Till not very long ago, Indian agriculture was marked by abundant supply of farm labour.

This gave rise to a negative relationship between labour productivity and labour absorption. This scenario of over-supply however has changed in recent years, particularly after the implementation of MGNREGA, expansion of public works and increased rural to urban migration owing to urbanization and generation of casual employment in the tertiary sector in towns and cities. In a typical village labour scenario, the common norm for the prevailing wage rate or labour charges are fixed by the simple relation between its demand and supply. Since Indian agriculture is predominantly rain-fed, the agricultural wages also respond to rainfall variability. This seasonal nature of agriculture employment has led to shift of agricultural labourers to non-farm sector for employment. The proportion of agricultural workers to the total work-force has been declining over the years, hence following impacts have been predominantly noticed in agriculture in recent years; reduction in crop yield, reduction in cropping intensity and changes in traditional cropping pattern. The scarcity of agricultural labourers may also cause delay in crop establishment, poor crop growth, no or untimely weeding, irrational use of fertilizers, insufficient irrigation to crops etc. These implications of labour scarcity if left unattended may discourage farmers who may leave their land fallow and shift to non-agricultural avenues for livelihood. Over the past couple of decades, there is a growing concern that the farm labour has been decreasing which has been caused by occupational changes, people's mindset, Government policies and reforms making

it imperative to investigate into the dynamics or scarcity of agricultural labour and its effect on agricultural economy.

F. Minimum Support Price

Minimum Support Price (MSP) is a form of market intervention by the Government of India to insure agricultural producers against any sharp fall in farm prices. The minimum support prices are announced by the Government of India at the beginning of the sowing season for certain crops on the basis of the recommendations of the Commission for Agricultural Costs and Prices (CACP). MSP is price fixed by Government of India to protect the producer - farmers - against excessive fall in price during bumper production years. The minimum support prices are a guarantee price for their produce from the Government. The major objectives are to support the farmers from distress sales and to procure food grains for public distribution. In case the market price for the commodity falls below the announced minimum price due to bumper production and glut in the market, government agencies purchase the entire quantity offered by the farmers at the announced minimum price.

Determination of MSP

Following factors are considered while fixing MSP:-

- Cost of production
- Changes in input prices
- Input-output price parity
- Trends in market prices
- Demand and supply
- Inter-crop price parity
- Effect on industrial cost structure
- Effect on cost of living
- Effect on general price level
- International price situation
- Parity between prices paid and prices received by the farmers.
- Effect on issue prices and implications for subsidy

Minimum Support Price for 2016-17

SN	Commodity (q/ha)	MSP for 2016-17 (Rs per quintal)	Increase over previous year (Rs per quintal)
1	Paddy	1470	60
2	Hybrid Jawar	1625	55
3	Bajra	1330	55
4	Maize	1365	40
5	Arhar	5050	425
6	Mung	5225	375

7	Cotton	3860	60
8	Groundnut in shell	4220	190
9	Wheat	1625	100
10	Gram	4000	500
11	Mustard	3700	350
12	Sugarcane (per tonne)	3000	--

G. Vision 2050 of ICAR

Guiding Principles for Future Research and Education

• Provide leadership in ensuring national food and nutritional security, farmers' prosperity, consumer health and enhancing the natural resource base of agriculture for future generations
• Ensure strategic competitive advantage of Indian agriculture to enable access to the existing and emerging markets, and address the emerging challenges
• Leverage the advances in other sciences, engineering and social science to enhance agricultural research.
• Nurture scientific excellence and promote interdisciplinary, systems-based, knowledge intensive, problem-solving research.
• Promote economic opportunities for the rural community and society.
• Promote complementary partnerships for value addition in agriculture and accelerate innovation.
• Respond proactively to farmers, consumers, partners and policy makers
• Promote ethical conduct, scientific integrity and accountability of performance and decisions
• Promote organizational transformation to an efficient, effective, and responsive innovation system
• Support higher education and create educational environments that foster continuous learning

ICAR 2050: Focus Areas of Research

• Genetic potential enhancement of agricultural commodities.
• Agricultural productivity, efficiency and profitability improvement
• Resilience to climate change and abiotic and biotic stresses
• Improve nutritional food, and health security
• Risk management against climate change and market stressors
• Agricultural value chains
• Sustainability of natural resources base of agriculture
• Valuation of ecosystem services
• Agricultural markets, policies, and institutions
• Bio-security, emerging from gene piracy and cross-border vector borne diseases
• New products and uses (eg, bio-energy, new crops, synthetic foods, special foods)
• New educational and learning systems and environments

H. Protected cultivation

In the present scenario of perpetual demand for better quality vegetables and continuously shrinking land holdings, protected cultivation is the best choice for quality produce and efficient use of land and other resources. Protected cultivation means some level of control over plant microclimate to alleviate one or more of abiotic stresses for optimum plant growth which can be achieved in naturally ventilated poly-house or net-/polynet-house. Crop yields can be several times higher than those under open field conditions, quality of produce is superior, higher input use efficiencies are achieved and vegetable export can be enhanced. Extreme weather conditions, in some countries, under the open field conditions are the major limiting factors for achieving higher yield and better quality of vegetables. Under such circumstances, protected cultivation is best option. Keeping these points in view, net-house and naturally ventilated poly-house technology has been recommended for the cultivation of different vegetables.

Modified design of net-house - polynet-house

Polynet-house is a framed structure consisting of GI pipes covered with ultra violet (UV) stabilized plastic film of 200-micron thickness at the top and UV stabilized net of 40-mesh size on the sides.

Selection of site

- The site for the net house should be well drained and fairly shadow free.
- It should be away from the obstruction at least three times the height of the obstruction.
- Windbreaks are desirable and at least 30 m away on all sides to minimize the adverse effect of wind.

Orientation

Polynet-house should be constructed in the east–west direction to get the maximum benefit of the sunlight throughout the year and to minimize the adverse effect of wind.

I. Conventional and Non conventional energy sources

Conventional : Energy that has been used from ancient times is known as conventional energy. Coal, natural gas, oil, and firewood are examples of conventional energy sources. (or usual) Sources of energy (electricity) are coal, oil, wood, peat, uranium.

Non-conventional **(or unusual) sources of energy and use**

• Solar power

• Hydro-electric power (dams in rivers)

• Wind power

• Tidal power

• Ocean wave power

• Geothermal power (heat from deep under the ground)

• Ocean thermal power (the difference in heat between shallow and deep water)

• Biomass (burning of vegetation to stop it producing methane)

• Biofuel (producing ethanol (petroleum) from plants

J. Agriclinics & Agribusiness Centres

The M. S. Swaminathan Research Foundation (MSSRF) along with an international organisation called CABI jointly piloted a project called plant clinic (PC) in Tamil Nadu, Puducherry and Maharashtra. The main aim of setting up such clinics is to diagnose pests and diseases in any crop and render accurate knowledge to the farming community. Basically it is a community-driven model, conducted in a common location, accessible to all categories of farmers in a village.

Need guidance

Farmers need guidance to distinguish the difference between pest and infestations, understand harmful effects of red labelled/banned pesticides, pest resurgence, resistance to pesticides etc.“The clinic provides an array of technological solutions along with cultural, biological and chemical methods, which are nationally and internationally permissible, ecologically safe and environmentally sustainable for mitigating crop loss and enhancing plant health and economic benefit.

Prescription

Farmers bring their affected crop samples to the clinics to recognise the problem and get technological solutions. Every farmer is provided with a prescription, detailing the case history along with recommendations. The PC treats the crop samples with the help of the comprehensive factsheets in the local vernacular brought by the farmers. Presently about 37 plant doctors serve through 14 Plant clinics; 391 clinic sessions have been conducted till now

across Tamil Nadu, Puducherry and Maharashtra, spanning 62 villages, in which more than 6,000 farmers including 992 women farmers have been reached.

The Ministry of Agriculture and farmers welfare, Government of India, in association with NABARD has launched a unique programme to take better methods of farming to each and every farmer across the country. This programme aims to tap the expertise available in the large pool of Agriculture Graduate who can set up AgriClinic or AgriBusiness Centre and offer professional extension services to innumerable farmers. Committed to this programme, the Government is now also providing start-up training to graduates in Agriculture, or any subject allied to Agriculture like Horticulture, Sericulture, Veterinary Sciences, Forestry, Dairy, Poultry Farming, and Fisheries, etc. Those completing the training can apply for special start-up loans for venture.

Earn money and prestige by becoming a consultant to farmers

Agribusiness Centres would provide paid services for enhancement of agriculture production and income of farmers. Centres would need to advice farmers on crop selection, best farm practices, post-harvest value-added options, key agricultural information (including perhaps even Internet-based weather forecast), price trends, market news, risk mitigation and crop insurance, credit and input access, as well as critical sanitary and phyto-sanitary considerations, which the farmers have to keep in mind.

Free Training to set up your Agriclinic or Agribusiness Centre

As an integral part of this nationwide initiative, specialised training will be provided to Agriculture Graduates interested in setting up such a centre. Being provided free of cost, the 2-month training course will be offered by select institutes across the country.

Bank loans available for Agriclinics and Agribusiness Centres

Ceiling of project cost for subsidy has been enhanced to Rs.20 lakhs for an individual project (25 lakhs in case of extremely successful individual projects) and to Rs.100 lakhs for a group project.

K. Information and communication technology (ICT)

It is an extended term for information technology (IT) which stresses the role of unified communications. The term *ICT* is also used to refer to the convergence of audio-visual and telephone networks with computer networks through a single cabling or link system.

Information and communication technology in agriculture (**ICT in agriculture**), also known as **e-agriculture**, is developing and applying innovative ways to use ICTs in the rural

domain, with a primary focus on agriculture. ICT in agriculture offers a wide range of solutions to some agricultural challenges. In this context, ICT is used as an umbrella term encompassing all information and communication technologies including devices, networks, mobiles, services and applications; these range from innovative Internet-era technologies and sensors to other pre-existing aids such as fixed telephones, televisions, radios and satellites. More specifically, e-agriculture involves the conceptualization, design, development, evaluation and application of innovative ways to use ICTs in the rural domain, with a primary focus on agriculture.

The Food and Agriculture Organization of the United Nations (FAO) has been assigned the responsibility of organizing activities related to the action line under C.7 ICT Applications on E-Agriculture.

Many ICT interventions have been developed and tested around the world, with varied degrees of success, to help agriculturists improve their livelihoods through increased agricultural productivity and incomes, and reduction in risks. Some useful resources for learning about e-agriculture in practice are the World Bank's e-sourcebook ICT in agriculture – connecting smallholder farmers to knowledge, networks and institutions (2011).

ICT tools can help in meeting the challenges in agricultural development in the following ways:

- Agriculture Information, Awareness and Education using ICT.
- Advanced information about adverse weather condition, so that farmers can take precautionary measures.
- Real time and near real times pricing and market information.
- Information dissemination about various government schemes.
- Information regarding agrifinance, agriclinicls and agribusiness.
- Online Farmer Communities

Government Initiatives on ICT in agriculture

Key Government initiatives to promote use of ICT in agriculture include National e-Governance Plan in Agriculture (NeGP-A), various Touch Screen Kiosks, Krishi Vigyan Kendras, Kisan Call Centres, Agri-Clinics, Common Service Centers, mKisan, Kisan TV and various other applications.

Second semester- B.Sc. (Hons.)Agri.

Agron. 1.2

Fundamentals of Agronomy

Compiled by

Dr. H. H. Patel
Assistant Professor

Agron. 1.2 Fundamentals of Agronomy Credits 4 (3+1)

Theory

Topic 1 : Agriculture: definition, meaning
Topic 2 : Agronomy:-definition, meaning and its scope
Topic 3: Tillage, land configuration and sub soiling
Topic 4: Seeds and sowing
Topic 5: Crop density and geometry
Topic 6: Crop nutrition, manures and fertilizers, nutrient use efficiency
Topic 7: Growth and development of crops
Topic 8: Agro-climatic zones of India and Gujarat
Topic 9: Classification of field crops and factors affecting on crop production
Topic 10: Drought, definition and types of drought
Topic 11: Cropping systems: Definition and types of cropping systems
Topic 12: Soil fertility and soil productivity
Topic 13: Fertility losses and maintenance of soil fertility, soil organic matter
Topic 14: Irrigation, Introduction, Importance, definition and objectives
Topic 15: Physical and biological classification of water
Topic 16: Irrigation efficiency and water use efficiency, consumptive use of water
Topic 17: Approaches for irrigation scheduling
Topic 18: Methods of irrigation including micro irrigation system
Topic 19: Quality of water, water logging
Topic 20: Weeds: definition, classification and characteristics

Practical's

1. Identification of crops, seeds, fertilizers, pesticides and tillage implements
2. Lay out and types of seed bed preparation
3. Practice of different methods of sowing
4. Study of yield contributing characters and yield estimation of major crops
5. Seed germination and viability test
6. Numerical exercises on plant population and seed rate
7. Use of tillage implements-reversible plough, one way plough, harrow and leveler
8. Study of sowing implements/equipment
9. Measurement of field capacity, bulk density and infiltration rate
10. Field layout of various irrigation methods
11. To work out the labour unit and unit of work for various field operations

Reference books

Sr. No.	Name of Books	Author
1	Introduction to agronomy and Principles of crop production	S. R. Reddy
2	Principles of agronomy	T. Y. Reddy and G. H. S. Reddy
3	Agronomy	Dr. K. L. Nandeha
4	Cropping and Farming Systems	S. C. Panda
5	Fertilizers and Manures	J. P. Chaudhary
6	Irrigation Agronomy	S. R. Reddy

Topic 1 : Agriculture: definition, meaning and its branches

Meaning of Agriculture : The term Agriculture is derived from two **Latin** words **ager or agri** and **cultura. Ager or agri** means soil or Land or Field and **Cultura** means cultivation.

Agriculture is very broad term covering all aspects of crop production, live stock farming, fisheries, forestry etc.

Agriculture may be defined as the art and science of cultivating land, raising crops and feeding, breeding, and raising livestock. **or**

Agriculture is the cultivation of lands for production of crops for a regular supply of food and other needs for progress of the nation.

There are three main spheres of agriculture as under;

Geoponic : Meaning cultivation in earth,

Hydroponic : Meaning cultivation in water and

Aeroponic : Meaning cultivation in air.

Agriculture is productive unit where the natural inputs i.e. light; air, water etc are converted in to usable product by the green plants. The livestock, birds and insect feed on the green plants and provide concentrated products such as milk, meat, eggs, wool, honey, silk and lack.

Agriculture provides us with the materials needed for our feeding, housing and clothing. Agriculture consists of growing plants and rearing animals which help to maintain a biological equilibrium in nature.

Agriculture is considered as mother of all agro based industries as it supplying the raw material to different industries as listed here under:

Sr. No.	Agricultural produce/ crop plant.	Industries maintained
1.	Cotton	Textile mills, Cottage industry, for spinning, weaving and rope making.
2.	Sugarcane	Sugar mills, Paper industry.
3.	Oil seeds	Oil mills, manufacturing of varnishes, paints, soap, perfumes, vegetable ghee and cakes.
4.	Maize	Starch industry and cattle feed industry.
5.	Grape	Vine and canning industry.
6.	Fruits and vegetables	Canning industry, Juices, Essential oils as by product.

Animals and their bye products:-

1.	Milk	Milk industry, processing and bottling of milk, manufacture of butter, cheese, ghee, milk powder, ice cream etc.
2.	Beef By products Hides Bones	Mutton industry, processing and packing of mutton. Leather industry. Fertilizer industry, manufacture of buttons.
Insects :-		
1.	Silk worm	Sericulture: Rearing of silkworm for silk production.
2.	Honeybee	Apiculture: Rearing of bees for production of honey.

Revolution in Agriculture

No.	Revolution	Concerned with	Achievements
1.	Green revolution	Food grain production	Food grain production increased from 51 million tones at independence to 223 million tones in (2006 - 07), 4.5 times increase.
2.	White revolution	Milk production	Milk production increased from 17 million tones at independence to 69 million tones, four times (1997-98).
3.	Yellow revolution	Oilseeds production	Oil seed production increased from 5 million tones to 25 million tones since independence, 5 times increase
4.	Blue revolution	Fish production	Fish production increased from 0.75 million tones to nearly 5.0 million tones during the last five decades.
5.	Brown revolution	Food processing/Fertilizer	Total fertilizer production = 178.10 Lakh tone (2015-16)
6.	Golden revolution	Horticulture	All India total horticulture (Fruits, vegetables, flowers, plantation crops and spices) production = 300642.95 (000 MT)(2016-17)
7.	Round revolution	Potato	All India total potato production = 48.60 Million tone (2016-17)
8.	Rainbow revolution	Overall development of agriculture sector	----
9.	Black revolution	Petroleum products	India produced 231.92 MTs of petroleum products in 2015-16, recording a growth of 4.88% over the previous year
10.	Silver revolution	Eggs Production	All India total egg production = 82.9 Billion Nos. (2016-17)
11.	Grey revolution	Fertilizer	Total fertilizer production = 178.10 Lakh tone (2015-16)
12.	Pink revolution	Onion production/Prawn production	All India total onion production = 22.42 Million tone (2016-17)
13.	Red revolution	Meat/Poultry/Pigarry	All India total meat production = 70.20 Million tone (2015-16)

Branches of Agriculture

Agriculture is a synthesis of several disciplines like Agricultural chemistry and soil Science, Agronomy, Plant breeding and genetics, Horticulture, Entomology, Plant pathology, Crop Physiology, Extension education, Plant Ecology, Biochemistry and Economics etc.

1) **Agronomy:** It deals with the production of various crops which includes food crops, fodder crops, fibre crops, sugar, oil seeds, etc.
2) **Horticulture:** Branch of agriculture deals with the production of flowers, fruits, vegetables, ornamental plants, spices, condiments (includes narcotic crops – opium, etc. which has medicinal value) and beverages.
3) **Forestry:** It deals with production of large scale cultivation of perennial trees for supplying wood, timber, rubber, etc. and also raw materials for industries.
4) **Animal Husbandry:** Maintenance of various types of livestock for direct energy (work energy) purpose. Husbandry is common for both crop and animals. The objective is to get maximum output by feeding, rearing, etc.
5) **Fishery Science:** It is for marine fish and inland fishes including shrimps and prawns.
6) **Agricultural Engineering:** It is an important component for crop production and horticulture particularly to provide tools and implements. It is aiming to produce modified tools to facilitate proper animal husbandry and crop production tools, implements and machinery in animal production.
7) **Home Science:** Application and utilization of agricultural produces in a better manner. When utilization is enhanced production is also enhanced.

Topic 2 : Agronomy:-definition, meaning and its scope

Agronomy is a Greek word derived from **agros** meaning field and **nomos** meaning management. It is a field management.

Agronomy is a specialized branch in agriculture dealing with crop production and soil management.

It is defined as an agricultural science deals with principles and practices of crop production and field management.

Agronomist is a scientist who is dealing with the study of problems of crop production and adopting/recommending practices of better field crop production and soil management to get high yield and income.

In recent times, agronomy has assumed newer dimensions and can be defined as a branch of agricultural science that deals with methods which provides favourable environment to the crop for higher productivity.

Norman (1980) has defined agronomy as the science of manipulating the crop environment complex with dual aims of improving agricultural productivity and gaining a degree of understanding of the process involved.

Scope of Agronomy

Agronomy is a dynamic discipline. With the advancement of knowledge and better understanding of plant and environment, agricultural practices are modified or new practices developed for higher productivity. For example;-

- Availability of chemical fertilizers and herbicides for control of weeds has led to development of a vast knowledge about time, method and quantity of fertilizer and herbicide application.

- Big irrigation projects are constructed to provide irrigation facilities. However, these projects created side effects like water logging and salinity. To overcome these problems, appropriate water management practices are developed.

- Population pressure is increasing but the area under cultivation is static. Therefore, to feed the increasing population, more number of crops has to be grown on the same piece of land in a year. As a result, intensive cropping has come into vogue.

- Similarly, no tillage practices have come in place of clean cultivation as a result of increase in cost of energy. (Fuel prices of oil).

- Likewise, new technology has to be developed to overcome the effect of moisture stress under dry land conditions.

- As new varieties of crops with high yield potential become available, package of practices has to be developed to exploit their full yielding potential.

Topic 3: Tillage, land configuration and sub soiling

Tillage is as old as agriculture. Primitive man used to disturb the soil for placing seeds. The word tillage is derived from the Anglo- Saxon words ***tilian*** **and** ***teolian*****,** meaning to plough and prepare soil for seed to sow, to cultivate and to raise crops. **Jethro Tull,** who is considered as father of tillage suggested that thorough ploughing is necessary so as to make the soil into fine particles.

After harvest of the crop, soil becomes hard and compact may be due to : (a) Beating action of rain drops, (b) irrigation and subsequent drying and (c) movement of intercultivation implements and labour cause soil compaction.

Definition of tillage

"Tillage is the mechanical manipulation of soil with tools and implements for obtaining conditions ideal for seed germination, seedling establishment and growth of crops is called tillage" **or**

Any operation carried out on the soil surface by agricultural implements for the purpose of softening the soil surface for better advantage to germination and plant growth.

Tilth:

It is the physical condition of soil obtained out by tillage **(or)** it is the resultant effect of tillage in which soil air, soil water and soil aggregates are in perfect harmony or in balance condition.

Purpose of Tillage:

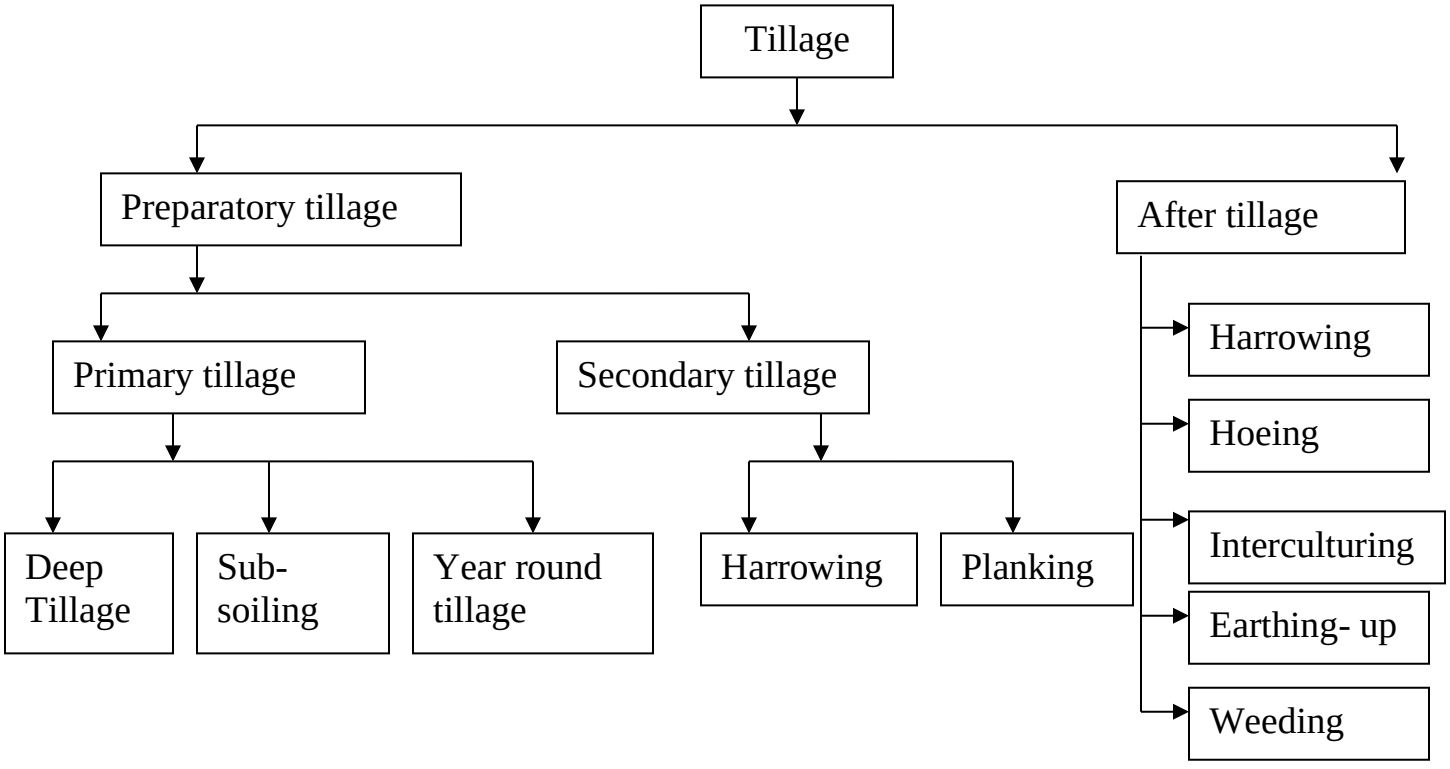
The purpose of tillage is to prepare a seedbed, break weed, insect and disease cycles, bury plant residues, incorporate fertilizers and amendments, break surface crust etc.

Objectives of tillage:

There are several objectives of tillage of which the most important are suitable seedbed preparation, weed control and soil and water conservation.

1. To produce a satisfactory seed bed for good germination and good crop growth.
2. To make the soil loose and porous.
3. To provide aeration to the soil
4. To control weeds
5. To remove the stubbles (that may harbour pests)
6. To expose the soil inhabiting pathogens and insect pests to sun and kill them.
7. To break hard pans in the soil
8. For deep tillage and inversion of soil
9. For incorporating bulky organic manures
10. To increase infiltration rate.

Classification of Tillage



Types of tillage:-

Tillage operations are grouped in to two types based on the time (with reference to crop) at which they are carried out. They are

(1) **Preparatory tillage:-** Which is carried out before sowing the crop and
(2) **After tillage:**- That is practiced after sowing of crop.

(1) Preparatory tillage

Tillage operation that are carried out to prepare the field for raising crops-from the time of harvest of a crop to the sowing of the next crop are known as preparatory tillage. It is divided in to primary and secondary tillage operations.

(A) Primary tillage or ploughing:-

"The Tillage operation that is done after the harvest of crop to bring the land under cultivation is known as primary tillage".

Ploughing is the opening of the compact soil with the help of different ploughs. Primary tillage is done mainly to open the hard soil and to separate the top soil from lower layers and to uprooting the weeds and stubbles of previous crop.

e.g. Country plough, Disc plough, Mould board plough, etc. are used for primary tillage.

Type of Primary tillage:-

1. Deep tillage 2. Sub soiling 3. Year round tillage

(1) Deep Tillage: - Central Research Institute for Dry land Agriculture (CRIDA) Hyderabad, classified poughing of

- 5-6 cm depth as shallow
- 15- 20 cm depth as medium deep and
- 25- 30 cm depth as deep ploughing

The rhizomes and tubers of perennial weeds and pupae of insects are die due to exposure to hot sun. Deep tillage also improves soil moisture.

(2) Sub soiling: - Hard pans may present in the soil which restrict root growth of crops. These may be silt pans, iron or aluminum, clay or manmade pans. Sub soiling is breaking the hard pan without inversion and with less disturbance of top soil. A narrow cut is made in the top soil while share of the sub soiler shatters hard pans. Chisel ploughs are also used to break hard pans present even of 60 - 70 cm.

(3) Y**ear round tillage: -** Tillage operations carried out throughout the year are known as year round tillage.

(B) Secondary tillage: -

Lighter or finer operations performed on the soil after primary tillage are known as secondary tillage. Disc harrows, cultivators, blade harrows, planking are used for this purpose. Generally sowing operation is also included in secondary tillage.

Harrowing: An agricultural implement with spikelike teeth or upright disks, drawn chiefly over plowed land to level it, break up clods, up root the weeds, etc.

Planking : It is secondary tillage equipment for clod crushing, levelling and smoothing of land surface before seeding

(2) After tillage

The tillage operations that are carried out in the standing crop are called after tillage. It includes harrowing, hoeing, intercultivation, earthing up and weeding.

Harrowing: An agricultural implement with spikelike teeth or upright disks, drawn chiefly over plowed land to level it, break up clods, up root the weeds, etc.

Hoeing: Any of several kinds of long-handled hand implement equipped with a light blade and used to till the soil, eradicate weeds, etc.

Inter-cultivation: Inter-cultivation also known as interculturing, is the cultivation of soil between crop rows. In other words, the soil between the two row of crops are ploughed using dedicated agricultural equipment (such as blade harrow, tined harrow, and even by hand) for weeding, improving soil aeration, and loosening the soil compaction.

Earthing up: To raise the soil at base of the plant for the purpose of proving support against lodging, root penetration etc.

Weeding: The process of eliminating the weeds from cropped area is called "weeding." Weeding can be done by hand or with a gardening tool.

❖ Modern concepts in tillage

Conventional tillage involves primary tillage to break open and turn the soil followed by secondary tillage to obtain seed bed for sowing or planting. With the introduction of herbicides in intensive farming systems, the concept of tillage has been changed. Continuous use of **heavy ploughs create hard pan in the subsoil**. This results in **poor infiltration**. It is more **susceptible to run off and erosion**. It is capital intensive and increase soil degradation. The concept of minimum tillage was **started in U.S.A.** The immediate cause for introducing minimum tillage was high cost of tillage **due to steep rise in oil prices in 1974. Dr. G.B. Triplett is considered as father of modern tillage.**

➢ Minimum Tillage:

Minimum tillage is aimed at reducing tillage to the minimum necessary for ensuring a good seedbed, rapid germination, a satisfactory stand and favorable growing conditions.

Tillage can be reduced in two ways:

(1) By omitting operations which do not give much benefit when compared to the cost.

(2) By combining agricultural operations like seeding and fertilizer application.

Advantages of minimum tillage:

(1) Improved soil conditions due to decomposition of plant residues in *Situ*

(2) Higher infiltration caused by the vegetation present on the soil and channels formed by the decomposition of dead roots

(3) Less resistance to root growth due to improved structure

(4) Less soil compaction by the reduced movement of heavy tillage vehicles and less soil erosion compared to conventional tillage

Disadvantages of minimum tillage:

(1) Seed germination is lower

(2) More nitrogen has to be added as rate of decomposition of organic matter is slow

(3) Sowing operations are difficult with ordinary equipment

(4) Continuous use of herbicides causes pollution problems and dominance of perennial problematic weeds.

➢ Zero Tillage

Zero tillage is an extreme form of minimum tillage. Primary tillage is completely avoided and secondary tillage is restricted to seedbed preparation in the row zone only. It is known as no-till and is resorted to where soils are subjected to wind and water erosion.

In zero tillage:

(1) The organic matter content increases due to less mineralization.

(2) Surface runoff is reduced due to presence of mulch.

(3) Clean a narrow strip over the crop row.

(4) Open the soil for seed insertion, place the seed and cover the seed properly.

(5) Before sowing, the vegetation present has to be destroyed for which broad spectrum, nonselective herbicides with relatively short residual effect (Paraquat, Glyphosate etc.) are used

(6) During subsequent stages, selective and persistent herbicides are needed.

(7) The seeding establishment is 20 per cent less than conventional methods.

(8) Higher dose of nitrogen to be applied as mineralization of organic matter is slow.

❖ Land configuration techniques

The productivity of any crop is the complex phenomenon governed by number of factors viz., use of improved varieties, appropriate sowing method, timely sowing, spacing, judicious use of water as well as nutrients and weeds, pests and disease management. Among all these, appropriate sowing method or proper land configuration is the most critical factor for realizing desired yield potential. The genotypes can express their full potential only when grown under optimum conditions and at optimum plant base.

Land management system plays a major important role in minimizing soil erosion and improving water use efficiency of field crops. Easy and uniform germination as well as growth and development of plant are provided by manipulation of sowing method. Land configuration increases water use efficiency and also increases availability of nutrients to crops. It is particularly useful in areas having saline irrigation water because it helps to avoid direct contact of young plants with saline irrigation water. Various land

configuration techniques helps in increasing growth and development of plants and thereby yield.

1. Flat beds

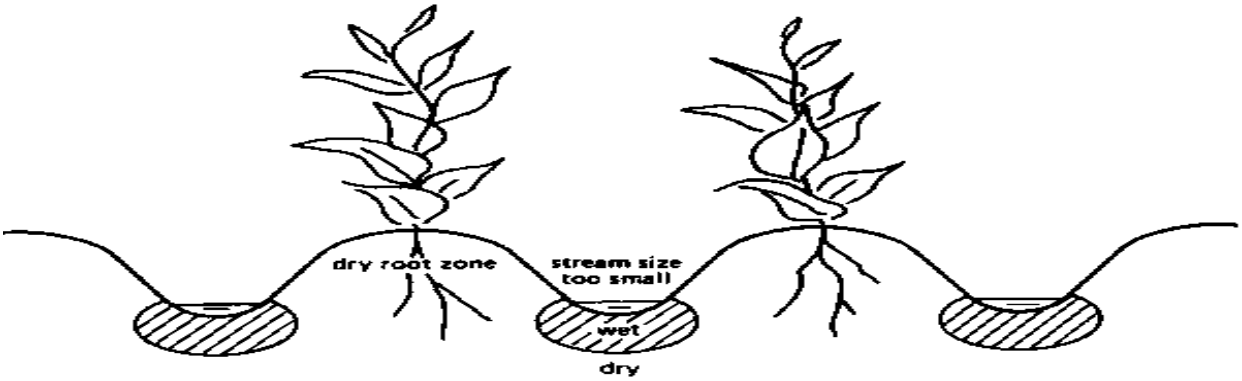
Flat beds are prepared easily in sandy loam type of soil because sandy soil is better workable. The length of the beds should be kept according to the slop of nursery. For easy working the beds should be prepared about 3.60 meter in length and 1.20 meter in width for easy and convenient operations.

2. Raised beds

Raised beds are mostly preferred in heavy black soil having maximum water holding capacity and poor drainage capacity. The basal measurement of raised beds should be 10.0 meter x 1.0 meter. Dig the soil near to the boundary of the beds and raised the soil on top.

3. Ridges and furrows

The field must be formed into ridges and furrows. Furrows of 30-45 cm width and 15-20 cm height are formed across the slope. The furrows guide runoff water safely when rainfall intensity is high and avoid water stagnation. They collect and store water when rainfall intensity is less. It is suitable for medium deep to deep black soils and deep red soils. It can be practiced in wide row spaced crops like cotton, maize, chillies, tomato etc. It is not suitable for broadcast sown crops and for crops sown at closer row spacing less than 30 cm.



Tied ridging

It is a modification of the above system of ridges and furrows wherein the ridges are connected or tied by a small bund at 2-3 m interval along the furrows to allow the rain water collection in the furrows which slowly percolated in to the soil profile.

4. Broad bed furrows (BBF)

This practice has been recommended by ICRISAT for vertisols or black soils in high rainfall areas (> 750 mm). Here beds of 90-120cm width, 15 cm height and convenient length are formed, separated by furrows of 60 cm width and 15 cm depth. When runoff occurs, its velocity will be reduced by beds and infiltration opportunity time is increased. The furrows have a gradient of 0.6%. Crops are sown on the broad beds and excess water is drained through number of small furrows which may be connected to farm ponds. It can be formed by bullock drawn or tractor drawn implements. Bed former cum seed drill enables BBF formation and sowing simultaneously, thus reducing the delay between receipt rainfall and sowing.

Broad bed furrow has many advantages over other methods.

- ✓ It helps in moisture storage
- ✓ Safely dispose of surplus surface runoff without causing erosion
- ✓ Provide better drainage facilities
- ✓ Facilitate dry seeding
- ✓ It can accommodate a wide range of crop geometry i.e. close as well as wide row spacing.
- ✓ It is suitable for both sole cropping and intercropping systems.
- ✓ Sowing can be done with seed drills.

5. Dead furrows

At the time of sowing or immediately after sowing, deep furrows of 20 cm depth are formed at intervals of 6 to 8 rows of crops. No crop is raised in the furrow. The dead furrows can also be formed between two rows of the crop, before the start of heavy rains (Sep – Oct). It can be done with wooden plough mostly in red soils. The dead furrows increase the infiltration opportunity time.

6. Scooping

Scooping the soil surface to form small depressions or basins help in retaining rain water on the surface for longer periods. They also reduce erosion by trapping eroding sediment. Studies have shown that runoff under this practice can be reduced by 50 % and soil loss by 3 to 8 t /ha.

Fig. : Scoops for insitu moisture conservation

❖ Sub soiling

"To gain maximum benefit from sub soiling, this operation needs to be done when the lower levels of the soil are relatively dry"

Sub soil meaning: The layer or bed of earth beneath the topsoil. **Also called under soil** the layer of soil beneath the surface soil and overlying the bed rock.

What is a Sub soiler?

A sub soiler is a type of tillage implement that's used to break up compacted soil in an effort to improve the setting for growing crops.

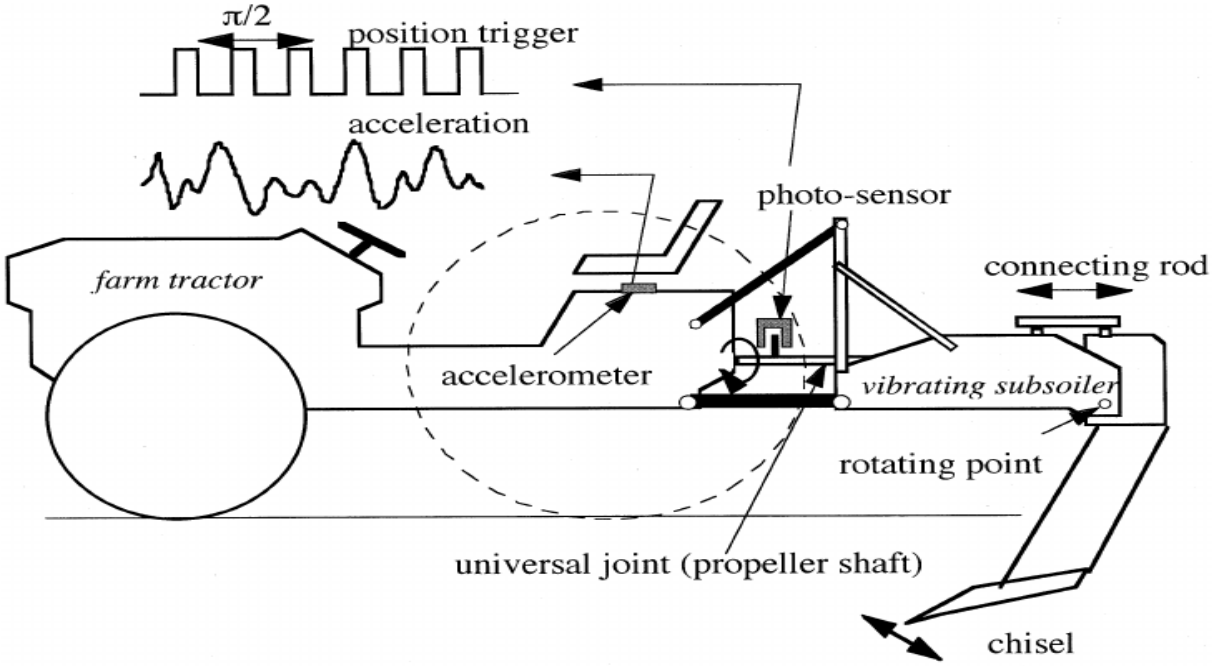
The subsoiler is so named because it cuts and loosens soil below the normal tillage depth of 100–200 mm. Its shape is similar to the chisel plow except that it is made with a stronger shank or leg in order to resist the higher force required to till soil at greater depth.

Subsoiling is a practice that breaks up soil, usually 12-18" deep, to allow increased water movement, better aeration of the roots and access to additional minerals and nutrients for plant growth.

Chisel ploughs are also used to break hard pans presents even at 60-70 cm.

- **Chisel Plough :** It is mainly used for breaking hard pans and for deep ploughing (60-70 cm) with less disturbance to the top layers. Its body is thin with replaceable cutting edge so as to have minimum disturbance to the top layers. It contains a replaceable share to shatter the lower layers.

- **Subsoil Plough :** The subsoil plough is designed to break up hard layers or pans without bringing them to the surface. The body of the subsoil plough is wedge shaped and narrow while the share is wide so as to shatter the hard pan and making only a slot on the top layers.



(Chisel Plough)

Topic 4: Seeds and sowing

Seeds are the vital part of agriculture. Selection of good quality seeds is a challenge for farmers. Only good quality seeds which are sown properly can give an expected result or yield. Seeds of a variety of types and strains are available; cultivators have to choose from these and these have to be sown in the field.

Definition: Seed is a fertilized ovule consisting of intact embryo, store food and seed coat which is viable and has got the capacity to germinate under favourable condition. **or**

A seed is the small, hard part of a plant from which a new plant grows.

Characters of good seeds

(1) Seed should be of recommended crop and their varieties.
(2) It must be true to its type.
(3) The seed must be healthy, pure and free from all the inert materials and weed seeds.
(4) The seed must be viable. The germination capacity is upto the standard and it has been tested recently.
(5) The seed must be uniform in its texture, structure and outlook.
(6) The seed should be free from insects, insect eggs, disease spores etc. in or on the seeds
(7) The seed should be collected from fully matured crop, well developed, bold and plump in size.

Quality of seed

Viability and vigour are the two important characters of seed quality. Viability can be expressed by the germination percentage, which indicates the number of seedlings produced by a given number of seeds.

Vigour of seed and seedlings is difficult to measure. Low germination percentage, low germination rate and low vigour are often associated. Seeds with low vigour may not be able to withstand unfavourable conditions in the seedbed. The seedlings may lake the strength to emerge if the seeds are planted too deep or if the soil surface is crusted.

Germination percentage

It is the number of seeds germinated to number of seeds planted and it is expressed as percentage.

Germination rate is expressed in two ways as under

- The number of days required to produced a given germination percentage.
- The average number of days required for radical or plumule to emerge.

Vigour is indicated by the higher germination percentage, high germination rate and quicker seedling growth.

Classes of seed

With respect to genetic purity and stages of development, seeds are classified into four different categories as under

❖ **Breeder seed**

It is also known as Nucleus seed. It is very important class of seed. It is produced at breeder's institute with the responsibilities of the concern breeder who developed a particular variety. Breeder seed is the main source for the increase of foundation seed. It is 100 % genetically pure.

❖ **Foundation seed**

This seed is directly produced from the breeder seed. Production of foundation seed is done carefully under the strict supervision of the highly qualified seed experts because genetic purity and identity of the variety should be maintained, as this seed is the source of all certified seed classes, either directly or through the registered seed. Foundation seed is produced at state Government farms and Agricultural university farms.

❖ **Registered seed**

This class of seed is increased from foundation seed or other registered seed produced by the private seed growers or seed companies.

❖ **Certified seed**

Certified seed means the production of commercial seed sold to the farmers for raising the crop. This type of seed is produced from foundation seed or registered seed. The National Seed Corporation, Agricultural Universities, State Government, Private seed companies, Private seed producers and some Co-operative society produce this type of seed. The seed produced by various agencies is certified by State Seed Certification Agency.

Sowing :-

Sowing is an operation for putting the seeds in the soil at particular distance and depth for raising the crop after proper preparation of a land.

Seeds are sown either directly on the field (seed bed) or in nursery where seedlings are raised and transplanted later in to the main field.

Time of Sowing

Sowing very early in the season may not be advantageous. For example, sowing rainfed groundnut in June may result in failure of the crop if there is prolonged dry spell from the second week of June to second week of July. But sometimes, sowing early in certain situations increases the yield of crop. Advancing sowing of rabi sorghum from November to September- October, increases the yields considerably as more moisture would be available for early sown crop.

Delayed Sowing

Delayed sowing invariably reduces the yields. Rainfed sorghum yields are reduced due to delay in sowing beyond June. In rainfed groundnut, sowing beyond July reduced the yields of all varieties at Tirupati. Similarly, the yields of pigeonpea and soybean are reduced due to delay in sowing. The reduction in yields is attributed to early induction of flowering, unfavourable temperature and rainfall. Most of the tropical crops are short-day plants. Day length starts falling from July onwards, but the reduction in day length is steep from October onwards. Flowering is induced in short-day crops earlier due to absolute short days or relative reduction in day length. If sowings are delayed, there is very little time for vegetative growth and thus, there is reduction in yield. In addition, late sown crops are exposed to increased population of pests and diseases. Sorghum sown late is subjected to severe attack of shoot borer.

Optimum Time of Sowing

Sowing the crop at optimum time increases yields due to suitable environment at all the growth stages of the crop. Flowering is induced after sufficient vegetative growth. Moisture stress or dry spells may be avoided during critical stages. The optimum time of sowing for most of tropical crops is immediately after the onset of monsoon i.e. June or July. The optimum time of sowing for temperate crops like wheat and barley are from last week of October to first week of November. The optimum time of sowing for most of the summer crops is first fortnight of January.

❖ Types of Sowing

➢ Dry sowing

Dry sowing is adopted in black soils where sowing operations are difficult to carry out once rains commence. Field is prepared with summer and seeds are sown in dry soil around seven to ten days before the anticipated receipts of sowing rains. The seeds germinate after the receipts of rains. By this method, rainfall is effectively utilized.

➢ Wet Sowing

Wet sowing is the most common method of sowing crops. The minimum amount of rainfall necessary for taking up sowing is 20 mm. Certain amount of moisture is wasted during the period between receipt of rainfall and sowing.

❖ Methods of sowing

1. Broadcasting:

This is an oldest method. This method is suitable for close planted crop which do not require a specific geographic area. Crop plants which do not require special type of cultural practices e.g. earthingup or interculturing etc. may be sown by broadcasting. This method is followed in the crop having short life period. Seeds are spread or scatter by hands over the field and covered with the help of wooden rake or light plank.

Advantages:

- This method is cheap.
- It is easy and quick.

Disadvantages:

- Require more seed rate.
- Uneven distribution of seed is possible.
- Uneven depth of sowing.
- Interculturing is not possible.
- Weeding becomes difficult.
- Selections of seeds are not possible.
- Covering seeds with the help of rake is necessary.
- e.g. Cumin, Isabgul, Lucerne, Coriander, Rajgira, Berseem etc. and in mix cropping situation.

2. Drilling:

Drilling is a practice of dropping the seeds in furrows by a mechanical device at a distance between rows. Seed are drilled in parallel line. Distribution of seeds is regulated by releasing seeds in to the bowl by the hand. For covering the seeds light planking is done by plank.

Advantages:

- Uniform distance between two rows can be maintained.
- Less seed rate as compared to broadcasting.
- Interculturing is possible between two rows.
- Seeds are placed at uniform depth and covered and compacted uniform

Disadvantages:

- Distance between two plants within the row is not maintained.
- Thinning and gap filling operations are necessary
- Selection of seed is not possible.
- e.g. Upland rice, Wheat, Bajra, Barley, Mustard, Greengram, Cowpea, etc. and in intercropping situation.

3. Dibbling:

Putting the seed or few seeds in a hole or pit or pocket, made at predetermine spacing and depth with a dibbler or very often by hand. This method is suitable for wide space crops requiring a specific geometric area for their canopy development or cultural practices. First all lines are marked vertically and horizontally with the help of marker at a particular distance. At each cross seeds are dibbled with the help of dibbler by manual labour. Then seeds are covered with soil.

Advantages:

- Spacing is maintained between two rows and between two plants within the row.
- Requirement of seed rate is less as compared to broadcasting and drilling.
- Depth of sowing is maintained.
- Selection of good seed is possible.
- Give rapid and uniform germination with good seedling vigour.

Disadvantages:

- More laborious and time consuming method.
- It is costly.
- e.g. Cotton, Castor, Indian bean, Pigeon pea etc.

4. Planting:

Placing of plant part (vegetative propagules) in soil called planting. The vegetative propagules are planted directly on the field should be good in health, vigour, age, stage of growth and desirable number of readily sprouting buds.

Advantages:

- Proper distance can be maintained between two rows and between two plants within the row.
- Providing opportunity for selection of planting material.
- Depth of sowing can be maintained.

Disadvantages:

- It requires more labour.
- It is costly and time consuming method.

e.g.	Tuber	: Potato,	Rhizomes	: Ginger and Turmeric,
	Bulb	: Onion,	Cloves	: Garlic,
	Vine set	: Sweet potato,	Setts	: Sugarcane,
	Root cutting	: Pointed gourd,	Rooted slips	: Napier grass, Blue panic grass.

5. Transplanting:

Transplanting is the removal of an actively growing plant from one place and planting it in another for further growth and production. In this method seeds are not directly sown in the field but seeds are sown first in nursery with proper care. After proper growth (generally four weeks), seedlings are uprooted and transplanted in well prepared main field. This method is useful for raising the crops which have small size seeds and require more care in the initial stage.

Advantages:

- Economy of costly seeds.
- Maintaining of desire plant density with healthy and pure seedlings.
- Available sufficient time for preparing seedbed.
- Provide better chances for better care in small area during seedling stage.

Disadvantages:

- Total duration of crop may be more.
- It increases the labour and power requirement in a peak period.
- It increases the cost of land preparation, uprooting and transplanting of seedling.
- **e.g. Seedlings**- Rice, Tobacco, Tomato, Brinjal, Chilly, Onion, Cabbage, Cauliflower etc.
  Saplings - Subabool, Sag, Eucalyptus.

Topic 5: Crop density and geometry

Plant Population or Plant Density

Number of plants per unit area in the cropped field is the plant population or plant density.

Optimum plant population

1. Optimum plant population – It is the number of plants required to produce maximum output or biomass per unit area.
2. Any increase beyond this stage results in either no increase or reduction in biomass.

Importance of plant population / crop geometry

1. Yield of any crop depends on final plant population
2. The plant population depends on germination percentage and survival rate in the field
3. Under rainfed conditions, high plant population will deplete the soil moisture before maturity, where as low plant population will leave the soil moisture unutilized
4. Under low plant population individual plant yield will be more due to wide spacing.
5. Under high plant population individual plant yield will be low due to narrow spacing leading to competition between plants.
6. Yield per plant decreases gradually as plant population per unit area is increased, but yield per unit area increases upto certain level of population, that level of plant population is called as optimum population

So to get maximum yield per unit area, optimum plant population is necessary. So the optimum plant population for each crop should be identified.

Plant geometry

Plant geometry refers the shape of the plant / plant canopy. Like Vertical growth in sorghum, maize, paddy etc. Horizontal growth in cotton, tobacco, pulses etc.

Crop geometry

Crop geometry refers the shape of the land available to individual plant to grow. e.g. random, square, rectangular etc.

The arrangement of the plants in different rows and columns in an area to efficiently utilize the natural resources is called crop geometry. It is otherwise area occupied by a single plant e.g. rice – 20 cm x 15 cm. This is very essential to utilize the resources like light, water, nutrient and space. Different geometries are available for crop production

❖ Different crop geometries are available for crop production

1. Random geometry

This type of geometry is observed under broadcasting method of sowing, where no equal space is maintained, resources are either under exploited or over exploited.

2. Square method or square geometry

The plants are sown at equal distances on either side. Mostly perennial crops, tree crops follow square method of cultivation.

Advantages

1. Light is uniformly available,
2. Movement of wind is not blocked and
3. Mechanization can be possible.

3. Rectangular method of sowing

There are rows and columns, the row spacing are wider than the spacing between plants.

The different types exist in rectangular method

a. Solid row

Each row will have no proper spacing between the plants. This is followed only for annual crops which have tillering pattern. There is definite row arrangement but no column arrangement, e.g., wheat.

b. Paired row arrangement

It is also a rectangular arrangement. If a crop requires 90 cm spacing and if paired row is to be adopted the spacing is altered to 75 -120 - 75 instead of 90 cm, i.e. distance between two pair is 120 cm, whereas the distance between two rows within pair is 75 cm. The intercrop can be grown in-between two pair. The base population is kept constant.

c. Skip row

A row of planting is skipped and hence there is a reduction in population. This reduction is compensated by planting an intercrop; practiced in rain fed or dry land agriculture.

d. Triangular method of planting

It is recommended for wide spaced crops like coconut, mango, etc. The number of plants per unit area is more in this system.

❖ **Factors affecting plant population / Plant density**

Many factors influence the optimum plant population for a crop, there are

1. Size of the plant

1. The volume occupied by the plant at the time of flowering decides the spacing of crop
2. Plants of red gram, cotton, sugarcane etc occupy larger volume of space in the field compared to rice, wheat, ragi
3. Even the varieties of the same crop differ in size of the plant

2. Foraging area or soil cover

1. Should cover the soil as early as possible so as to intercept maximum sunlight
2. Higher the intercepted radiation more will be the dry matter produced
3. Close spaced crops intercept more Solar radiation than wide spaced crops

3. Dry matter partitioning

1. Dry matter production is related to amount of solar radiation intercepted by the canopy which depends on plant density
2. As the plant density increases the canopy expands more rapidly, more radiation is intercepted and more dry matter is produced.

4. Crop and variety

Crop	Duration	Distance	Plant population
Rice	Short duration	15 cm x 10 cm	6,66,666 plants/ha
	Medium duration	20 cm x 10 cm	5,00,000 plants/ha
	Long duration	20 cm x 15 cm	3,33,333 plants/ha
Cotton	Medium duration	60 cm x 30 cm	55,555 plants/ha
	Long duration	75 cm x 30 cm	44,444 plants/ha
	Hybrids	120 cm x 45 cm	18,518 plants/ha
Maize	Varieties	60 cm x 20 cm	83,333 plants/ha
	Hybrids	60 cm x 35 cm	47,619 plants/ha
Groundnut	Erect	30-45 cm x 10 cm	2,22,222 plants/ha
	Semi-spreading	45-60 cm x 10 cm	1,66,666 plants/ha
	Spreading	60-90 cm x 10 cm	1,11,111 plants/ha

5. Time of sowing

1. The crop is subjected to various weather conditions when sown at different periods.
2. Among weather factors, day length and temperature influence the plant population. As low temperature retards growth, high plant population is required to cover the soil

6. Rainfall / irrigation

1. Plant population has to be less under rainfed than irrigated condition
2. Under more plant densities, more water is lost through transpiration
3. Under adequate rainfall / irrigation, high plant population is recommended.

7. Seed rate

1. Quantity of seed sown/unit area, viability and establishment rate decides the plant population Under broadcasting the seed rate is higher when compared with line sowing / transplanting, e.g. for rice

Direct sowing	-	100 kg/ha
Line sowing	-	60 kg/ha
Transplanting	-	40 kg/ha

7. Depth of sowing:

Depth of sowing is governed by size **of seed** and **soil moisture content.** Uneven depth of sowing results in uneven crop stand. Plants will be of different sizes and ages and finally harvesting is a problem as there is no uniformity in maturity. **Shallow or deep sowing results in low plant population because all seeds do not germinate.** Therefore, it is essential to sow the crop at optimum depth for obtaining good stand of the crop.

Crops with bigger sized seeds like groundnut, castor, sunflower, etc. can be sown even up to the depth of 6 cm. Whereas, small sized seeds like tobacco, sesamum, bajra, mustard have to be sown as shallow as possible.

If the seeds are sown too shallow, the surface soil dries up quickly and germination may not occur due to lack of moisture. Therefore, small sized seeds which are sown shallow should be watered frequently to ensure good emergence of the crop.

If the small seeds are sown deep in the soil, the seed reserve food may be inadequate to put forth long coleoptiles for emergence. Even if the seedling emerges, it is too weak to survive as an autotrophic.

For better germination, the soil should have sufficient moisture in the surface layer. Crop grown in *rabi* are sown deeper than *kharif* crop, because in *rabi* surface soil have insufficient moisture for germination.

The thumb rule is to **sow seeds to a depth approximately 3 to 4 times their diameter.** The optimum depth of sowing for most of the field crops ranges between **3 cm to 5 cm. Shallow depth of planting of 2 cm to 3 cm is follow for small seeds like bajra, sesamum, mustard.** Very small seeds like tobacco are placed at a depth of 1 cm. This is generally done by broadcasting on the soil surface and mixing them by racking.

Topic 6: Crop nutrition, manures and fertilizers, nutrient use efficiency

Yield and the quality of products from crops are strongly linked to the supply of nutrients. In the absence of fertilizer application, most nutrients are supplied from the soil. Over 95 percent of the dry weight of a flowering plant is made up of three elements—carbon, hydrogen, and oxygen—taken from the air and water. The remaining 5 percent of the dry weight comes from chemicals absorbed from the soil. Roots absorb the chemicals present in their surroundings, but only 14 of the elements absorbed are necessary for plant growth. These 14 elements, along with carbon, hydrogen, and oxygen, are called the **17 essential inorganic nutrients** or **elements**.

Macronutrients: Some of the essentials nutrients are needed in larger amounts than others are called **macronutrient**.

Micronutrients: those nutrients are needed in lesser amounts called **micronutrients**. All elements are needed in specific amounts.

- **Macronutrients absorbed from the air**: oxygen, carbon, and hydrogen.
- **Macronutrients absorbed from the soil**: nitrogen, potassium, magnesium, phosphorus, calcium, and sulfur.
- **Micronutrients from the soil**: iron, boron, chlorine, manganese, zinc, copper, molybdenum, and nickel.

Criteria for essentiality of nutrient

Armon and Stout (1939) proposed criteria of essentiality which was refined by Arnon (1954) as:

1. The plant must be unable to grow normally or complete its life cycle in the absence of the element.
2. The element is specific and cannot be replaced by another.
3. The element plays a direct role in plant metabolism.

Nutrient use efficiency

Nutrient use efficiency may be defined as yield (biomass) per unit input (fertilizer, nutrient content).

Agronomic efficiency

Agronomic efficiency may be defined as the economic production obtained per unit of nutrient applied.

Calculation: Expressed in kg / kg

$$Agronomic\ \ Efficiency\ \ = \frac{Yield\ \ of\ \ fertilized\ \ crop\ -\ Yield\ \ of\ \ unfertilized\ \ crop}{Quantity\ \ of\ \ fertilizer\ \ applied}$$

❖ Manures and fertilizers

The word “Manure” is originated from the French word “MANOEUVRER” which refers to “work with soil”.

Differences between Manures and Fertilizers

Sr. No	MANURES	FERTILIZERS
1	Organic in nature	Inorganic in nature
2	Slow acting	Quick acting
3	Having low nutrient value	Having high nutrient value
4	Having no definite chemical composition	Having definite chemical composition
5	Obtained from plant, animal and human resources	Obtained from Mined or manufactured
6	Improves physical properties of soils	Don’t improve the physical properties of Soils
7	Supply almost all major, minor and micronutrients	Supply one or very few plant nutrients.
8	Bulky in nature	Non-bulky in nature

Manure:

Manures are the substances which are organic in nature, capable of supplying plant nutrients in available form, bulky in nature having low analytical value and having no definite composition and most of them are obtained from animal and plant waste products.

❖ Bulky Organic Manures

Bulky organic manures contain small percentage of nutrients and they are applied in large quantities.

1. **FYM**

   Farmyard manure refers to the decomposed mixture of dung and urine of farm animals along with litter and left over material from roughages or fodder fed to the cattle. It contains 0.5 per cent N, 0.2 per cent P_2O_5 and 0.5 per cent K_2O.

2. **Compost**

   A mass of rotted organic matter made from waste is called compost. It contains 0.5 per cent N, 0.15 per cent P_2O_5 and 0.5 per cent K_2O.

3. **Night soil**

   Night soil is human excreta, both solid and liquid. It contains 5.5 per cent N, 4.0 per cent P_2O_5 and 2.0 per cent K_2O.

4. **Sewage and Sludge**

   The solid portion in the sewage is called sludge and liquid portion is sewage water.

5. **Vermicompost**

   Compost that is prepared with the help of earthworms is called vermicompost. It contains 3.0 per cent N, 1.0 per cent P_2O_5 and 1.5 per cent K_2O.

6. Green Manure

Definition : Crops grown for the purpose of restoring or increasing the organic matter content in the soil are called green manure crops while there green undecomposed plant material used as manure is called green manure. Their use in cropping system is generally referred as green manuring. It is obtained in two ways-either by grown in situ or brought from out site.

1. **In situ green manuring:** Growing of green manure crops in the field and incorporating it in its green stage in the same field (i.e. in situ) is termed as green manuring.
2. **Green leaf manuring:** is the application of green leaves and twigs of trees, shrubs and herbs collected from nearby location and adding in to the soil. Forest tree leaves are the main source of green leaf manuring.

Advantage of green manuring : -

1. It has positive influence on the physical and chemical properties of soil.
2. Helps to maintain the organic matter status of arable soil.
3. All green manures supply extra organic matter to feed and breed beneficial soil organisms for soil fertility and soil health.
4. Increases the water holding capacity of light soils.
5. It facilities the penetration of rain water, thus decreasing run off and soil erosion.
6. The green manure crops hold plant nutrients that would otherwise be lost by leaching (e.g. Nitrogen)
7. When leguminous plants like sannhemp and dhaincha are used as green manure crops, they add nitrogen to the soil for the succeeding crops.
8. Green manuring crops helps in reclamation of saline and alkaline soils by the release of organic acids.

Limitations of green manuring : -

(1) Under rainfed condition it is feared that proper decomposition of the green manure crop may not take place if sufficient rainfall is not received after burying the green manure crop.

(2) Since green manuring for wheat loss of Kharif crops, the practice of green manuring may not be always economical.

(3) Sometimes the cost of green manure crops may more than the cost of commercial fertilizers.

(4) Sometimes it increases termite problem.

(5) The green manure crop may be failed if sufficient rainfall is not available.

Characteristics of green manure crops : - An ideal green manure crop should have the following characteristics.

(1) It should be preferably from leguminous family so that atmospheric nitrogen can be fixed.

(2) It should have quick initial growth so as to suppress the weed growth.

(3) It should have more leafy growth than woody so that its decomposition will be rapid.

(4) It should yield a large quantity of green material in short period.

(5) It should have a deep rooted system so that it would penetrate deep layers of the soil and thus aid in creating good will structure.

Plants	**Nutrient content (%) on air dry basis**		
	N	**P_2O_5**	**K_2O.**
Green manure crops			
Sunnhemp	2.30	0.50	1.80
Dhaincha	3.50	0.60	1.20
Sesbania	2.71	0.53	2.21

Green leaf manure			
Gliricidia	2.76	0.28	4.60
Pongania	3.31	0.44	2.39
Neem	2.83	0.28	0.35
Gulmohur	2.76	0.46	0.50
Weeds			
Parthenium	2.68	0.68	1.45
Water hyacinth	3.01	0.90	0.15
Trianthema	0.64	0.43	1.30
Ipomoea	2.01	0.33	0.40

7. Sheep and Goat Manure, Penning

It contains 3.0 per cent N, 1.0 per cent P_2O_5 and 2.0 per cent K_2O.

8. Poultry Manure

It contains 3.03 per cent N, 2.63 per cent P_2O_5 and 1.4 per cent K_2O.

❖ Concentrated Organic Manures

Concentrated organic manures have higher nutrient content than bulky organic manure.

Oilcakes	**Nutrient content (%)**		
	N	**P_2O_5**	**K_2O.**
Nonedible oilcakes			
Castor cake	4.3	1.8	1.3
Cotton seed cake	3.9	1.8	1.6
Karanj cake	3.9	0.9	1.2

Mahua cake	2.5	0.8	1.2
Safflower cake	4.9	1.4	1.2
Edible oilcakes			
Coconut cake	3.0	1.9	1.8
Cotton seed cake	6.4	2.9	2.2
Groundnut cake	7.3	1.5	1.3
Linseed cake	4.9	1.4	1.3
Niger cake	4.7	1.8	1.3
Rapeseed cake	5.2	1.8	1.2
Safflower cake	7.9	2.2	1.9
Sesamum cake	6.2	2.0	1.2

❖ **Average nutrient content of animal based concentrated organic manure**

Organic manure	**Nutrient content (%)**		
	N	**P_2O_5**	**K_2O**
Blood meal	10-12	1-2	1.0
Meat meal	10.5	2.5	0.5
Fish meal	4-10	3-9	0.3-1.5
Horn and hoof meal	13	……	……
Raw bone meal	3-4	20-25	……
Steamed bone meal	1-2	25-30	……

Fertilizer:

A fertilizer can be defined as a mined or manufactured material containing one or more essential plant nutrients in potentially available forms in commercially valuable amounts.

It is most essential to apply fertilizer at proper time and at proper place for its efficient use. Thus, the time and method of fertilizer application will vary in relation to (i) Nature of fertilizer (ii) Soil types (iii) Differential nutrient requirement and (iv) Nature of field crops.

❖ Classification of Fertilizers

1. Nitrogenous fertilizers :

- Ammonium fertilizer : eg. Ammonium sulphate, ammonium chloride
- Nitrate fertilizer : eg. Potassium nitrate, sodium nitrate, calcium nitrate
- Ammonium – nitrate fertilizers : eg. Ammonium nitrate, calcium ammonium nitrate
- Amide fertilizers : eg. Urea, calcium cyanamide

2. Phosphatic fertilizers :

- Water soluble P fertilizers : eg. Superphosphate
- Citrate soluble P fertilizers : eg. Basic slag
- Insoluble P fertilizers : eg. Rock phosphate

3. Potassic fertilizers : eg. Muriate of potash (KCL), potassium sulphate

❖ Different Methods

A. Application of Fertilizers in Solid Form

1. Broadcast

- **Broadcasting :** Application of fertilizer uniformly on the soil surface or in the standing crop is known as broadcasting of fertilizers.
- **Top – dressing :** It involves the spreading of fertilizer in the standing crop.

2. Placement

- **Plough-sole placement :** The fertilizer is put in a continuous band or strip at a depth of 5.5 to 7 inches at the bottom of the furrow while ploughing. Each band is covered with the turn of the next furrow.
- **Deep placement :** Nitrogen fertilizers are applied deep in paddy fields. Deep placement of the fertilizer ensures its better distribution in the root zone and prevents any loss of nitrogen by surface drain-off.
- **Sub-soil Placement :** It refers to the placement of fertilizers in the subsoil with the help of high power machinery.

3. Localized placement : Application of fertilizers in the soil very close to the seed or the plant.

- **Contact placement :** The seed and small quantity of fertilizer are placed together in the same row by drilling.
- **Band Placement :** Application of fertilizers in narrow bands beneath and by the side of the crop rows is known as band placement of fertilizers.
    - Hill placement
    - Row placement

- **Pellet application :** The N-fertilizer is applied in the form of pellets at a depth of 1 to 2 inches between the rows of paddy crops.
- **Side-dressing :** The fertilizer is spread between the rows or around the plant.

B. Application of Fertilizer in Liquid Form

1. Starter Solution : The solutions of fertilizers that are applied to young vegetable plants at the time of transplanting are called starter solutions. It contain N, P_2O_5 and K_2O in the ratio 1 : 2 : 1 or 1 : 1 : 2.

2. Foliar Spray : Application of fertilizers to foliage of the crop as spray solution is known as foliar spray of fertilizers.

3. Direct application to the soil : Anhydrous NH_3 and solutions of N-fertilizers can be directly applied to the soil with the help of special equipments. Nitrogen from NH_3 may be lost if the application is shallow.

4. Fertigation : Application of fertilizers with irrigation water is known as fertigation.

❖ Brown manuring

Brown manuring is a technique to grow Sesbania in standing rice crop and kill them with the help of herbicide for manuring . After killing the color of the sesbania residue become brown so it called brown manuring. Brown manuring practice introduced where *Sesbania* crop @ 20 kg/ha is broadcasted three days after rice sowing/TP and allowed to grow for 30-40 days and was dried by spraying 2,4-D ethyle easter which supplied upto 35 kg/ha N from biomass, control of broad leaf weeds, higher yield by 4 -5 q/ha in rice crop due to addition of organic matter in low fertile soils.

❖ Biofertilizers

Bio-fertilizer is microorganism's culture capable of fixing atmospheric nitrogen when suitable crops are inoculated with them. Bio-fertilizer offers an economically attractive and ecologically sound means of reducing external inputs and improving the

quality and quantity of products. Microorganisms are capable of mobilizing nutritive elements from non-usable form to usable form through biological process. These are less expensive, eco-friendly and sustainable. The Biofertilizers containing biological nitrogen fixing organism are of utmost important in agriculture in view of the
following advantages:

1. They help in establishment and growth of crop plants and trees.
2. They enhance biomass production and grain yields by 10-20%.
3. They are useful in sustainable agriculture.
4. They are suitable organic farming.
5. They play an important role in Agroforestry / silvipastoral systems.

❖ **Types of Biofertilizers:** There are two types of bio-fertilizers.

1. Symbiotic N-fixation: These are *Rhizobium* culture of various strains which multiply in roots of suitable legumes and fix nitrogen symbiotically.
Rhizobium: It is the most widely used bio-fertilizers, which colonizes the roots of specific legumes to form tumours like growth called root nodules and these nodules act as factories of ammonia production.

2. Asymbiotic N-fixation: This includes *Azotobacter*, *Azospirillium*, BGA, Azolla and Mycorrhizae, which also fixes atmospheric N in suitable soil medium.
Mycorrhizae: Mycorrhizae are the symbiotic association of fungi with roots of Vascular plants. The main advantage of Mycorrhizae to the host plants is facilitating an increased phosphorous uptake. In many cases the Mycorrhizae have been shown to markedly improve the growth of plants. In India, the beneficial effects of Vascular-Arbuscular Mycorrhizae (VAM) have been observed in fruit crops like citrus, papaya and litchi.

Rhizobium stains used for the seed treatment to pulses

Name of the strain	Crop
Rhizobium leguminosarum	Pea
Rhizobium japonicum	Soybean
Rhizobium phaseolus	Bean

Rhizobium spp	Cowpea

PGPR/Bio-Consortium

The "**Bio NPK consortium**" having multiple utility as biofertilizer cum biopesticide.

This product contains five strains of agriculturally beneficial microorganism (two Nitrogen fixers, two Phosphate solubilizers and one potash mobilizer) is the one time solution for all the macronutrient (N, P, K) requirement of crops. Moreover, this formulation will also provide an additional benefit of protecting plant from phytopathogenic fungi and nematodes.

❖ **Field applications liquid biofertilizers & Bio NPK consortium:**

- Applied through seed coating, soil drenching, seedling dip and drip irrigation in cereals, vegetables, fruit crops, horticultural crops, sugarcane, cotton, fodder crops etc. as per method of crop cultivation. Use of Bio NPK consortium @ 1 litre /ha can save 25 % N, P and K chemical fertilizers with increase in yield with reduction in soil, water and air pollution.
- Use of Bio NPK consortium along with organic manure can increase population of beneficial microorganisms inside soil, wherein they work continuously and keep biogeochemical cycles of N, P and K alive with increase in soil fertility and crop yield. Beneficial in Organic farming and precision farming approach of Integrated Farming System.

❖ **Integrated Nutrient Management**

Plant nutrients can be supplied from different sources viz. organic manure, crop residues, biofertilizers and chemical fertilizers. For better utilization of resources and to produce crops with less expenditure, integrated nutrient management is the best approach.

Topic 7: Growth and development of crops

What is growth?

Growth can be defined as an irreversible permanent increase in size of an organ or its parts or even of an individual cell.

❖ Types of growth / Stages of growth

Vegetative growth: The earlier growth of plant producing leaves, stem and branches without flowers is called 'vegetative growth'/ Phase.

Reproductive growth: After the vegetative growth, plants produce flowers which is the reproductive part of the plant. This is called reproductive growth/phase.

Growth curve: It is an 'S' shaped curve obtained when we plot growth against time (Fig. 2). It is also called 'sigmoid 'curve. This curve mainly shows four phases of growth-

1. Initial slow growth (Lag phase),

2. The rapid period of growth (log phase/grand period of growth/exponential phase) where maximum growth is seen in a short period and

3. The diminishing phase where growth will be slow and

4. Stationary / steady phase where finally growth stops.

Stationary phase
Diminishing
growth phase
Log or
exponential
phase
Lag phase
Growth (size/weight of the organism)
Time

The three phases of cell growth are **cell division**, **cell enlargement** and **cell differentiation.** The first two stages increase the size of the plant cell while the 3rd stage brings maturity to the cells.

❖ MEASUREMENT OF GROWTH

Growth can be measured by a variety of parameters as follows

A. Fresh Weight

Determination of Fresh weight is an easy and convenient method of measuring growth. For measuring fresh weight, the entire plant is harvested, cleaned for dirt particles if any and then weighed.

B. Dry Weight

The dry weight of the plant organs is usually obtained by drying the materials for 24 to 48 h at 70 to 80^0C and then weighing it. The measurements of dry weight may give a more valid and meaningful estimation of growth than fresh weight. However, in measuring the growth of dark grown seedling it is desirable to take fresh weight.

C. Length

Measurement of length is a suitable indication of growth for those organs which grow in one direction with almost uniform diameter such as roots and shoots. The length can be measured by a scale. The advantage of measuring length is that it can be done on the same organ over a period of time without destroying it.

D. Area

It is used for measuring growth of plant organs like leaf. The area can be measured by a graph paper or by a suitable mechanical device. Nowadays modern laboratories use a photoelectric device (digital leaf area meter) which reads leaf area directly as the individual leaves is fed into it.

❖ GROWTH ANALYSIS

Growth analysis is a mathematical expression of environmental effects on growth and development of crop plants. This is a useful tool in studying the complex interactions

between the plant growth and the environment. Growth analysis in crop plants was first studied by British Scientists (Blackman 1919, Briggs, Kidd and west 1920, William 1964, Watson 1952 and Blackman, (1968). This analysis depends mainly on primary values (Dry weights) and they can be easily obtained without great demand on modern laboratory equipment.

The basic principle that underlie in growth analysis depends on two values (1) total dry weight of whole plant material per unit area of ground (w) and (2) the total leaf area of the plant per unit area of ground (A).

The total dry weight (w) is usually measured as the dry weight of various plant parts viz, leaves, stems and reproductive structures. The measure of leaf area (A) includes the area of other organs viz, stem petioles, flower bracts, awns and pods that contain chlorophyll and contribute substantially to the overall photosynthesis of the plants

According to the purpose of the data, leaf area and dry weights of component plant parts have to be collected at weekly, fortnightly or monthly intervals. This data are to be used to calculate various indices and characteristics that describe the growth of plants and of their parts grown in different environments and the relationship between assimilatory apparatus and dry matter production. These indices and characteristics are together called as growth parameters. Some of the parameters that are usually calculated in growth analysis are crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), Leaf area ratio (LAR), Leaf weight ratio (LWR). Specific Leaf Area (SLA), Leaf area index (LAI) and Leaf area duration (LAD). Accuracy in calculations of these parameters and their correct interpretation are essential aspect in growth analysis.

Advantages of growth analysis

a) We can study the growth of the population or plant community in a precise way with the availability of raw data on different growth parameters.

b) These studies involve an assessment of the primary production of vegetation in the field i.e. at the ecosystem level (at crop level) of organization.

c) The primary production plays an important role in the energetic of the whole ecosystem.

d) The studies also provide precise information on the nature of the plant and environment interaction in a particular habitat.

e) It provides accurate measurements of whole plant growth performance in an integrated manner at different intervals of time.

Drawbacks of Growth Analysis

In classical growth analysis sampling for primary values consist of harvesting (destructively) representative sets of plants or plots and it is impossible to follow the same plants or plots throughout whole experiment.

❖ Growth Characteristics - Definition and Mathematical Formula

The following data are required to calculate different growth parameters in order to express the instantaneous values and mean values over a time interval. In the following discussion W, WL, WS and WR are used to represent the dry weights of total plant (w), dry leaves (wL), stem (WS) and roots (WR) respectively. Whereas A is the leaf area and P is the land area.

1. Crop Growth Rate (CGR):

D.J. Watson coined the term Crop growth rate. It is defined as the increase of dry matter in grams per unit area per unit time. The mean CGR over an interval of time T_1 and T_2 is usually calculated as show in the following formula

$$CGR = \frac{W_2 - W_1}{P(T_2 - T_1)}$$

Where, CGR is the mean crop growth rate, P= ground area, W_1 and W_2 are the dry weights at two sampling times T_1 and T_2, respectively and it is expressed in $g/m^{-2}/day^{-1}$.

2. Relative Growth Rate (RGR):

The term RGR was coined by Blackman. It is defined as the rate of increase in dry matter per unit of dry matter already present. This is also referred as Efficiency index since the rate of growth is expressed as the rate of interest on the capital. It provides a valuable overall index of plant growth. The mean relative growth rate over a time interval is given below.

$$RGR = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1} \quad (g\ g^{-1}\ day^{-1})$$

Where, Log is natural logarithm, T_1= time one (days), T_2= time two (days), W_1= dry weight of plant at time one (days), W_2= dry weight of plant at time two (days) and it is expressed as g/g/day.

3. Net Assimilation Rate (NAR):

The NAR is a measure of the amount of photosynthetic product going into plant material i.e. it is the estimate of net photosynthetic carbon assimilated by photosynthesis minus the carbon lost by respiration. The NAR can be determined by measuring plant dry weight and leaf area periodically during growth and is commonly reported as grams of dry weight increase per square centimeter of leaf surface per week. This is also called as Unit leaf rate because the assimilatory area includes only the active leaf area in measuring the rate of dry matter production.

The mean NAR over a time interval from T_1 to T_2 is given by

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

Where L_1 and L_2 are total leaf are at time t_1 and t_2 respectively. W_1 and W_2 are total dry wt. time t_1 and t_2 respectively and it is expressed as ($g\ cm^{-2}\ wk^{-1}$).

4. Leaf Area Ratio (LAR)

The LAR is a measure of the proportion of the plant which is engaged in photosynthetic process. It gives the relative size of the assimilatory apparatus. It is also called as capacity factor. It is defined as the ratio between leaf area in square centimeters and total plant dry weight. It represents leafiness character of crop plants on area basis.

$$LAR = \frac{A}{W} \quad (cm^2 g^{-1})$$

Where, A= leaf area in square centimeters, W= total plant dry weight

5. Leaf Weight Ratio (LWR)

It is one of the components of LAR and is defined as the ratio between grams of dry matter in leaves and total dry matter in plants (g). Since the numerator and denominator are on dry weight basis LWR is dimensionless. It is the index of leafiness of the plant on weight basis.

$$LWR = \frac{W_L}{W}$$

Where, WL= Dry matter in leaves, W= Total dry matter in plants

6. Specific Leaf Area (SLA)

It is another component of LAR and defined as the ratio between leaf area in cm2 and total leaf dry weight in grams. This is used as a measure of leaf density. The mean SLA can be calculated as

$$SLA = \frac{A}{W_L}$$

Where, A= leaf area plant^{-1} and WL= leaf weight plant^{-1} and it is expressed as cm^2 g^{-1}.

7. Specific Leaf Weight (SLW)

The reversal of SLA is called as SLW. It is defined as the ratio between total leaf dry weight in gms and leaf area in cm^2. It indicates the relative thickness of the leaf of different genotypes.

$$SLW = \frac{W_L}{A}$$

Where, WL= leaf weight plant^{-1} and A= leaf area plant^{-1} and it is expressed as g cm^{-2}.

8. Leaf area index (LAI):

D.J. Watson coined this term. It is defined as the functional leaf area over unit land area. It represents the leafiness in relation to land area. At an instant time (T) the LAI can be calculated as

LAI = Leaf area / ground area

It is expressed as m^2/m^2

For maximum production of dry matter of most crops, LAI of 4-6 is usually necessary. The leaf area index at which the maximum CGR is recorded is called as 'optimum leaf area index'.

Growth indices in summary

Few key indices are commonly derived as an aid to understanding growth responses. Mathematical and functional definitions of those terms are summarised below.

Growth index	Functional definition
Relative growth rate (RGR)	Rate of mass increase per unit mass present (efficiency of growth with respect to biomass)
Net assimilation rate (NAR)	Rate of mass increase per unit leaf area (efficiency of leaves in generating biomass)
Leaf area ratio (LAR)	Ratio of leaf area to total plant mass (a measure of 'leafiness' or photosynthetic area relative to respiratory mass)
Specific leaf area (SLA)	Ratio of leaf area to leaf mass (a measure of thickness of leaves relative to area)
Leaf weight ratio (LWR)	Ratio of leaf mass to total plant mass (a measure of biomass allocation to leaves)

Development

What is development?

It is an overall term which refers to the various changes that occur in a plant during its life cycle.

Plants produce new tissues and structures throughout their life from **meristems** located at the tips of organs, or between mature tissues.

INITIATION AND DEVELOPMENT OF VEGETATIVE STRUCTURES

1. Root growth: Radicle is the embryonic root. During the seed germination and seedling formation, it grows to form primary root of the seedlings.
2. Stem growth: The life of stem starts as a plumule. It grows to form the shoot of the seedling. The longitudinal growth of stem and formation of various organs like branches, leaves, flowers is the function of stem meristem.
3. Leaf initiation and Growth: Elevations appear on the periphery of the meristem in a regular pattern. Leaf primordia appear as dome shaped on the periphery of the stem.

INITATION AND DEVELOPMENT OF REPRODUCTIVE STRUSCTURES

1. Initiation and Development of Flower:

Once the biochemical requirements for evocation of flowering are completed and the meristem has reached the point of no return, it develops either into an inflorescence (a cluster of flowers) or solitary flowers. In most plants, the pattern of flower initiation and development is almost similar.

2. Fruit and Seed Development:

The first stage in fruit and seed development is rapid cell division without much enlargement due to cytokinin production by the endosperm which is growing at this stage. Various tissues of the parent plant *viz*, the ovary, receptacle and sometimes parts of the floral tube may be involved in the formation of fruits.

Developmental Stages

1. Germination and Emergence
2. Seedling Growth
3. Maximum Vegetative Growth Stage
4. Primordial Differentiation
5. Flowering Stage
6. Fruit Growth
7. Fruit Maturity
8. Physiological Maturity
9. Harvest Maturity

Difference between growth and development

Sr.No.	Growth	Development
1.	Growth is quantitative.	Development is quantitative as well as qualitative.
2.	Growth is for limited period.	Development takes place till death.

Factors affecting Growth and Development

1. Germination

- Temperature
- Soil Moisture
- Depth of Sowing

2. Seedling Growth

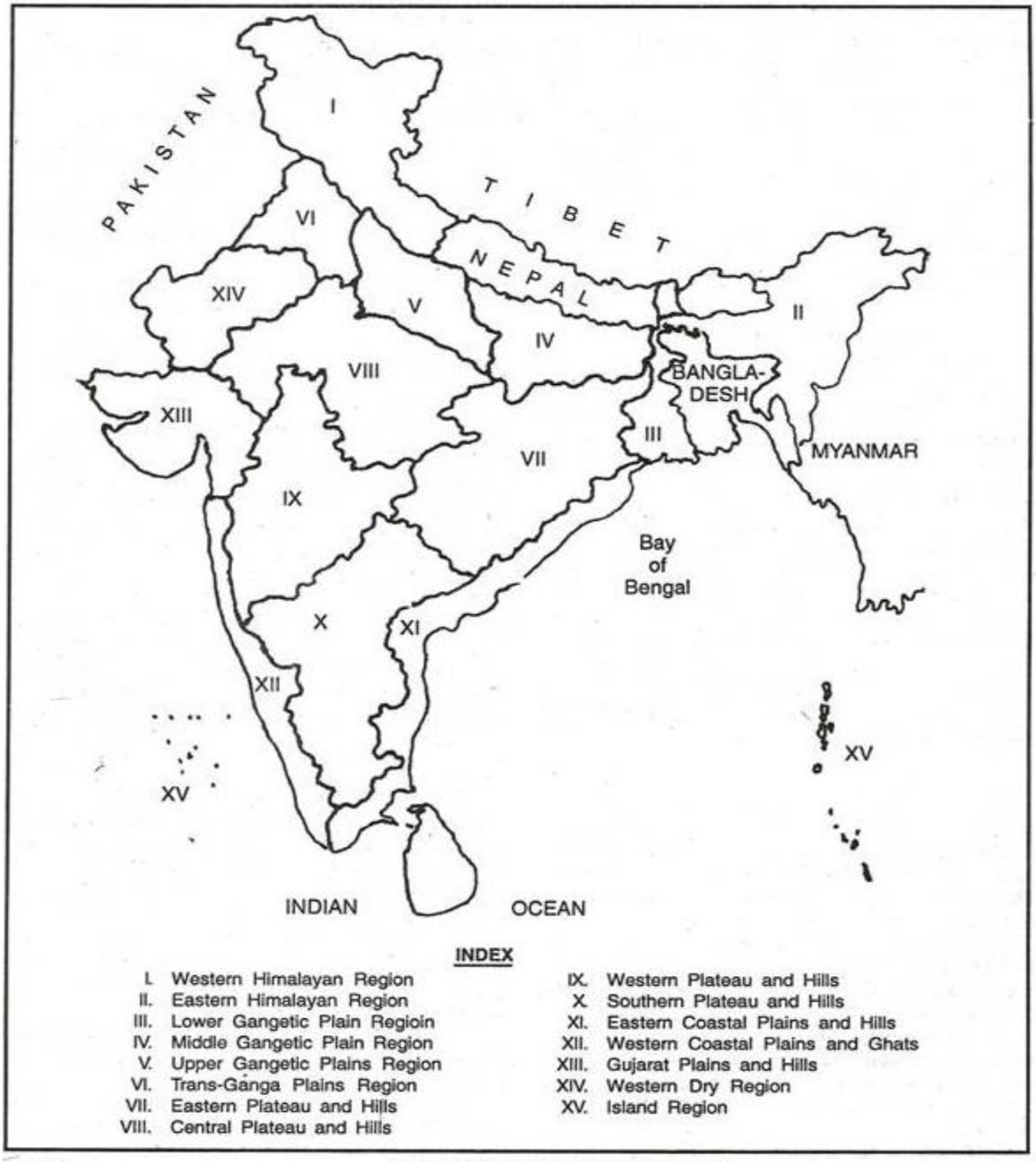
3. Leaf Growth

4. Tillering and Branching

Topic 8: Agro-climatic zones of India and Gujarat

❖ Agro-climatic zones of India

The Planning Commission has categorized 15 agro-climatic zones in India, taking into account the physical attributes and socio-economic conditions prevailing in the regions.



Map showing Agro-Climatic Regions.

I. Western Himalayan Region:

The Western Himalayan Region covers Jammu and Kashmir, Himachal Pradesh and the hill region of Uttarakhand.

Average temperature in July ranges between 5°C and 30 °C, while in January it ranges between 5 °C and -5 °C. Mean annual rainfall varies between 75 cm to 150 cm.

The valley floors grow rice, while the hilly tracts grow maize in the kharif season. Winter crops are barley, oats, and wheat. The region supports horticulture, especially apple orchards and other temperate fruits such as peaches, apricot, pears, cherry, almond, litchis, walnut, etc. Saffron is grown in this region.

II. Eastern Himalayan Region:

The Eastern Himalayan Region includes Arunachal Pradesh, the hills of Assam, Sikkim, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, and the Darjeeling district of West Bengal.

Temperature variation is between 25 °C and 30 °C in July and between 10 °C and 20 °C in January. Average rainfall is between 200-400 cm. The red-brown soil is not highly productive. Jhuming (shifting cultivation) prevails in the hilly areas.

The main crops are rice, maize, potato, tea. There are orchards of pineapple, litchi, oranges and lime.

III. Lower Gangetic Plain Region:

West Bengal (except the hilly areas), eastern Bihar and the Brahmaputra valley lie in this region.

Average annual rainfall lies between 100 cm-200 cm. Temperature in July varies from 26 °C to 41 °C and for January from 9 °C to 24 °C. The region has adequate storage of ground water with high water table.

Rice is the main crop which at times yields three successive crops (Aman, Aus and Boro) in a year. Jute, maize, potato, and pulses are other important crops.

IV. Middle Gangetic Plain Region:

The Middle Gangetic Plain region includes large parts of Uttar Pradesh and Bihar.

The average temperature in July varies from 26 °C to 41 °C and that of January 9 °C to 24 °C average annual rainfall is between 100 cm and 200 cm. It is a fertile alluvial plain drained by the Ganga and its tributaries. Rice, maize, millets in kharif, wheat, gram, barley, peas, mustard and potato in rabi are important crops.

V. Upper Gangetic Plains Region:

In the Upper Gangetic Plains region come the central and western parts of Uttar Pradesh and the Hardwar and Udham Nagar districts of Uttarakhand.

The climate is sub-humid continental with temperature in July between 26 °C to 41 °C and temperature in January between 7 °C to 23 °C. Average annual rainfall is between 75 cm-150 cm. The soil is sandy loam. Canal, tube-well and wells are the main source of irrigation. This is an intensive agricultural region wherein wheat, rice, sugarcane, millets, maize, gram, barley, oilseeds, pulses and cotton are the main crops.

VI. Trans-Ganga Plains Region:

This region (also called the Satluj-Yamuna Plains) extends over Punjab, Haryana, Chandigarh, Delhi and the Ganganagar district of Rajasthan.

Semi- arid characteristics prevail over the region, with July's mean monthly temperature between 25 °C and 40 °C and that of January between 10 °C and 20 °C. The average annual rainfall varies between 65 cm and 125 cm. The soil is alluvial which is highly productive. Canals and tube-wells and pumping sets have been installed by the cultivators and the governments. The intensity of agriculture is the highest in the country.

Important crops include wheat, sugarcane, cotton, rice, gram, maize, millets, pulses and oilseeds etc. The region is also facing the menace of water logging, salinity, alkalinity, soil erosion and falling water table.

VII. Eastern Plateau and Hills:

This region includes the Chhotanagpur Plateau, extending over Jharkhand, Orissa, Chhattisgarh and Dandakaranya.

The region enjoys 26 °C to 34 °C of temperature in July, 10 °C to 27 °C in January and 80 cm-150 cm of annual rainfall. Soils are red and yellow with occasional patches of laterites and alluviums. The region is deficient in water resources due to plateau structure and non-perennial streams. Rainfed agriculture is practiced growing crops like rice, millets, maize, oilseeds, ragi, gram and potato.

VIII. Central Plateau and Hills:

The region is spread over Bundelkhand, Baghelkhand, Bhander Plateau, Malwa Plateau, and Vindhyachal Hills.

Semi-arid climatic conditions prevail over the region with temperature in July 26 °C to 40 °C, in January 7 °C to 24 °C and average annual rainfall from 50 cm-100 cm. Soils are mixed red, yellow and black.

There is scarcity of water. Crops grown are millets, wheat, gram, oilseeds, cotton and sunflower.

IX. Western Plateau and Hills:

Comprising southern part of Malwa plateau and Deccan plateau (Maharashtra), this is a region of the regur (black) soil with July temperature between 24 °C and 41 °C, January temperature between 6 °C and 23 °C and average annual rainfall of 25 cm-75 cm.

Wheat, gram, millets, cotton, pulses, groundnut, and oilseeds are the main crops in the rain-fed areas, while in the irrigated areas, sugarcane, rice, and wheat, are cultivated. Also grown are oranges, grapes and bananas.

X. Southern Plateau and Hills:

This region falls in interior Deccan and includes parts of southern Maharashtra, the greater parts of Karnataka, Andhra Pradesh, and Tamil Nadu uplands from Adilabad District in the north to Madurai District in the south.

The mean monthly temperature of July varies between 25 °C and 40 °C, and the mean January temperature is between 10 °C and 20 °C. Annual rainfall is between 50 cm and 100 cm.

It is an area of dry-zone agriculture where millets, oilseeds, and pulses are grown. Coffee, tea, cardamom and spices are grown along the hilly slopes of Karnataka plateau.

XI. Eastern Coastal Plains and Hills:

In this region are the Coromandal and northern Circar coasts of Andhra Pradesh and Orissa.

The mean July temperature ranges between 25 °C and 35 °C and the mean January temperature varies between 20 °C and 30 °C. The mean annual rainfall varies between 75 cm and 150 cm.

The soils are alluvial, loam and clay and are troubled by the problem of alkalinity. Main crops include rice, jute, tobacco, sugarcane, maize, millets, groundnut and oilseeds.

XII. Western Coastal Plains and Ghats:

Extending over the Malabar and Konkan coastal plains and the Sahyadris, the region is humid with the mean July temperature varying between 25 °C and 30 °C and mean January temperatures between 18 °C and 30 °C. The mean annual rainfall is more than 200 cm.

The soils are laterite and coastal alluvial. Rice, coconut, oilseeds, sugarcane, millets, pulses and cotton are the main crops. The region is also famous for plantation crops and spices which are raised along the hill slopes of the Western Ghats.

XIII. Gujarat Plains and Hills:

This region includes the hills and plains of Kathiawar and the fertile valleys of Mahi and Sabarmati rivers. It is an arid and semi-arid region with the mean July temperature reading 30 °C and that of January about 25 °C. The mean annual rainfall varies between 50 cm and 100 cm.

Soils are regur (black) in the plateau region, alluvium in the coastal plains and red and yellow soils in Jamnagar area. Groundnut, cotton, rice, millets, oilseeds, wheat and tobacco are the main crops. It is an important oilseed producing region.

XIV. Western Dry Region:

Extending over Rajasthan, West of the Aravallis, this region has an erratic rainfall of an annual average of less than 25 cm. The desert climate further causes high

evaporation and contrasting temperatures 28 °C to 45 °C in June and 5 °C to 22 °C in January. Bajra, jowar and moth are main crops of kharif and wheat and gram in rabi. Livestock contributes greatly in desert ecology.

XV. Island Region:

The island region includes Andaman-Nicobar and Lakshadweep which have typically equatorial climate (annual rainfall less than 300 cm; the mean July and January temperature of Port Blair being 30 °C and 25 °C respectively). The soils vary from sandy along the coast to clayey loam in valleys and lower slopes.

The main crops are rice, maize, millets, pulses, arecanut, turmeric and cassava. Nearly half of the cropped area is under coconut.

❖ Agro-climatic zones of Gujarat

Taking into consideration the rainfall pattern, topography, soil characteristics, the climate in general and the cropping patterns, eight (8) agro-climatic zones have been identified in Gujarat.

Agro Climatic Zone of Gujarat State			
Zone -I	South Gujarat Heavy Rainfall Zone	**Zone -V**	North-west Zone
Zone -II	South Gujarat Zone	**Zone -VI**	North Saurashtra Zone
Zone -III	Middle Gujarat Zone	**Zone -VII**	South Saurashtra Zone
Zone -IV	North Gujarat Zone	**Zone -VIII**	Bhal and Coastal Zone

Salient – geographical and agro-climatic features of 8 zones of Gujarat state

Zone No.	Name of the zone	Geographical area included in the zone	Mean annual rainfall (mm)	Broad soil group	Major crops of the zone

I	South Gujarat (Heavy rain fall)	Whole of Dangs district, Part of Valsad district (excluding Navsari and Gandevi), Part of Surat district (Including Valod, Songadh and Mahuva).	1500 – 2200	typical lateritic, Deep black with few coastal alluvial, Medium black.	Nagli, Vari, Sugarcane, Paddy, Sorghum, Vegetables & Fruit crops.
II	South Gujarat	Area between river Ambica & Narmada, Part of Valsad district (Navsari & Gandevi), Part of Surat district (Kamrej, Chhoriashi, Nizer, Palsana, Bardoli, Mangrol and Mandvi)	1000-1500	Heavy black Clayey soils	Cotton, Sorghum, Paddy, Wheat, Sugarcane, Vegetables & Fruit crops.
III	Middle Gujarat	Area between Narmada and Vishwamitri river including Whole of Panchmahals district, Part of Vadodra district (Karjan, Sinor, Dabhoi, Sankheda, Naswadi and Jabugam) Part of Bharuch district (Bharuch, Amod, and Jambusar) Part of Kheda district (Khambhat and Matar)	800 - 1000	Medium black to Goradu soils	Cotton, Pearlmillet, Tobacco, Pulses, Wheat, Paddy, Maize & Sorghum
IV	North Gujarat (Dry zone)	Whole of Kheda district (except Khambhat and Matar), Whole of Sabarkantha district, Part of Ahmedabad district (Dehgam, Daskroi and Sanand), Gandhinagar district, Part of Banaskantha district (Deesa, Dhanera, Palanpur, Danta and Vadgam), Whole of Mehsana district except (Sami and Harij), Part of Vadodra district (Baroda, Savli, Waghodia and Padra)	625 – 875	Sandy loam to Sandy soils	Pearlmillet, Cotton, Wheat, Pulses, Sorghum, Mustard, Groundnut, Potato, Spices & Condiments crops.
V	North-Weast Gujarat (Arid zone)	Whole of Kutch district, Maliya of Rajkot, Halvad, Dhangadhra & Dasada of Surendranagar, Sami, Harij & Chansama of Mehsana, Santalpur, Radhanpur, Kankrej, Diodar, Vav & Tharad of Banaskantha and Viramgam of Ahmedabad districts.	250 - 500	Sandy and Saline soils	Cotton, Sorghum, Pearlmillet, Wheat, Groundnut & Pulses crops

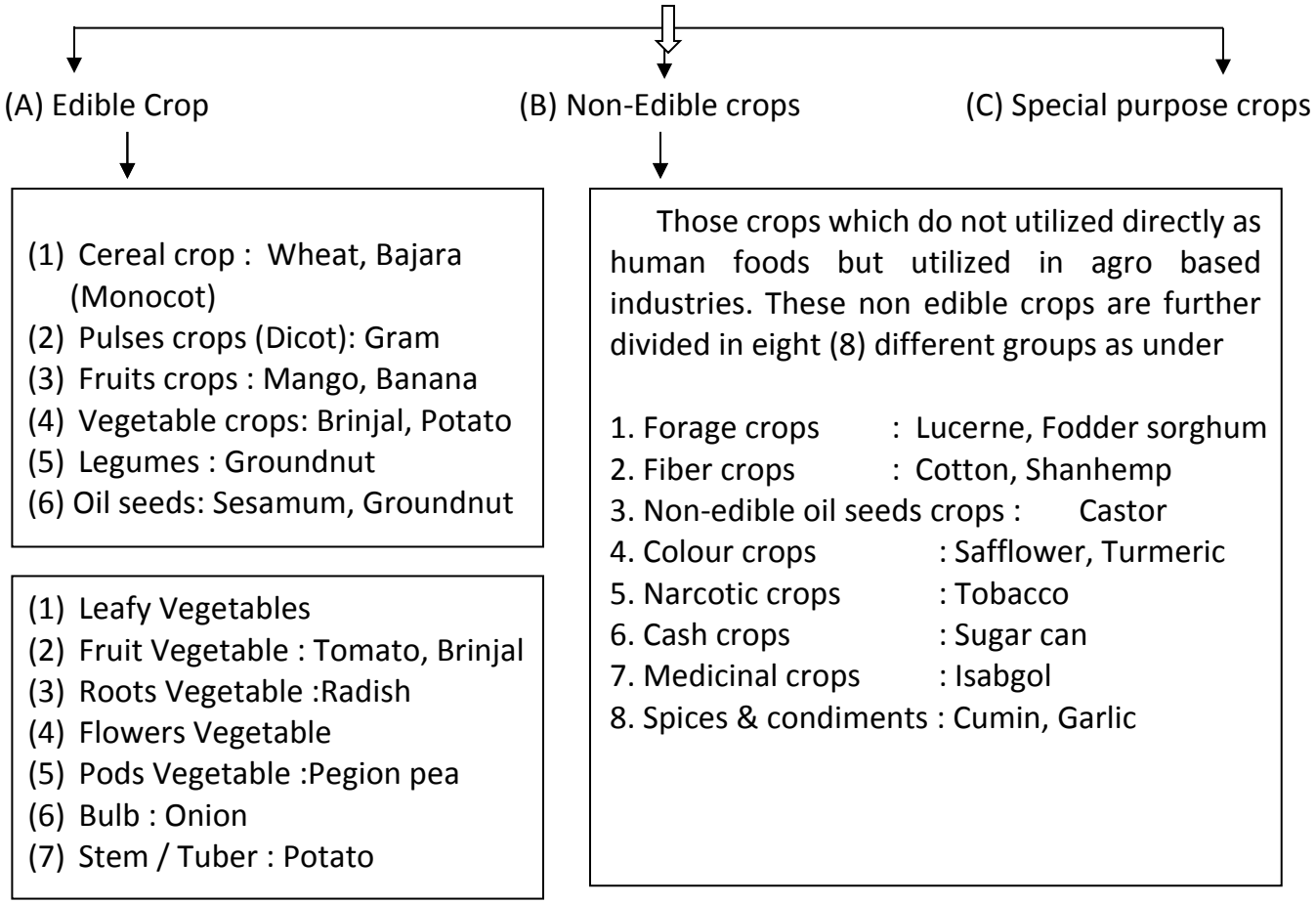
VI	North Saurashtra	Whole of Jamnagar district, Part of Rajkot (Paddhari, Lodhika, Jasdan, Rajkot, Vankaner & Morvi), Part of Surendranagar (Vadhwan, Muli & Sayla), Part of Bhavnagar (Gadhda, Umrala & Botad)	400 - 700	shallow and Medium black to Sandy soils	Groundnut, Cotton, Wheat, Pearlmillet, Pulses crops.
VII	South Saurashtra	Whole of Junagadh, Part of Bhavnagar (Shihor, Ghogha, Gariadhar, Palitana, Talaja, Mahuva & Savarkundla), Part of Amreli (Dhari, Kodinar, Rajula, Jafrabad, Khambada, Amreli, Babra, Liliya Lathi &Kunkawav), Part of Rajkot (Jetpur, Gondal, Dhoraji & Upleta)	625 – 750 few pockets with 1000 mm around Junagadh	Medium black, Shallow soils with few pockets of Calcareous soils.	Groundnut, Cotton, Wheat, Pearlmillet, Sorghum, Pulses, Sugarcane & fruit crops.
VIII	The Bhal region	Area around Gulf of Cambay and Bhal tract & coastal area of Bharuch and Surat districts. Olpad of Surat, Hansot and Wagra of Bharuch, Cambay of Kheda, Dholka & Dhandhuka of Ahmedabad, Vallbhipur & Bhavnagar of Bhavnagar district and Limbdi of Surendranagar district.	625 - 700	Medium black, Poorly drain & Saline soils.	Paddy, Pearlmillet, Pulses, Cotton, Wheat, Groundnut, Tobacco, Sorghum, Vegetables & Oil seed crops.

Topic 9: Classification of field crops and factors affecting on crop production

Classification of field crops

Detailed classification of crops

1. Classification according to Agronomical or economic: This type of classification is done on the base of use of agriculture products there are another three class in this group.



(C) Special purpose crops: Some time edible or non-edible crops which are not grown for the common uses, but they are grown for the certain /special purposes

1. Row crops : Cotton, Pigeon pea, Pearl millet
2. Cover crops : Ground nut, Lucerne, Kidney bean
3. Mixed crops : Pigeon pea – Maize, Pigeon pea – Castor
4. Nurse crops : Shan hemp, Pulse crop

5. Pasture crops : This type of groups grown where former crops are not taken as to prevent soil erosion Guinea grass

6. Silage crops : Sorghum, Maize

7. Green manure crops: These types of crops are buried in the soil at flowering stage. Organic matter is added in soil to improve **physical and chemical** properties of the soil.

8. Support crops : To provide the support to main crops

9. Truck crops : Production of this type of crops is highest and transported trough truck, e.g. Potato, Onion, sugar can

10. Wind breaking crops: To protect to crops against high wind velocity to avoid the logging to the crop e.g. Sugar cane, Banana, Castor, Shevri

11. Companion crops: Mustard – Rap seed Cabbage flower

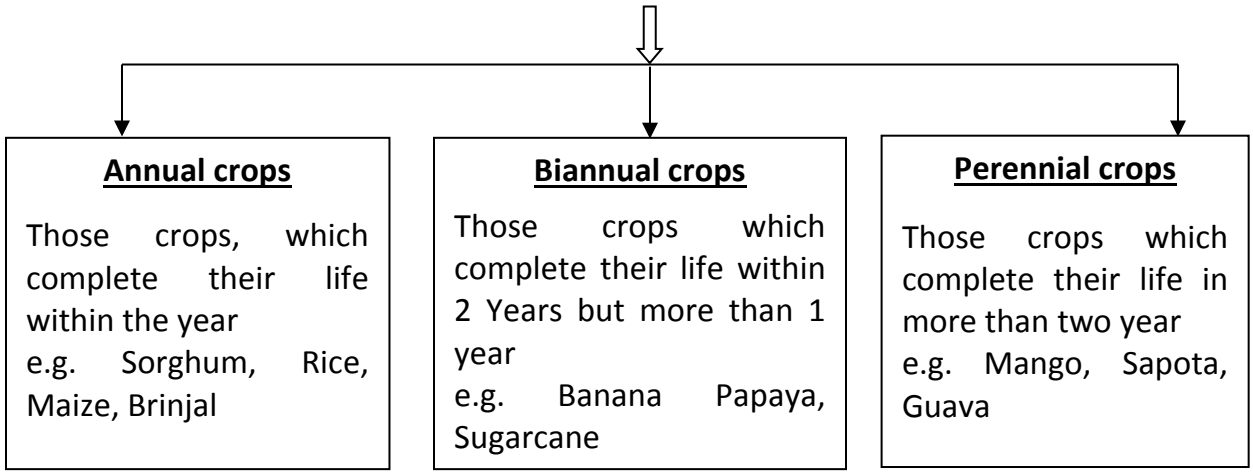
12. Trap crop: To control several pests of main crops same selected plants which were grown on bunds of the main crops. e.g. Lady's finger around the cotton Marigold around the tomato, castor around the tobacco nursery

13. Cash crops: Cotton, Tobacco, Sugar cane

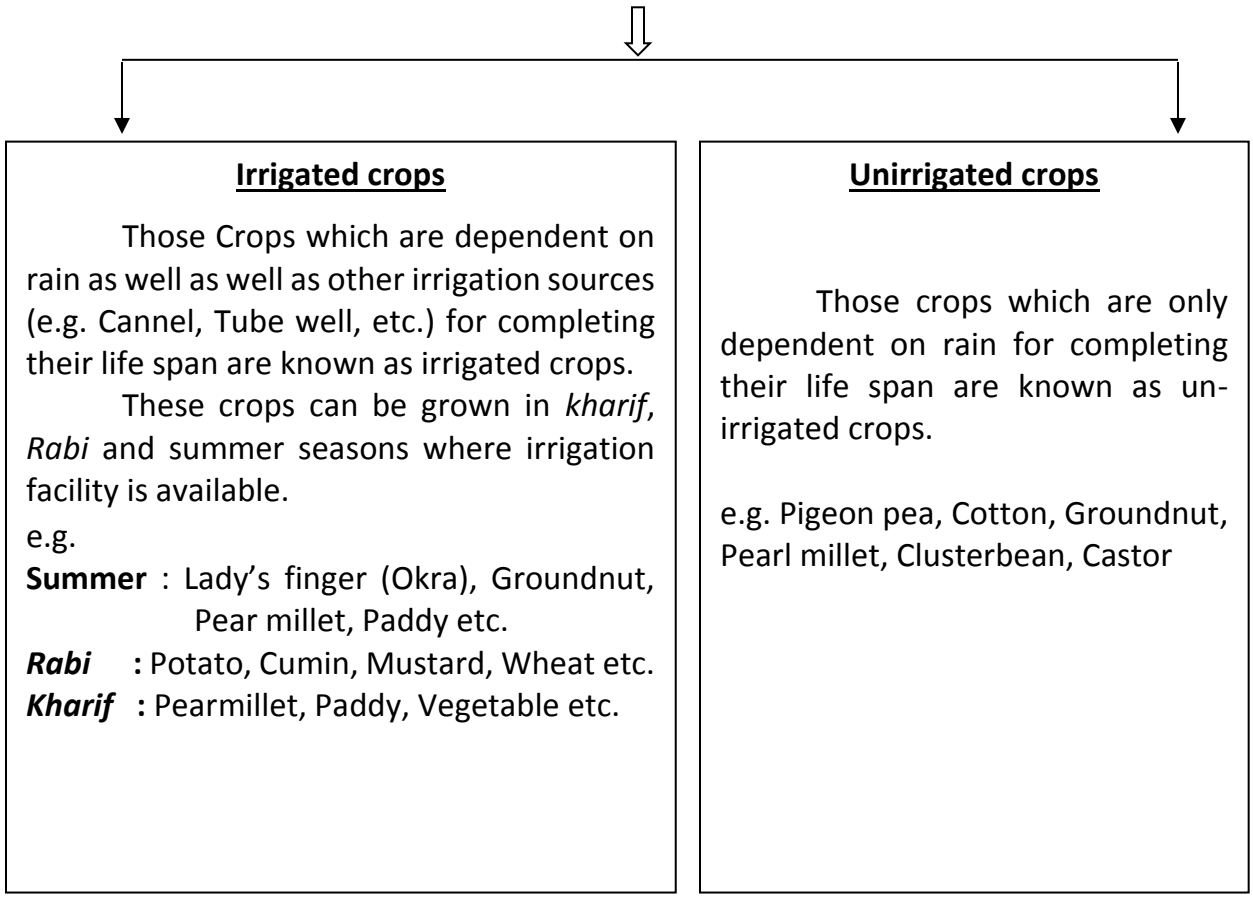
14. Catch crops: Semi rabi Sesamum, Sorghum, Castor

2. Classification according to season

A) Monsoon/*Kharif* crops	**B) Winter/*Rabi* crops**	**C) Summer crops**
- The crop which requires hot and humid weather for their better growth and production are raised in monsoon season. **Sowing time:** June to September e.g. Pear millet, Sesamum, Sorghum, Groundnut, Maize, Cotton, Paddy etc.	- The crop which requires cold and dry weather for their better growth and production are raised in winter season. **Sowing time:** October to January e.g. Wheat, Barley, Gram, Safflower, Cumin, etc.	**-** The crop which requires hot weather for their better growth and production are raised in summer season. **Sowing time:** February to May e.g. Summer bajra, Summer groundnut, Watermelon, Fodder sorghum etc.



4. Classification according to Water requirement

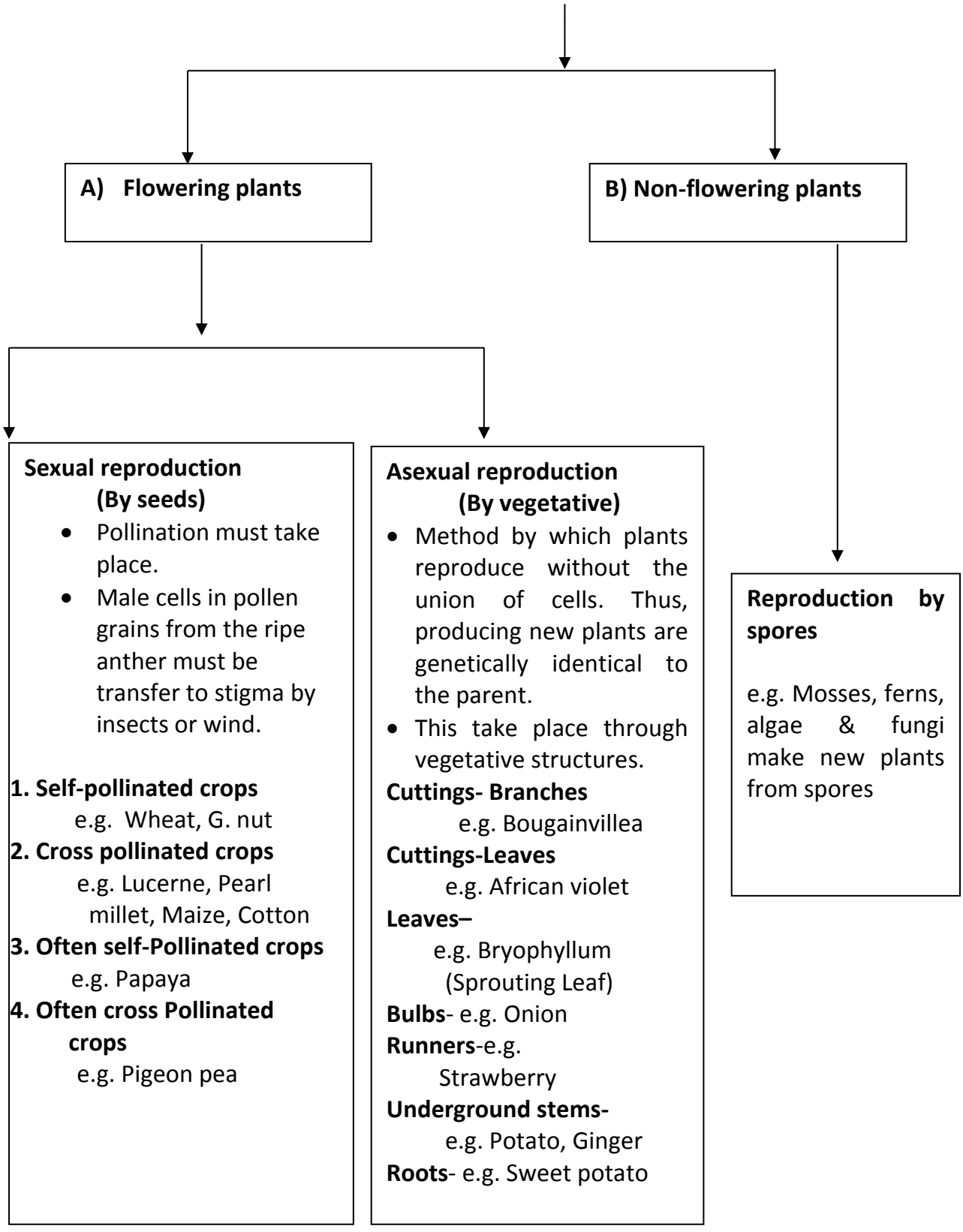


5. Classification according to No. of cotyledons

⇩

	Monocotyledon	Di-cotyledons
1.	Embryos have a single seed leaf, referred to as a cotyledon - hence the name mono (one) Cotyledon.	Embryos have two seed leaves, referred to as cotyledons- hence the name di (two) cotyledon.
2.	Leaves have parallel veins and are long and narrow	Leaves have network of veins and are broad.
3.	Flowers have petals and floral parts in multiples of three	Flowers have petals and floral parts in multiples of four or five
4.	In the stem, vascular bundles are scattered	In the stem, the vascular tissue is arranged circularly
5.	A pollen grain with one opening	A pollen grain with three openings
6.	Root system is generally fibrous , shallow	Root system is generally branched and taproot.
7.	It contains carbohydrates.	It contains proteins.
8.	When seed is broken, it does not break in certain shape.	When seed is broken, it breaks in certain shape (being split).
8.	**Two important monocotyledon families are:** **1. Gramineae** : e.g millet, corn, wheat, barley, rye, rice, oats, and other cereal grains. **2. Liliaceae :** e.g. lilies, onions, tulips, and garlic.	**Di-cotyledon plants include six important families :** 1. **Fabaceae :** e.g. beans, peas, peanuts, vetches, alfalfa, clovers, soybeans. 2. **Solanaceae :** e.g. white potatoes, tobacco, peppers, eggplants, and ground cherries. 3. **Brassicaceae :** e.g. turnips, cabbage, cauliflower, brussels , radishes, watercress, and mustard. 4. **Convolvulaceae :** e.g. morning glories, sweet potatoes, and dodder. 5. **Malvaceae:** e.g. cotton and okra. 6. **Rosaceae:** e.g. ornamental roses, peaches, almonds, apricots, pears,

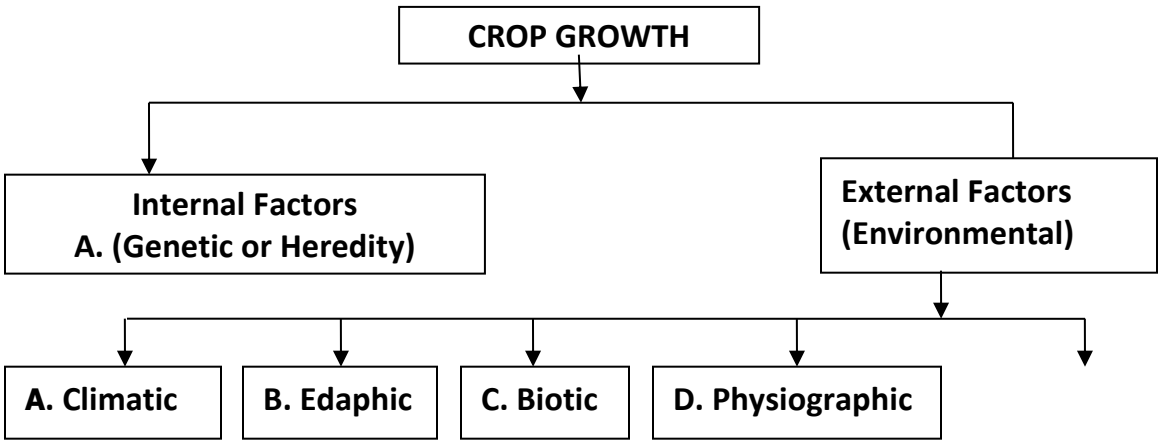
6. Classification of field crops according to reproduction



7. Classification according cultural practices

1. **Sole Cropping** : Only one crop grown in a year. Eg. Cotton, Groundnut, Rice
2. **Mono Cropping** : Same crop is grown year after year on same field
3. **Inter cropping** : Growing of two or more crops simultaneously, on the same piece of land, base crop necessarily in distinct row arrangement. Eg.Pigeon pea +sorghum, Cotton + Black gram
4. **Mixed cropping** : Cultivation of two or more crops simultaneously, on the same piece of land without definite row pattern or fixed ratio. Eg. Perl millet + Kidney bean, Cotton + Maize
5. **Irrigated crops** : Crops grows with the help of irrigation water. Eg. Sugar cane, Paddy
6. **Dry land crops** : It include non-irrigated cultivation of crops. Eg. Pearl millet, Groundnut, Sesame
7. **Row crop** : Growing of crops in rows. Eg. Groundnut, Cotton, Pearl millet
8. **Relay crop** : A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest. Eg. Groundnut – Pigeon pea
9. **Root crop** : Roots are the economic produce in root crop. Eg. Radish, Carrot
10. **Mixed Farming** : It refers any agriculture enterprenures (Dairy, Forestry, Live stock, Fisheries, bee keeping, floriculture, olericulture, mushroom cultivation, piggery, vermicompost etc besides a field crop cultivation)

Factors affecting on crop production



1. Internal factors

A. Genetic or Heredity factors

The increase in crop yields and other desirable characters are related to Genetic make up of plants

(1) High yielding ability
(2) Early maturity
(3) Resistance to lodging
(4) Drought flood and salinity tolerance
(5) Tolerance to insect pests and diseases
(6) Chemical composition of grains (oil content, protein content)
(7) Quality of grains (fineness, coarseness)
(8) Quality of straw (sweetness, juiciness)

2. External factors

A. Climatic factors

The major climatic or atmospheric factors are

(1) Precipitation (2) Temperature (3) Atmospheric humidity
(4) Solar radiation (5) Wind velocity (6) Atmospheric gases

1. Precipitation

- Precipitation includes all water which falls from atmosphere such as rainfall, snow, hail, fog and dew.
- **Dew:** condensation of water vapour present in the air in cool nights results in dew.
- Rainfall one of the most important factor influences the vegetation of a place.

- Most crops receive water supply from rainwater.
- Total precipitation in amount and distribution greatly affects the choice of a cultivated species in a place.
- In heavy and evenly distributed rainfall areas, crops like rice in plains and tea, coffee and rubber in Western Ghats.
- Low and uneven distribution of rainfall is common in dryland farming where drought resistance crops like bajra, sorghum and minor millets are grown.
- Distribution of rainfall is more important than total rainfall to have longer growing period especially in dry lands.

2. Temperature

Temperature is a measure of intensity of heat energy. The minimum, optimum and maximum temperature requirement of individual's plant is called as **cardinal temperature**.

The temperature of a place is largely determined by it's distance from the **equator** (latitude), **altitude**. Based on the above the vegetations are classified as **tropical**, **temperate**, **taiga, tundra** and **polar**. For each species there are **upper** (maximum) and **lower** (minimum) limits of temperature at which growth is nil or negligible and **optimum** temperature at which growth is maximum. Most of the crop plants grow best at 15 to 30^0C. Many crop plants die at a very high temperature of 45 to 55^0C. There are also optimal temperatures for different growth stages. Based on temperature the crops are classified as **Cool season (Winter/ *rabi*)** and **Warm season (Hot/ Summer) crops.**

Cool Season Crops:

The crops which grow best in cool weather period are called cool season crops and generally grown in **winter season** (November to February). The important cool season crops are wheat, barley, potato, oats etc. These crops are also called **temperate crops** because they are mostly grown in temperate regions.

Warm Season Crops:

The important warm season crops are rice, sorghum, maize, sugarcane, pearl millet, groundnut, red gram, cowpea etc. These crops are also called **tropical crops**. These crops are generally grown in **monsoon season** and some time also in **summer season**.

Effect of high and low temperature on growth of plants

High temperature stress:

- ✓ High temperature causes reduction in absorption and assimilation of nutrients.
- ✓ Nutrient uptake is reduced e.g. Absorption of calcium is reduced at 28^0C in maize.
- ✓ High temperature even for short period affects shoot growth in temperate crops like wheat.
- ✓ High temperature results in abortion of pollen. In wheat high temperature results in under development of anther and loss of viability of pollen.

Low temp stress: affects crop growth in several ways

- ✓ Survival, cell division and elongation, photosynthesis, water transport, vegetative growth and reproductive growth are adversely affected.
- ✓ At Low temperature, the entry of water into the plant is restricted due to low permeability of cells.
- ✓ Temperate crops like wheat prefer low temperature during vegetative growth and high temperature at maturity.
- ✓ Tropical crops like rice prefer high temperature during early stage and low temperature at maturity.

3. Atmospheric humidity

Water is present in the atmosphere in the form of invisible water vapour, normally known as humidity.

Relative humidity is ratio between the amounts of moisture present in the air to the saturation capacity of the air at a particular temperature. If relative humidity is 100% it means that the entire space is filled with water. There is no evaporation. Very low and very high relative humidity is not suitable for crop production. Relative humidity of **40 – 60%** is suitable for most of the crop plants. Very few crops can perform well when relative humidity is 80% and above, when relative humidity is high there is chance for the infestation of pest and disease, e.g., **brown plant hopper (BPH) in rice multiplies enormously.**

4. Solar radiation

Solar energy provides light energy required for **photosynthesis** and many other functions like **seed germination, leaf expansion, growth of stem and shoot, flowering, fruiting and thermal conditions** for physiological functions of the plant.

- ✓ Light is indispensable for the synthesis of the most important pigment of the plant – called **chlorophyll**
- ✓ The chlorophyll is capable of absorbing radiant energy and converting it into potential chemical energy of carbohydrates.
- ✓ It regulates the opening and closing of stomata.
- ✓ Light affects the plants through it's intensity, quality and duration.

Duration of light

- ✓ It is important from farmer's point of view in selecting the variety of the crop.
- ✓ The **length of day** has greater influence than **light intensity**.

Photoperiodism : The response of plants to the relative length of day and night is known as **photoperiodism.**

Long day plants : Plants which develop and produce normally when photoperiod is greater than a critical minimum **(>12 hours of illumination)** are called **long day plants**. e.g. **Wheat , barley, Sugarbeet.**

Short day plants : Plants require less than **10 hours illumination** are called **short day plants**. e.g**. rice, sorghum, maize.**

Day neutral plants: Such plants are found to be unaffected by day length. e.g. **tomato, asparagus**. i.e. plants do not require either long or short dark periods e.g. **cotton, sunflower.**

- ✓ If a long day plant is subjected to short day length, the stem will shorten and look like rosette appearance.

5. Wind velocity

The basic function of wind is to carry moisture and heat. The moving wind not only supplies moisture and heat, also supplies fresh CO_2 for the photosynthesis. Mild wind is essential for cropped. Wind movement for 4 – 6 km/hour is suitable for more crops. When wind speed is enormous then there is **mechanical damage of the crops (i.e.) it removes leaves and twigs.**

Evapotranspiration (ET) also increases with increase in wind speed. When speed of the wind is high moisture loss is more and hence **frequent irrigation is needed.** When

wind movement is static then the availability of CO_2 is less and flow of nutrients is also less. **Soil erosion** is also caused due to high wind velocity.

- ❖ Wind affects crop growth **mechanically and physiologically**

Mechanical damage due to high winds:

- ❖ Lodging of crop and trees due to violent winds.
- ❖ In bare soil, wind cause severe soil erosion.

Physiological effects:

- ❖ Higher wind speed leads to more evapotranspiration loss.
- ❖ Hot dry winds cause much damage at flowering time.
- ❖ Internal water balance of plants is affected.

Beneficial effects of winds

- ❖ Wind is also responsible for rainfall. In India monsoon type of winds are mainly due to wind movements.
- ❖ Wind helps in pollination of flowers.
- ❖ Hot dry winds reduce the incidence of yellow rust of wheat.
- ❖ Moderate wind has a beneficial effect on photosynthesis.

6. Atmospheric gases and plant growth

Atmosphere contains Carbon dioxide (0.03%), Oxygen (20.95%), Nitrogen (78.09%), Argon (0.93%) and others (0.02%).

- ✓ **CO_2** is important for Photosynthesis, CO_2 taken by the plants by diffusion process from leaves through stomata.
- ✓ **CO_2** is returned to atmosphere during decomposition of organic materials, all farm wastes.
- ✓ **O_2** is important for respiration of both plants and animals. During Photosynthesis oxygen is released by plants.
- ✓ **Nitrogen** is one of the important major plant nutrients; Atmospheric N is fixed in the soil by N fixing microbes in pulses crops and available to plants.
- ✓ Certain gases like SO_2, CO, CH_4, HF released to atmosphere are toxic to plants.

B. Edaphic Factors:

Plants grown in land completely depend on soil on which they grow. The soil factors that affect crop growth are

1. Soil moisture : The quantity of water contained in a soil is called soil moisture.

2. Soil air : The air and other gases in spaces in the soil; specifically, that which is found within the zone of aeration. It is also known as soil atmosphere.

3. Soil temperature : The temperature measured at a given soil depth, typically at 2, 4, 8, and sometimes 20 and 40 cm. Many biological processes, including seed germination, plant emergence, microbial activity, and soil respiration are a function of soil temperature.

4. Soil mineral matter : Any soil consisting primarily of mineral (sand, silt and clay) material, rather than organic matter.

5. Soil organic matter : Soil organic matter is carbon-containing material in the soil that derives from living organisms.

6. Soil organisms : They are creatures that spend all or part of their lives in the soil.

1. Flora – macro flora - roots of higher plants
   -- micro flora - Algae, bacteria, fungi and actinomycetes
2. Fauna - Macro fauna- Earthworms, Burrowing vertabrates (moles, rats)
   - Micro fauna - Protozoa, Nematodes, Mites, insects

These microflora like ***Azospirillum, Azotobacter, Rhizobium*** (bacteria group) **fix atmospheric nitrogen** in the soil and is available to crop plants.

Blue green algae - fix atmospheric Nitrogen in rice field.

Phosphobacteria – released the **soil fixed Phosphorus** to the plants

7. Soil reaction (pH)

pH is defined as the negative logarithm of H^+ ion concentration in the soil solution.

Soil Reaction

Soil pH or soil reaction is an indication of the acidity or alkalinity of soil and is measured in pH units. The pH scale goes from 0 to 14 with pH 7 as the neutral point.

When hydrogen ions increase in the soil, the soil pH decreases and becomes more acidic. From pH 7 to 0 the soil is increasingly more acidic and from pH 7 to 14 the soil is increasingly more alkaline or basic.

Most of the plant nutrients are available freely to the plant **when the pH is around seven**. When pH > 7 very few elements like **Fe, Al, Mn are available freely**.

C. Biotic factors:

Beneficial and harmful effects caused by other plants and animals on the crop plants.

1. Plants

1. Competition between plants occurs when there is demand for nutrients, moisture and sunlight particularly when they are in short supply or when plants are closely spaced.
2. Synergistic effect
3. Competition between weed and crop.
4. Plants as parasites
5. Symbiosis relationship with each other.

2. Animals

Soil fauna like protozoa, nematode, snails, and insects help in organic matter decomposition, while using organic matter for their living.

3. Harmful organisms

Insects and nematodes cause considerable damage to crop yield.

4. Beneficial organisms

1. Honey bees and wasps help in cross pollination and increases yield.

2. Beetle pollination is necessary in oil palm.

3. Burrowing earthworm facilitate aeration and drainage of the soil. Ingestion of organic and mineral matter results in constant mixing of these materials in the soils.

4. Large animals cause damage to crop plants by grazing (cattle, goats etc)

D. Physiographic factors:

Topography: It refer the nature of surface earth (levelled or slopy) is known as topography. Topographic factors affect the crop growth indirectly.

(1) Altitude (2) Steepness of slope (3) Exposure to light and wind:

E. Socio-economic factors:

The economic condition of the farmers greatly decides the input/ resource mobilizing ability. **(Marginal, Small, Medium and Large farmers)**

Marginal Farmer

Means a farmer cultivating (as owner or tenant or share cropper) agricultural land up to 1 hectare (2.5 acres).

Small Farmer

Means a farmer cultivating (as owner or tenant or share cropper) agricultural land of more than 1 hectare and up to 2 hectares (5 acres).

Medium Farmer

Means a farmer cultivating (as owner or tenant or share cropper) agricultural land of more than 4 ha and upto 10 hectare.

Large farmer

Means a farmer cultivating (as owner or tenant or share cropper) agricultural land more than 10 hectare.

Topic 10: Drought, definition and types of drought

Low rainfall or failure of monsoon rain is a recurring feature in India. This has been responsible for droughts and famines. The word drought generally denotes scarcity of water in a region. Drought is a temporary condition that occurs for a short period due to deficient precipitation for vegetation, river flow, water supply and human consumption.

Definition

The irrigation commission of India defines drought as a situation occurring in any area where the annual rainfall is less than 75% of normal rainfall. **or** drought as prolonged period without rainfall.

❖ Types of drought

Seven (7) main types of drought recognized in India

1. Meteorological Drought

It describes a situation where there is a reduction in rainfall for a specific period (days, months, seasons or year) below a specific amount (long term average for a specific time).

Uncertain, unreliable and erratic nature of rainfall by south-west monsoons creates drought conditions in different parts of the country.

2. Hydrological Drought

Meteorological drought, when prolonged results in hydrological drought with depletion of surface water and consequent drying of reservoirs, tanks etc.

3. Agricultural Drought

It is the result of soil moisture stress due to imbalance between available soil moisture and evapotranspiration of a crop. In other words, when soil moisture and rainfall conditions are not adequate enough to support a healthy crop growth to maturity thereby causing extreme moisture stress and wilting of major crop area, it leads to agricultural drought.

4. Soil Moisture Drought

This is a situation of inadequate soil moisture particularly in rainfed areas which may not support crop growth. This happens in the event of a meteorological drought when the water supply to soil is less and water loss by evaporation is more.

5. Socio-Economic Drought

It reflects the reduction of availability of food and income losses on account of crop failures cause danger to food and social security of the people in the affected areas.

6. Famine

A famine is a widespread scarcity of food, caused by several factors including crop failure, population imbalance, or government policies.

7. Ecological Drought

Ecological drought takes place when the productivity of a natural eco-system fails significantly as a consequence due to induced environmental damage.

❖ Important causes for agricultural drought are

- ✓ Inadequate precipitation
- ✓ Erratic distribution
- ✓ Long dry spells in the monsoon
- ✓ Late onset of monsoon
- ✓ Early withdrawal of monsoon
- ✓ Lack of proper soil and crop management

❖ Effect of drought on crop production

a) Water relations: Alters the water status by its influence on absorption, translocation and transpiration. The lag in absorption behind transpiration results in loss of turgor as a result of increase in the atmospheric dryness.

b) Photosynthesis: Photosynthesis is reduced by moisture stress due to reduction in Photosynthetic rate, chlorophyll content, leaf area and increase in assimilates saturation in leaves (due to lack of translocation).

c) Respiration: Increase with mild drought but more serve drought lowers water content and respiration.

d) Anatomical changes: Decrease in size of the cells and inter cellular spaces, thicker cell wall, greater development of mechanical tissue. Stomata per unit leaf tend to increase.

e) Metabolic reaction: All most all metabolic reactions are affected by water deficits.

f) Hormonal Relationships: The activity of growth promoting hormones like cytokinin, gibberlic acid and indole acetic acid decreases and growth regulating hormone like abscisic acid, ethylene, etc., increases.

g) Nutrition: The fixation, uptake and assimilation of nitrogen is affected. Since dry matter production is considerably reduced the uptake of NPK is reduced.

h) Growth and Development: Decrease in growth of leaves, stems and fruits. Maturity is delayed if drought occurs before flowering while it advances if drought occurs after flowering.

i) Reproduction and grain growth: Drought at flowering and grain development determines the number of fruits and individual grain weight, respectively. Panicle initiation in cereals is critical while drought at anthesis may lead to drying of pollen.

Drought at grain development reduces yield while vegetative and grain filling stages are less sensitive to moisture stress.

j) Yield: The effect on yield depends hugely on what proportion of the total dry matter is considered as useful material to be harvested. If it is aerial and underground parts, effect of drought is as sensitive as total growth. When the yield consists of seeds as in cereals, moisture stress at flowering is detrimental. When the yield is fibre or chemicals where

economic product is a small fraction of total dry matter moderate stress on growth does not have adverse effect on yields.

❖ Management of drought

Strategies for drought management

The different strategies for drought management are discussed under the following heads.

1 Adjusting the plant population: The plant population should be lesser in dryland conditions than under irrigated conditions. The rectangular type of planting pattern should always be followed under dryland conditions. Under dryland conditions whenever moisture stress occurs due to prolonged dry spells, under limited moisture supply the adjustment of plant population can be done by

a) Increasing the inter row distance: By adjusting more number of plants within the row and increasing the distance between the rows reduces the competition during any part of the growing period of the crop. Hence it is more suitable for limited moisture supply conditions.

b) Increasing the intra row distance: Here the distance between plants is increased by which plants grow luxuriantly from the beginning. There will be competition for moisture during the reproductive period of the crop. Hence it is less advantageous as compared to above under limited moisture supply.

2 Mid season corrections: The contingent management practices done in the standing crop to overcome the unfavourable soil moisture conditions due to prolonged dry spells are known as mid season conditions.

a) Thinning: This can be done by removing every alternate row or every third row which will save the crop from failure by reducing the competition

b) Spraying: In crops like groundnut, castor, redgram, etc., during prolonged dry spells the crop can saved by spraying water at weekly intervals or 2 per cent urea at week to 10 days interval.

c) Ratooning: In crops like sorghum and bajra, ratooning can practiced as mid season correction measure after break of dry spell.

3 Mulching: It is a practice of spreading any covering material on soil surface to reduce evaporation losses. The mulches will prolong the moisture availability in the soil and save the crop during drought conditions.

4 Weed control: Weeds compete with crop for different growth resources are seriously under dryland conditions. The water requirement of most of the weeds is more than the crop plants. Hence they compete more for soil moisture. Therefore, the weed control especially during early stages of crop growth reduces the impact of dry spell by soil moisture conservation.

5 Water harvesting and life saving irrigation: The collection of runoff water during peak periods of rainfall and storing in different structures is known as water harvesting. The stored water can be used for giving the life saving irrigation during prolonged dry spells.

Topic 11: Cropping systems: Definition and types of cropping systems

A system consists of several components which depend on each other. A system is defined as set elements or components that are inter – related and interacting among

themselves. Farming system consists of several enterprises like cropping system, dairying, piggery, poultry, fishery, bee keeping etc. These enterprises are interrelated. The end products and wastes of one enterprise are used as inputs in others. The wastes of dairying like dung, urine, refuse etc., are used for the preparation of farmyard manure which is an input in cropping systems. The straw obtained from the crops is used as fodder for cattle. Cattle are used for different field operations for growing crops. Thus different enterprises for farming systems are highly interrelated.

Cropping System: The term cropping system refers to the crops and crop sequences and the management techniques used on a particular field over a period of years.

Cropping pattern: It indicates the yearly sequence and spatial arrangement of crops and fallow in an area. It is for larger area like zone, district, taluka etc.

Types of Cropping Systems

Depending on the resources and technology available, different types of cropping systems are adopted on farms. Broadly three types of cropping system are followed

1. Sole cropping

Only a single crop or variety grown alone in a pure stand at normal density during one farming year.

2. Monocropping or Monoculture

Mono cropping or monoculture refers to growing of only one crop on same piece of land year after year.

It may be due to climatologically and socio-economic condition or due to specialization of a farmer in growing a particular crop. Under rainfed conditions, groundnut or cotton or sorghum are grown year after year due to limitation of rainfall. In canal irrigate areas, under waterlogged condition, rice crop is grown, as it is not possible to grow any other crop.

Problems of mono cropping

1. The resources like labour, fertilizers, water and machines are not utilized efficiently.
2. The soil health is not cared and nutrients are depleted.
3. There are chances of occurrence of pest and diseases infestation.
4. Natural resources are not fully utilized.

3. Multiple cropping

"Growing two or more crops on the same piece of land in succession within one calendar year is known as multiple cropping" e.g. Rice-Rice-G' nut or Cotton-Wheat etc.

It aims of maximum production per unit area per unit time. It offers multiple use of resource. It is the intensification of cropping in time and space dimensions i.e. more number of crops within a year & more no of crops on the same piece of land at any given period. It includes inter-cropping, mixed cropping, sequence cropping etc.

Multiple cropping is of different types as discuss below;

A. Inter cropping

Inter cropping is a process of growing a short duration companion crops in between the spaces of widely spaced principal or main crop.

The main objective of inter-cropping is to utilize the space left between two rows of main crops and to produce more grain per unit area. Inter cropping was originally practiced as an insurance against crop failure under rainfed condition.

Advantages of Inter cropping

1. Additional yield is obtained from unit area of land as two-component crops are grown together.
2. Additional care is not needed for the companion crop.
3. It helps to restore soil fertility when legumes are included as component crops.
4. Control of weeds as well as soil erosion is possible, as the soil remains covered with plants.
5. Inter crop provide shade and support to the other crop.
6. Inter-cropping was originally practiced as an insurance against crop failure under rainfed conditions.
7. Inter-cropping system utilizes resources efficiently and their productivity is increased.
8. Inter cropping with cash crops is highly profitable.

B. Mixed cropping

Two crops are grown by sowing a mixture of their seed at certain proportion e.g. Wheat and Mustard seeds are mixed together in 2:1 rates and shown broadcast No spacing is maintained between the crops.

No spacing is maintained between the crops it is a common practice in areas where climatic hazards such as flood, drought, frost etc. are frequent and common. Under such circumstances the farmers always fear that their crops will fail. Under mixed cropping, the time of sowing of all the crops is almost the same, however they may mature either together e.g. Wheat + Gram or Wheat + Barley or Wheat + Mustard or they may mature

at different times, e.g. Pigeonpea + Jowar + mung and til (Sesamum) or groundnut + bajara etc. The object of mixed cropping is to meet the family requirement of cereals, pulses and vegetables. It is subsistence farming.

Principles of mixed cropping

The most important point is the selection of crops. Crops which compete with each other should not be chosen. Therefore, the following points should be considered while selecting crops.

1. Legumes should be shown with non-legumes, e.g. pigeonpea with Jowar- bajra, gram with wheat.
2. Tall growing crop should be sown with short-growing crops, e.g. maize with mung/ blacgram
2. Deep-rooted crops (Tap rooted crops) should be sown with shallow \rooted crops.
3. Bushy crops (Spreading, cover crops) should be sown with erect- growing crops.
4. Crops being attacked by similar insect, pest and diseases should not be sown together.
5. Mixtures should consist short and long duration crops.

C. Sequence cropping / Crop rotation

It is a practice of growing two or more crops on the same piece of land during one farming year in particular sequence to increase the production without any detrimental effect on soil health. Depending on the number of crops grown in a year, it is called as **double, triple and quadruple cropping.**

Crop sequence and crop rotation are generally used synonymously. Crop rotation refers to recurrent succession of crop on the same piece of land either in a year or over a longer period of time. Component crops are so chosen so that soil health is not impaired.

Double Cropping :- Growing two crops a year in sequence
Triple Cropping :- Growing three crops a year in sequence
Quadruple Cropping :- Growing four crops a year in sequence.

Principles of crop rotation

- Leguminous crops should be grown before non-leguminous crops because legumes fix atmospheric N into the soil and add organic matter to the soil.

- Crops with tap roots (deep rooted like cotton) should be followed by those which have fibrous (shallow rooted crops like sorghum or maize) root system. This facilitates proper and uniform use of nutrients from the soil.
- More exhaustive crops should be followed by less exhaustive crops because crops like potato, sugarcane, maize etc. need more inputs such as better tillage, more fertilizers, greater number of irrigation etc.
- Selection of crop should be based on need or demand.
- Crops of same family should not be grown in succession because they act as alternate hosts for insect pests and diseases.
- The crop selected should also suit to the soil and climatic condition.
- Selection of crops should be based on the situations such as
    - On sloppy lands, alternate cropping of erosion permitting and erosion resisting crops should be adopted.
    - Under rain fed situations crops which can tolerate drought should be selected
    - In low-lying and flood prone areas crops which can tolerate water stagnation should be selected
    - In areas where salt affected soils are there, salt tolerant varieties should be grown
- An ideal crop rotation must provide maximum employment to the farm family and labour, permits farm mechanization to ensure timely operations besides maintaining soil health

Advantages of crop rotation

An ideal crop rotation has the following advantages.

(1) The soil fertility is restored by fixing atmospheric N encouraging microbial activity and maintaining physico-chemical properties of the soil.
(2) Alternate cropping with other crops helps in controlling crop bound weeds.
(3) Proper utilization of all resources and inputs could be made by following crop rotation.
(4) The farmer gets a better price for his produce because of its higher demands in the market.
(5) Best utilization of residual moisture, fertilizer and organic residues is made by growing crops of different nature.
(6) The family needs of feed, food, fuel, fiber, spices; condiments, sugar etc are fulfilled.

D. Relay cropping

It is just like a relay race where land is transferred to another crop before previous crop is harvested. e.g. Green Gram-maize-potato-Wheat.

Science next crop is sown before the harvest of the earlier crop, the crop variety to be chosen must be of short duration and quick growing. There is no gap between harvesting of earlier crop and sowing of next crop. So before the harvest of previous crop, the land is irrigated and the soil is worked up slightly for sowing of the subsequent crop.

e.g. sowing of pigeon pea in-between two rows of *kharif* groundnut just one month before groundnut harvest. The main purpose is to utilize the residual soil moisture and nutrients after groundnut.

Advantage of relay cropping

1. Minimum tillage is needed for relay cropping and thus reduce the cost of cultivation.
2. Weed problem is low as the land is engaged with crops all the year round.
3. Crops residues are added in the soil and they converted to organic manure after decomposition. Increase fertility of soil.
4. The succeeding crops are benefited by the residual fertilizer of the pervious crops.

E. Ratoon cropping

Ratooning refers to raising a crop with regrowth coming out of roots or stalks after harvest of the crop. Ratooning sorghum for fodder and grain is more popular than other cereals. Chief advantages of rationing are to avoid planting of another crop and save time & costs for seed and land preparation.

e.g. Raising a crop from regrowth of sugarcane, maize, sorghum etc.

F. Alley Cropping

It is a cropping system in which arable crops are grown in alleys (Vacancy space) formed by the rows of tree shrub with a view mainly to enhancing soil productivity.

G. Multi story or multi-tier cropping

Growing plants of different heights in the same field at the same time is termed as multi-story or multi-tier cropping.

It is mostly practiced in orchards and plantation crops for maximum use of solar energy even under high planting density e.g. Eucalyptus + Papya + Berseem. Sometimes it is practiced under field crops such as s'cane + potato + onion (seed crop) or s'cane + mustard + potato.

H. Paira / Utera cropping

Growing of such crops sown a few days or weeks before harvesting of standing mature crops is called paira/utera cropping and the sown crop is called paira/utera crop. Eg. Lathyrus in rice. Paira cropping in succession may constitute relay cropping.

Pulses like mung, black gram, gram, lentil and lathyrus come up well as paira cropping in the *rabi* season. Where the land after harvest of paddy remains slaucy making it unsuitable for tillage, these crops may be broadcast atleast 15-20 days before harvest using 1.50 times the seeds required for normal sowing.

Topic 12: Soil fertility and Soil productivity

Soils are the uppermost part of the earth's crust, formed mainly by the weathering of rocks, formation of humus and by material transfer. Soils vary a great deal in terms of origin, appearance, characteristics and production capacity.

Soils vary largely with respect to their natural fertility and productivity resulting in plant growth ranging from practically zero (no growth at all on extreme problem soils) to abundant luxuriant growth of natural vegetation. However, only a small proportion of world's soils have a very good level of fertility. Most soils have only good to medium fertility and some have very low fertility and are often referred to as marginal soils. Such areas should not generally be used for cropping but only for grazing in a controlled manner. However, under natural vegetation in a suitable climate, even soils of poor fertility may produce luxuriant vegetation where the nutrient cycle is closed, e.g. the Amazon forests

What is soil fertility?

Soil fertility defined as the ability of the soil to provide the entire essential plant nutrient in the available forms and suitable balance.

Soil fertility refers to the inheritance capacity of the soil to supply nutrient to the plants in adequate amount and in suitable proportion.

It also understood that soil should be free of any toxic substance e.g. saline or alkaline soils.

Soil fertility is a manageable soil property and its management is of utmost importance for optimizing crop nutrition on both a short-term and a long-term basis to achieve sustainable crop production.

The presence of nutrient & availability of nutrients is quite different thing. The nutrient may present in the soil but may not be available due to other factor (pH) or shortage of moisture in the soil. Thus, soil may be fertile but may not be productive .So fertile soil may or may not be productive but productive soil always fertile.

❖ Factors governing soil fertility

- **Parent material:** Fertility of a soil depends on the chemical composition of parent material from which it derived.

- **Topography:** Soils on the upper slope are less fertile than the soils on lower slope because high leaching and erosion on upper slope.

- **Climate:** In tropical climate decomposition of organic matter is faster than temperate climate. Thus soils of tropical regions are less fertile when compared to temperate region.

- **Depth of Soil Profile:** Deep soils are more fertile than the shallow soils and the roots are spread well enough in deep soils than the shallow soils.

- **Physical Condition of Soil:** The soil texture and soil structure influence the soil fertility.

❖ **Artificial Factors:**

I. Water logging
ii. Cropping system
iii. Toxic chemicals and
iv. Pesticides in the soil

What is soil productivity?

Productivity is the present capacity of the soil to produce crop yield under a defined set of management practices. It is measured in terms of the yield in relation the inputs of production factors.

A productive soil is one in which the chemical, physical, and biological conditions are favorable for plant growth.

The response to management of soils in term of yield per unit area depends upon:

(1) Availability of nutrients and status of soil
(2) Tilth and workability of surface soil
(3) Erosion control
(4) Organic matter content

❖ **Hans jenny:**

Crop production = f (cl,v,m,s,t)

Where,
f = function,
cl = climate,
v = vegetation or crop variety

m = management (irrigation, tillage),
s = soil, t = time (growth period)

Differences between soil fertility and productivity

Sr. No.	Soil fertility	Soil Productivity
1.	It is an index of available nutrients to plants	It is a broader term used to indicate yields
2.	Influenced by the physical, chemical and biological factors of the soil.	Depends upon fertility and location.
3.	It can be analyzed in the laboratory	It can be assessed in the field under particular climatic conditions
4.	It is the function of available nutrients of the soil.	It is the function of soil fertility, management and climate.
5.	It is the potential status of the soil to produce crops	It is the resultant of various factors influencing soil management
6.	All fertile soils are not productive.	All productive soils are fertile.

Topic 13: Fertility losses and maintenance of soil fertility, soil organic matter

In farming, soil fertility may lost through many ways, some of these ways are as result of human activities while others are through natural process.

The following are some ways through which soil fertility may be lost:

(1) Leaching

This is common with nutrients that are highly soluble such as nitrogen, these nutrients are carried to lower far from beyond the reach of many plants roots, soil with many leached nutrients are infertility.

(2) Soil capping

This is when the soil is covered (capped) with an impervious material which prevents the penetration of rainwater into the soil, this leads to surface run – off. This denies the soil adequate moisture and exposes the soil to erosion

(3) Soil erosion

This is the carrying away of the top fertile soil by moving water and wind. Erosion leads to loss of the fertile top soil and plant nutrients, this makes the soil infertility.

(4) Mono-cropping

Mono-cropping is the practice of growing one type of gropes on a piece of land for a long time. The gropes grown uses only those nutrients it needs while other nutrients remain unused, this leads to exhaustion of some nutrients and eventually to their deficiency in the following years

There is also likelihood of buildup of pests and disease, the same pest and disease are passed on from the residue of previous crop, this leads to low yield

(5) Accumulation of salt

Soil water contains dissolved minerals salts from the parent rock; some of the salt comes from decomposition of organic matter.

Under normal condition, the salts are washed away by rain water, thereby keeping their concentration in the soil low. However in arid and semi-arid areas the rainfall is irregular and is not enough to remove the salt from the soil.

This together with the high evaporation rate and poor drainage, leads to accumulation of salt on or below of the soil surface. The salt cause deficiency of water in plants as water moves out of the root in the soil under the osmotic pressure of the salt solution.

(6) Change in the pH

Inappropriate use of fertilizers may change the soil pH, for example, the use of acidic fertilizer over a long period of time can make the soil acidic.

Change in pH affects the activity of the soil microorganisms and the availability of some nutrients. This, in run, affects the fertility of the soil.

(7) Burning of vegetation

When vegetation is burned, organic matter is destroyed; this affects the activities of microorganisms such as nitrogen fixation and decomposition of organic matter.

Accumulation of the resulting ash also causes imbalance of nutrients in the soil. Burning of vegetation also exposes the soil to agents of erosion such as wind and water.

❖ Maintenance of soil fertility

Maintenance of soil fertility is a great problem to our farmers. Cultivation of particular crop year after year in the same field decreases the soil fertility. To increase the soil fertility, it is necessary to check the loss of nutrient and to increase the nutrient content of soil.

The following things must be properly followed for increasing the fertility of soil.

- **Proper use of land**

Good yield of crop is not possible if we cultivate any crop in any land. So it is necessary to select the crop which is suitable for a particular land. Practical experience will be helpful in this regard. The crop should be cultivated on the basis of the nature soil, for example, cultivation of paddy is best suited in low land clay soil.

- **Good tillage**

Good tillage is necessary to bring the soil in suitable condition for the production of crops. Tillage makes the soil loose and friable. Weeds and stubbles of previous crops ploughed under by tillage are turned into organic matter. As a result, the physical, chemical and biological change of soil takes place which is necessary for the maintenance of soil fertility.

- **Crop rotation**

If we cultivate the particular crop year after year in the same field, the particular nutrients of soil become exhausted and the fertility of soil is decreased. For this, different crops should be cultivated in a year.

- **Control of weeds**

Weeds compete with crop plants for water, space, light and mineral matter. Weeds grown on a particular land absorb the plant nutrient and make the soil unfertile. For this, to maintain and improve the soil fertility, it is necessary to control the weeds in times.

- **Maintenance of optimum moisture in soil**

Optimum moisture in the soil is essential for the proper growth of crops. The quantity of soil moisture in more or less amount hampers the growth of crop. Excessive water in the soil causes the losses of nutrient by leaching and as a result, the fertility of the soil decreases. So it is essential to conserve the soil moisture which is helpful in the conservation of soil fertility.

- **Control of soil erosion**

Some of the nutrient especially nitrogen, remains on the upper layer of the soil is removed by in any means, the fertility of the soil decreases. So it is essential to conserve the soil moisture which is helpful in the conservation of soil fertility.

- **Cultivation of green manuring crops**

If we cultivate green manuring crops i.e. leguminous crop such as daincha, sunhemp, cowpea etc. in the field and turned under the soil by ploughing, the organic matter and nitrogen in case of leguminous crop increases in the soil and thereby the fertility of soil increases. The leguminous crop fix nitrogen from air with the help of nitrifying bacteria (i.e. Rhizobium) living in root nodule of that crop. Addition of those crops increases the organic matter and nitrogen content of soil. As a result, the fertility of soil is increased.

- **Application of manures**

Manure is organic in nature. Application of manures i.e. plant origin (oil cakes, compost, farm yard manure etc.) and animal origin (i.e. cow dung, urine, bone meal etc.) increases the organic matter in the soil and thereby the fertility of soil is increased.

- **Cultivation of cover crops**

Cover crops such as cowpea, sweet potato etc. make a cover of surface of the soil which reduces the soil erosion and leaching loss of nutrients from the soil. As a result, the fertility of soil is conserved.

- **Removal of excess water**

Removal of excess water from the soil is very much essential. Otherwise, nutrients are lost by the process of leaching. Besides this, aeration is also inhibiting the microbial activity and mineralizations of nutrients do not take place properly. So it is essential to remove excess water from the soil to maintain soil fertility.

- **Application of fertilizers as soil health card / STV**

Manure contains fewer amounts of nutrients. So we should apply fertilizer to meet the requirement of plant. Applications of fertilizer do not increase the fertility of soil. But it is possible to meet the demand of plant through the fertilizer application.

- **Maintenance of proper acidity/ alkalinity of soil**

Acid and alkali soils are not suitable for the cultivation of all crops. In acid soil, iron, aluminium and manganese remain in unavailable form. It is essential to reclaim the acidity and alkalinity of soil to maintain the fertility of soil. Lime is applied for reclamation of acid soil and gypsum is applied for the reclamation of alkali soil.

❖ Role of organic matter in Soil:

- ✓ Organic matter is the store house of food for the plant. The major plant nutrient namely nitrogen, phosphorus and potassium remain in organic matter and the nutrient releases throughout the year which becomes available to plants.
- ✓ Organic matter helps to improve and conserve the fertility of soil.
- ✓ Organic matter imparts a dark colour of the soil and thereby helps to maintain soil temperature.
- ✓ Organic matter improves soil structure by enhancing the granulation of soil particles. As a result, clay soil becomes porous and aeration and movement of water improved. On the other hand, water holding capacity of sandy soil increases.
- ✓ The plant nutrients remain in insoluble and complicated state in organic matter. As a result, loss of nutrient by rain water or other natural agencies becomes minimum.
- ✓ Organic matter increases cation exchange capacity (CEC) of the soil. Thus it prevents the loss of nutrient by leaching and retains them in available form.
- ✓ Organic matter increases the water holding capacity of the soil. This is specially important in case of sandy soil.
- ✓ Organic matter makes the soil porous and thus, helps in proper aeration.

- ✓ Organic matters serve as a store house of food for the soil microorganism. They make the plant nutrient available to plants.
- ✓ Organic matter increases the availability of phosphorus by locking up the calcium, iron and aluminium which are responsible for phosphate fixation.
- ✓ Organic matter increases the buffering capacity of soil. Buffering cheeks rapid chemical changes in soil pH and in soil reaction.
- ✓ Organic mulching helps to conserve the soil moisture.
- ✓ Organic acid released from decomposing organic matter helps to reduce alkalinity in soils.
- ✓ Organic matter reduces the undesirable properties of clay soil like cohesion and plasticity. It makes the clay soil friable and make it easy for cultivation.
- ✓ Organic matter reduces the loss of soil by wind erosion and reduces the surface run-off and makes soil water more available to plants.
- ✓ Soil becomes inert without organic matter and plant cannot grow well in that soil.

Topic 14: Irrigation, Introduction, Importance, definition and objectives

Water is one of the most important inputs essential for the production of crops. Plants need it continuously during their life and in huge quantities. It profoundly influences photosynthesis, respiration, absorption, translocation and utilization of mineral nutrients, and cell division besides some other processes. Both its shortage and excess affects the growth and development of a plant directly and, consequently, its yield and quality.

Soil is a porous medium, and serves as a water reservoir or bank. Water is deposited in this bank as rain or irrigation, and plants withdraw it during their growth. There should be minimum or no wastage of water either through surface run-off or through deep percolation below the root-zone of a crop. Management of irrigation practices, if not adopted as per the suitability of soil types, land topography, methodology, and agro-climatic conditions can lead to imbalances in sub-soil water. The most common problem associated with irrigation is the water logging. Draining out this excess water from the root zone is the only solution to reclaim such lands. The techniques to be adopted should be economically and environmentally viable and in line with the soil, climate and agriculture system.

Definition

Irrigation is defined as the artificial application of water to the soil for the purpose of supplying moisture essential for plant growth.

Water requirement (WR) :

It is the quantity of water, regardless of its sources, required by a crop or diversified pattern of crops in a given period of time for their normal growth under field conditions.

WR = IR + EP + S

Where, IR = Irrigation water
EP = Effective precipitation
S = Soil profile contribution

Irrigation requirement (IR) :

It is the total amount of water applied to a cropped field for supplementing precipitation and soil profile moisture contribution to meet crop water needs for optimum growth and yield.

IR = WR – (EP + S)

Importance/Role of water to plants

Water is considered as elixir of any living organism. It is indispensable for human, animal and plant.

1. Green Plants contain 90% water which gives turgidity and keeps them erect.
2. Water is an essential part of protoplasm.
3. It regulates the temperature of the plant system.
4. It is essential to meet the transpiration requirements.
5. It serves as a medium for dissolving the nutrients present in the soil.
6. It is an important ingredient in photosynthesis.
7. It is necessary for bio- chemical processes and building up of the plant contents.

Definition and Objectives of Irrigation

Irrigation generally defined as the artificial application of water to the soil for the purpose of supplying moisture essential for plant growth.

However, broad and more inclusive definition is that irrigation is the application of water to the soil for any of the following purposes/ objectives.

1. To add water to soil for supplies the moisture essential for plant growth.
2. To provide crop insurance against short period of drought.
3. To cool soil and atmosphere, thereby making more favorable environment for plant growth.
4. To washout salts from the root zone of plant.
5. To dissolve the plant nutrients present in soil.
6. Regulating the temperature of the plant system.
7. To reduce the hazard of soil piping (Cracking).
8. To soften the tillage pan or facilitate tillage operation.
9. To reduce the hazard of frost.
10. To supplement the natural precipitation.

Topic 15 : Physical classification and Biological classification of water.

Forms of soil water

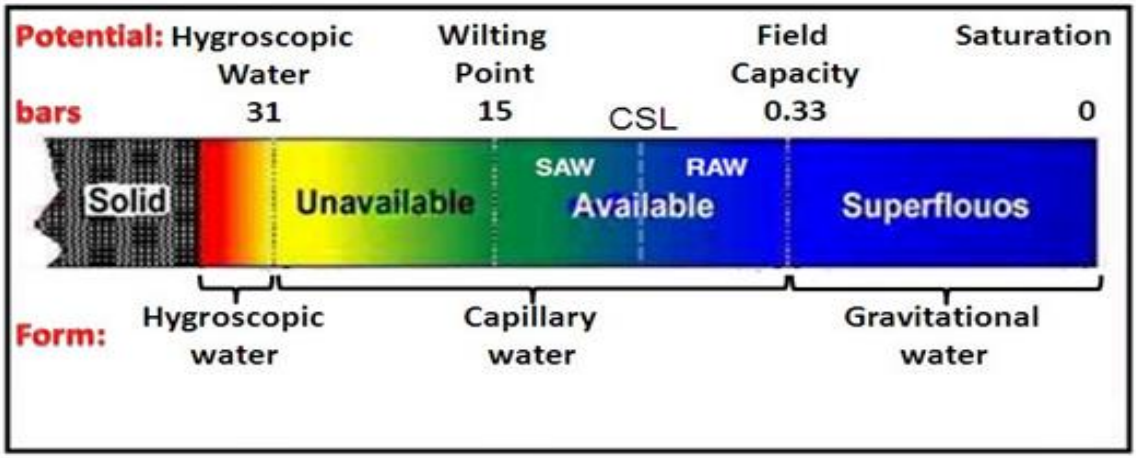
The water content at field capacity, wilting point and the hygroscopic coefficient are all based on the OVEN-DRY reference mass. The percentage of water held under each of these conditions can therefore be used to define the following and other forms of soil water.

Gravitational Water (%)	= Water content - Field capacity
Capillary water (%)	= Field capacity - Hygroscopic coefficient
Hygroscopic water (%)	= Hygroscopic coefficient
Available water (%)	= Field capacity - Wilting point
Unavailable water (%)	= Wilting point

Each of these forms of water can be calculated from the appropriate soil mass

Classification of soil water

Soil water has been classified from a physical and biological point of view as Physical classification of soil water, and biological classification of soil water.



❖ Physical classification of soil water

1. Gravitational water: Gravitational water occupies the larger soil pores (macro pores) and moves down readily under the force of gravity. Water in excess of the field capacity is termed gravitational water. Gravitational water is of no use to plants because it occupies the larger pores. It reduces aeration in the soil. Thus, its removal from soil is a requisite for optimum plant growth. Soil moisture tension at gravitational state is zero or less than 1/3 atmosphere.

2. Capillary water: Capillary water is held in the capillary pores (micro pores). Capillary water is retained on the soil particles by surface forces. It is held so strongly that gravity cannot remove it from the soil particles. The molecules of capillary water are free and mobile and are present in a liquid state. Due to this reason, it evaporates easily at ordinary temperature though it is held firmly by the soil particle; plant roots are able to absorb it. Capillary water is, therefore, known as available water. The capillary water is held between 1/3 and 31 atmosphere pressure.

3. Hygroscopic water: The water that held tightly on the surface of soil colloidal particle is known as hygroscopic water. It is essentially non-liquid and moves primarily in the vapour form. Hygroscopic water held so tenaciously (31 to 10000 atmospheres) by soil particles that plants cannot absorb it.

❖ Biological classification of soil water

There is a certain relationship between soil moisture retention and its utilization by plants. On the basis, superfluous, available water and unavailable water are recognized.

1. Superfluous water (Free water or drainable water)

It is excess of that held in soil at field capacity and has no use for higher plants. This water is held at a tension below 0.1 to 0.3 atmospheres. It is also known as free or gravitational water. The harmful effect of this water on the plants and soil are as follows. This water can be calculated as.

$$\text{Drainable water (cm/depth)} = \frac{\text{MWHC - FC x BD x D}}{100}$$

- Poor aeration of the soil, which deprives the roots and aerobic organism of their oxygen.
- Adverse biological changes may be encouraged.
- Nutrients may be leached down especially from coarse textured soil.

2. Available water (Available soil moisture, ASM)

This water is held between field capacity and permanent wilting point (PWP or permanent wilting coefficient) tension between 0.1 (0.3) to 15 atmospheres. It is expressed as percentage moisture (PW) or as volume basis (cm/m depth).

$$\text{ASM (cm/depth)} = \frac{\text{FC- PWP x BD x D}}{100}$$

3. Unavailable water

It is held in the soil at the permanent wilting point (≥15 atm.). Unavailable water includes hygroscopic water and that part of the capillary water held between 15 to 31 atmospheres, which is utilized by plants too slowly to prevent wilting.

$$\text{Unavailable water (cm/depth)} = \frac{PWP \times BD \times D}{100}$$

❖ Soil moisture constant

The water contents expressed under certain standard conditions are commonly referred to as soil moisture constants. The soil moisture constant, therefore, represents definite soil moisture relationship and retention of soil moisture in the field. They are used as reference points for practical irrigation water management. These constants are briefly explained below:

1. MWHC: The amount of the water held in the soil when all the pores are filled with water is called maximum water holding capacity. It is the amount of water at 100 % saturation. Therefore, the sum of the hygroscopic, capillary and gravitational water is the MWHC.

Moisture **equivalent** is proposed by Lyman Briggs and McLane (1910) as a measure of field capacity for fine-textured soil materials.

2. Moisture Equivalent : Moisture equivalent is defined as the percentage of water which a soil can retain in opposition to centrifugal forces 1000 times that of gravity. Briggs and McLain introduced this term in 1907. The term FC, which is introduced later on, is used in place of moisture equivalent in soil- water relationship.

Sandy soil = M E < FC

Clay soil = M E > FC

Medium soil = M E = FC

3. Field capacity: It is the moisture content of a well-drained soil on oven-dried basis a few days after complete saturation when downward movement of excess water is practically ceased. Such a stage is reached generally in 48 to 72 hours after saturation. Sandy soil reaches FC earlier than clayey soils. Organic matter and fine texture increases FC. It is also termed as field carrying capacity (FCC), moisture capacity (MC), capillary capacity (CC), water holding capacity (WHC) or moisture holding capacity (MHC), moisture retention capacity (MRC).

Field capacity is the upper limit of soil moisture and force with which moisture is held at this point varies from 0.1 to 0.3 atmospheres. FC values of sandy soils, sandy loam, loam, clay loam and clay soils are generally about 5-10 %, 10-18 %, 18-25 %, 24-32 % and 32-40 %, respectively.

4. PWP: Moisture content at which plant leaves wilt permanently and do not regain turgidity even they are watered again this is called permanent wilting and the percentage of soil moisture at this point is known as permanent wilting point.

This is the lower limit of available soil moisture range for plant growth. The force with which moisture is held by the soil at this stage (point) corresponds to

about 15 atmospheres. The PWP values of sandy, sandy loam, loam, clay loam and clay soils are generally about 2-6% , 4-8% , 8-12% , 11-15% and 15-19% .

5. Hygroscopic coefficient: The hygroscopic coefficient is the percentage of water remaining in an air-dry soil. At this point, water in the soil is adsorbed on the soil colloids so tightly that it can move only in vapour form.

Topic 16: Irrigation efficiency and water use efficiency, consumptive use of water

Introduction:

Irrigation water is an expansive input and has to be used very efficiently. The main losses occur during irrigation of fields as conveyance, runoff, seepage and deep percolation. Irrigation efficiency can be increased by reducing these losses. Uneven spreading and inadequate filling of root zone are the other causes for low irrigation efficiency. Irrigation efficiency at the field level can be increased by selecting suitable method of irrigation, adequate land preparation and engaging an efficient irrigator.

An efficient irrigation system implies effective transfer of water from the source to the field with minimum possible loss. The objective of irrigation efficiency concept is to identify the nature of water loss and to decide the type of improvements in the system. Evaluation of performance in terms of efficiency is prerequisite for proper use of irrigation water.

1. **Irrigation Efficiency**

It is defined as the ratio of water output to the water input, i.e., the ratio or percentage of the irrigation water consumed by the crop of an irrigated farm, field or project to the water delivered from the source. *In most irrigation projects of India, the irrigation efficiency ranges between 20 to 40 percent.*

$$Irrigation\ Efficiency\ (Ei) = \frac{Wc}{Wr} \times 100$$

Where,

Ei = Irrigation efficiency (%)

Wc = Irrigation water consumed by crop during its growth period.

Wr = Water delivered from canals during the growth period of crops.

2. **Water Conveyance Efficiency**

It is a measure of efficiency of water conveyance system from canal network to watercourses and field channels. It is the ratio of water delivered in fields at the outlet head to that diverted into the canal system from the river or reservoir. Water losses occur

in conveyance from the point of diversion till it reaches the farmer's fields which can be evaluated by water conveyance efficiency as:

$$Water\ Conveneyance\ Efficiency\ (Ec) = \frac{Wf}{Ws} \times 100$$

Where,

Ec = Water conveyance efficiency (%)

W_f = Water delivered at the field

Ws = Water delivered at the source (at field supply channel)

The water conveyance efficiency is generally low; about 21% losses occur in earthen watercourses only.

3. **Water Application Efficiency**

It is a measure of efficiency of water application in the field. It is the ratio of volume of water that is stored in the root zone of crops and ultimately consumed by transpiration or evaporation or both to the volume of water actually delivered at the field. Alternatively, it may be defined as the percentage of water applied that can be accounted for as increase in soil moisture in soils as occupied by the principal rooting system of the crop. It is also termed as farm efficiency as it takes into account water lost in application at the farm and calculated as:

$$\text{Water Application Efficiency (Ea)} = \frac{Ws}{Wf} \times 100$$

Where,

Ea = Water application efficiency (%)

Ws = Irrigation water stored in the root zone of the soil

Wf = Irrigation water delivered to the farm

In general, water application efficiency decreases as the amount of water during each irrigation increases. Water losses due to inefficient application of water in the field vary from 28 to 50 per cent. The common sources of loss of irrigation water during application are mainly surface runoff from the farm and deep percolation below the farm root zone.

4. **Water Storage Efficiency:**

It is also known as water storage factor. This parameter estimates whether the amount of water necessary for crop is stored in the root zone or not. It is defined as the ratio of the water stored in the root zone depth by irrigation to the water needed in the root zone depth to bring it to the field capacity. It can be calculated as:

$$\textbf{Water Storage Efficiency (Es)} = \frac{\text{Water stored in the root zone (W}s\text{)}}{\text{Water needed in the root zone (W}n\text{)}} \times 100$$

Where,

Es = Water storage efficiency (%)

Ws = Water stored in the root zone during the irrigation

Wn = Water needed in the root zone prior to irrigation, i.e., field capacity soil moisture

5. **Water Distribution Efficiency**

It may be defined as the percentage of difference from unity of the ratio between the average numerical deviation from the average depth stored during the irrigation. Expression for distribution efficiency to evaluate the extent to which the water is uniformly distributed in the root zone and calculated as:

$$\text{Water Distribution Efficiency(Ed)} = \{1 - \frac{d}{D}\} \times 100$$

That is,

$$Ed = \left\{1 - \frac{\text{Average deviation}}{\text{Average depth applied}}\right\} \times 100$$

Where,

Ed = Water distribution efficiency (%)

d = *Average numerical deviation* in depth of water stored from average depth stored during irrigation

D = *Average Depth of water stored* along the run during irrigation

For example, If 10% water is lost in irrigation channel, 20% during application and 25% during distribution, it means the water conveyance efficiency, water application efficiency and water distribution efficiency are 90%, 80% and 75%, respectively. The irrigation efficiency in this case will be $E_c \times E_a \times E_d$ or $0.90 \times 0.75 \times 0.80 = 0.54$ or 54%.

6. Consumptive Use Efficiency

It is defined as the ratio of consumptive water use by the crop of irrigated farm or project and the irrigation water stored in the root zone of the soil on the farm or the project area. After irrigation water is stored in the soil, it may not be available for use by the crop because water may evaporate from the ground surface or continuously move downward beyond the root zone as it may happen in wide furrow spacing. The loss of water by deep penetration and by surface evaporation following irrigation is evaluated from the following expression:

$$Ecu = \frac{\text{Wcu}}{\text{Wd}} \times 100$$

Where,

Ecu = Consumptive use efficiency (%)

Wcu = Normal consumptive use of water

Wd = Net amount of water depleted from the root zone of the soil

Consumptive use efficiency is useful in explaining the difference in crop response from different methods of irrigation.

7. Water Use Efficiency

Having conveyed water to the point of use and having applied it, the next efficiency concept of concern is the efficiency of water use. It may be defined as the yield of marketable crop produced per unit of water used in ET. It is expressed in kg/ha-cm of water. The proportion of water delivered and beneficially used on the project can be calculated using the following formula:

$$\text{WUE} = \frac{Wu}{Wd} \times 100$$

Where,

WUE = water use efficiency (%)

Wu = water beneficially used

Wd = water delivered

The water use efficiency (WUE) is also defined as **i) crop water use efficiency** and **ii) field water use efficiency.**

a) Crop Water Use Efficiency (WUE_{Crop}) :

It is the ratio of yield of crop (Y) to the amount of water depleted by crop in evapotranspiration (ET).

$$WUE_{Crop} = \frac{Y}{ET}$$

The crop WUE is otherwise called consumptive water use efficiency. It is the ratio of crop yield (Y) to the sum of the amount of water taken up and used for crop growth (G), evaporated directly from the soil surface (E) and transpired through foliage (T) or consumptive use (Cu).

$$WUE_{Crop} = \frac{Y}{G + E + T}$$

Where,

(G + E + T) = Cu

In other words ET is Cu since water used for crop growth is negligible.

$$WUE_{Crop} = \frac{Y}{CU}$$

It is expressed in kg/ha/mm or kg/ha/cm.

b) Field Water Use Efficiency:

It is the ratio of yield of crop (Y) to the total amount of water used in the field.

$$WUE_{Field} = \frac{Y}{\text{-------}}$$

WR

Where,

WUE_{Field} = Field water use efficiency

WR = Water requirement

This is the ratio of crop yield to the amount of water used in the field (WR) including growth (G), direct evaporation from the soil surface (E), transpiration (T) and deep percolation loss (D).

$$WUE_{Field} = \frac{Y}{G + E + T + D}$$

Where, G + E + T + D = WR

It is expressed in kg/ha/mm (or) kg/ha/cm

Deep percolation is important for rice crop. For other crops seepage is important. Of the two indices defined, the *crop* water use efficiency is more important for research purposes whereas the *field* water use efficiency has grater practical importance for planners and farmers.

❖ Factors affecting water use efficiency of crops

Water use efficiency is influenced by soil, plant and environmental factors. It is increased by genetically environment and cultural manipulation of crops. Being a ratio, WUE is influenced by changes in both numerator and denominator. The

numerator is crop yield, which depends on soil, plants and environmental factors. Under field conditions, denominator (water supply) is also subjected to manipulation and thus controlling water supply to crops can also increase WUE. The effect of all these factors on water use efficiency of crop is briefly discussed as under.

1) Climatic factors

Plant transpiration and soil evaporation are dependent upon the temperature, wind velocity, relative humidity, sunshine hours and rainfall of a particular area. Evapotranspiration is directly correlated with temperature and wind velocity thereby reducing WUE. Similarly, evaporation is inversely proportional to humidity of climate which results in reduced consumption of water thereby increasing water use efficiency. Increased availability of light to plants increases photosynthesis resulting in greater production, which consequently increases WUE of crops.

2) Nature of crops

Crops with higher canopies have greater growth and consequently higher photosynthesis, which results in greater yield and concomitant higher WUE. Plants with shallow and less developed roots are able to absorb less water and fertilizers resulting in their lesser growth and production. Consequently, their WUE is reduced.

On the basis of carboxylation reaction, which occurs during photosynthesis, crops are broadly divided into two groups viz, C_3 and C_4. Crops belonging to C_3 group like wheat, barley, oats, pulses and oilseeds have less WUE because they have respiration even in the presence of light, which results in lesser production. But crops belonging to C_4 groups like sugarcane, maize and sorghum etc. have very little or no respiration in the presence of light which results in greater WUE and hence greater production.

3) Cultural practices

Cultural practices which directly affect WUE is as under.

a) Sowing time

The crops sown at proper time have greater production and hence higher water use efficiency. The crops grown latter have lesser growth and development produce low yield and hence lesser WUE.

b) Method of sowing

Compared to broadcasting method of sowing of crops, line sowing of crops has greater utilization and absorption of nutrients, water and light resulting in higher production, which results in higher WUE. Grain yields of wheat, oats and pearl millet were also increased when crops were sown in the N - S direction.

c) Depth of sowing

Crops whose seeds are sown at optimum depth have greater growth since germination and hence higher production resulting in greater WUE.

d) Use of antitranspirants

Antitranspirants are those materials whose spray upon plants reduced transpiration. Kaolin, phenyl mercuric acetate and abscises acid are a few well-known anti-transpirants. The spraying of anti-transpirants upon plants results in their reduced transpiration, which lessens their consumptive use thereby increasing WUE.

e) Use of growth retardants

Experiments have proved that there exist certain chemical substances like cycocel (CCC), phosphon etc. whose spraying upon plants in good production despite lack of water. Hence, it generates higher WUE.

f) Use of mulch

Mulches refers to the artificial or natural materials covered on the surface of soil with a object to reduce evaporation and destruction of weeds resulting in greater use of light, fertilizers, air and water by crops which results in higher production consequently higher WUE.

g) Method of irrigation

Compared to flooding method of irrigation, sprinkling and drip methods of irrigation results in lesser loss of water through evaporation and infiltration etc. that results in greater production using less water thereby increasing WUE.

h) Fertilizer application

The optimum application of fertilizer at proper time increases the growth and development of crops thereby increasing their WUE.

i) Weed control

Weeds always compete with crops for the use of water, nutrients, air and light. Hence, destruction of weeds through proper methods is essential for the proper growth of crops and their consequent higher WUE.

j) Insect-pest and disease control

The insect-pest and disease management at proper time is imperative for production of a good crop. If crops are not saved from insect-pest and other diseases, their growth and development is lessened resulting in reduced WUE.

k) Use of shelterbelts

There is a greater irrigation water loss in areas having hot and high velocity winds through evaporation. In such area, use of shelterbelts helps to reduce evaporation loss of water and ultimately increase WUE.

Besides all above factors, certain factors like crop rotation, soil testing, seed treatment, soil and water management practices, addition of organic matter in the soil and type of soil etc. that also affect the WUE of crops.

Economic efficiency of irrigation:

It is the ratio of the actual income (net or gross) obtained with the operating irrigation system, compared with the income expected under ideal conditions. It is measure of overall efficiency because it compares the final output to input. It can be calculated as:

$$\textbf{Economic efficiency of irrigation} = \frac{\text{Actual income obtained with the operating irrigation (Net or Gross)}}{\text{Income expected under ideal condition}}$$

❖ Consumptive use of water (Cu or U)

This term is use to denote the amount of water that is used in metabolic activity of plant and the water lost through the process of evaporation and transpiration. But the water used for metabolic activity is negligible (1 per cent or less than one per cent of ET). Hence, both the term evapotranspiration and consumptive use of water are simultaneously interchangeable in field of water and irrigation management.

Pan evaporation (E pan)

It is a water loss through evaporation from an open water surface of a pan (Pan evaporimeter) - mm / day

Pan evaporimeter (Pan)

It is the device used to measure daily loss of water through evaporation. USWB class - A open pan evaporimeter.

Seasonal consumptive use of water

The total amount of water used in evaporation and transpiration by a crop during the entire growing season is called seasonal consumptive use. It is expressed as depth of water in cm or volume in ha-cm.

Factors affecting CU or ET or water requirement

❖ Climatic factors

- Radiation (intensity of light)
- Period of light
- Temperature
- Humidity
- Wind velocity

❖ Water supply

- Availability of irrigation water
- Quality of irrigation water
- Method of irrigation
- Frequency of irrigation

❖ Plant characteristics

- Type of plant
- Root development
- Leaf area
- Stage of the crop
- Attack of insect pest and diseases
- Seed rate

- Weeding
- Hoeing
- Fertilizers application

❖ **Soil factors**

- Soil moisture
- Soil structure
- Soil texture
- Organic matter
- Presence of salts
- Soil temperature
- Soil colour

Topic 17 : Approaches for Irrigation scheduling

What is irrigation scheduling?

- Irrigation scheduling is defined as frequency with which water is to be applied based on need of the crop and nature of the soil.
- Irrigation scheduling is nothing but number of irrigations and their frequency required to meet the crop water requirement.

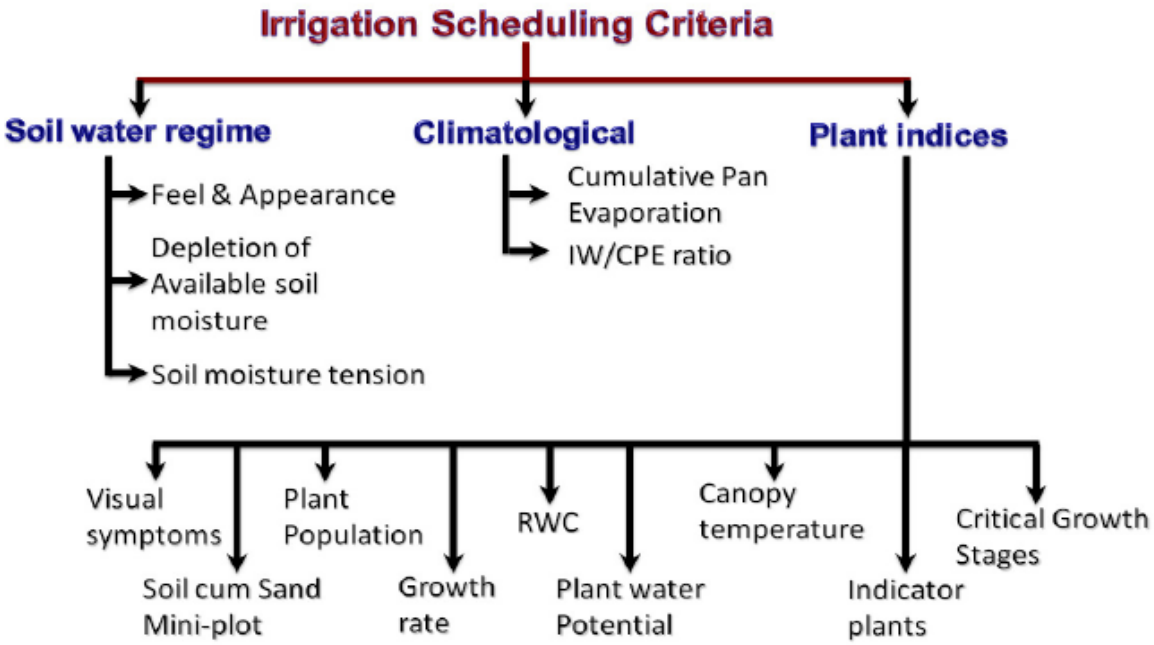
- Irrigation scheduling may be defined as scientific management techniques of allocating irrigation water based on the individual crop water requirement (ETc) under different soil and climatic condition which an aim to achieve maximum crop production per unit of water applied over a unit area in unit time.
- Based on the above definition the concept made is: **"If we provide irrigation facility, the agricultural production and productivity will go up automatically"**

Advantages of Irrigation Scheduling

i. Helps to lower water losses and minimize water logging problems.
ii. Enhances the efficiencies of other applied inputs viz., fertilizers, pesticides, herbicides *etc*.
iii. Help to reduce energy and labour requirement by avoiding over-irrigation.
iv. Helps in maintaining soil health.
v. Water saved can be used to irrigate additional area.
vi. Increase net profits by increasing crop yields and quality.

Criteria for scheduling irrigation

With the advancement of knowledge in the field of soil-plant-atmospheric system several criteria for scheduling irrigations are now available and are being used by investigators and farmers. All the available criteria can be broadly classified into the following three categories:



However, criteria most suitable for scheduling irrigation's would vary with soils, plants, climatic and management factors.

A. Soil water regime approach

The amount of water to be applied on each irrigation depends upon the capacity of the soil to store and supply water. Soil may contain large amount of water but the water stored between field capacity (upper limit) and permanent wilting point (lower limit) is the available water for plant growth.

Different methods of scheduling irrigation following soil moisture regime approach are as follows:

- **Feel and appearance of soil**

This is one of the oldest and simple methods of determining the soil moisture content. It is done by visual observation and feel of the soil by hand. The accuracy of judgement improves with experience.

Based on several years of experience guidelines have been developed which help the farmers to judge the soil moisture present in the soil samples drawn from the crop root

zone depth and based on depletion of available soil moisture (DASM) irrigations are scheduled.

Description on the guide for judging moisture deficiency for different soils is given in Table.

% Moisture between FC and PWP	Soil type			
	Course	Light	Medium	Heavy
0	Dry and flows through fingers	Dry, loose and flows through finger	Dry and easily breakdown to powdery	Hard and has loose crumbs on surface
50 or less	Appears dry and will not form ball with pressure	Appears dry and will not form ball	Somewhat crumbly holds together under pressure	Somewhat pliable and easily form ball under pressure
50-75	Appears dry and will not form ball under pressure	Tends to ball under pressure but seldom holds together	Forms ball somewhat plastic will stick with pressure	Form ball and ribbons out between thumb and forefingers
75 to FC	Tends to stick together and forms ball very weak under pressure	Forms very weak balls and breaks easily and will not stick	Forms ball and readily sticks if high in clay content	Easily ribbon out between thumb and forefingers has stick feeling
FC	Wet out line of ball is left on hand upon squeezing	Same as coarse soil	Same as coarse soil	Same as coarse soil
Above FC	Free water is appeared when soil is squeezed	Free water released with kneading	It can squeeze out free water	Puddles and free water on soil surface

- **Depletion of the available soil moisture (DASM)**

In this method the permissible depletion level of available soil moisture in the effective crop root zone depth is commonly taken as an index or guide for scheduling irrigations to field crops. In general, for many crops scheduling irrigation's at 20 – 25% DASM in the soil profile was found to be optimum at moisture sensitive stages. While at other stages irrigations scheduled at 50% DASM were found optimum.

- **Soil moisture tension**

Soil moisture tension a physical property of film water in soil, as monitored by tensiometers at a specified depth in the crop root zone could also be used as an index for scheduling irrigations to field crops.

Tensiometers are installed in pairs, one in the maximum rooting depth and the other below this zone. Whenever critical soil moisture tension is reached say for example 0.4 or 0.6 or 0.75 bars etc in the upper tensiometer the irrigation is commenced. While the lower one (tensiometer) is used to terminate the irrigations based on the suction readings in the below soil profile zone. It is generally used for irrigating orchards and vegetables in coarse textured soils because most of the available soil moisture is held at lower tensions.

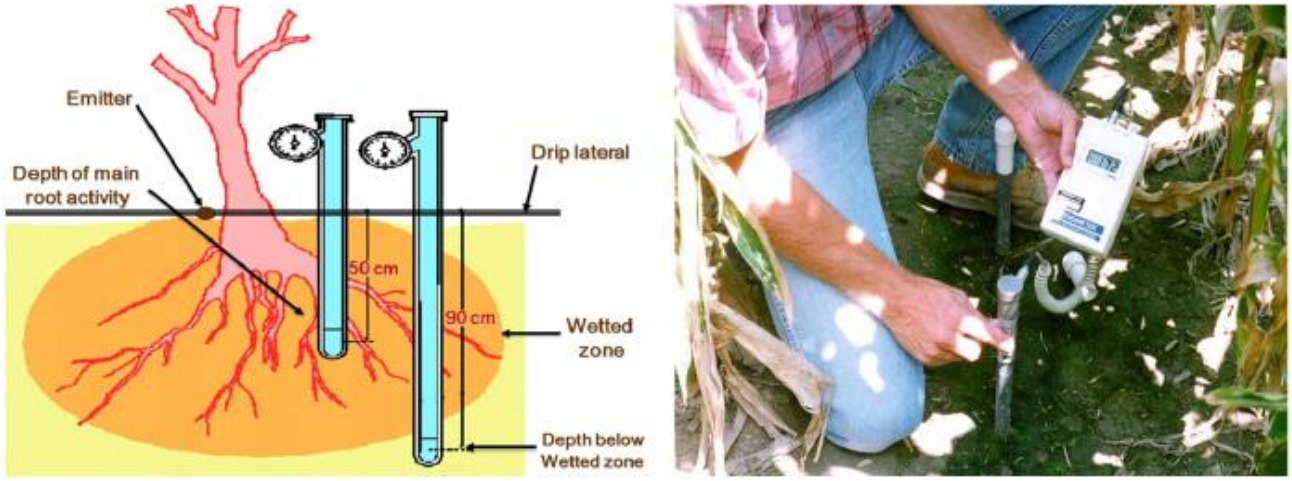


Fig.: Tensiometers for irrigation scheduling

B. Climatological Approach

The potential rate of water loss from a crop is primarily a function of evaporative demand of the atmosphere under adequate soil water conditions. Thus in this method the water loss expressed in terms of either potential evapotranspiration (PET) or cumulative pan evaporation (CPE) over short periods of time are taken as an index for scheduling irrigation's. Different climatological approaches are described below:

- **Cumulative pan evaporation**

Transpiration of a crop is closely related to free water evaporation from an open pan evaporimeter. Thus, the open pan evaporimeter being simple and as they incorporate the effects of all climatic parameters into a single entity i.e., pan evaporation could be used as a guide for scheduling irrigation's to crops. USWB Class A Pan evaporimeter is used.

- **IW : CPE ratio**

Prihar*et al*. (1974) advocated irrigation scheduling on the basis of ratio between the depth of irrigation water (IW) and cumulative evaporation from USWB class A pan evaporimeter minus the precipitation since the previous irrigation (CPE). An IW/CPE ratio of 1.0 indicates irrigating the crop with water equal to that lost in evaporation from the evaporimeter.

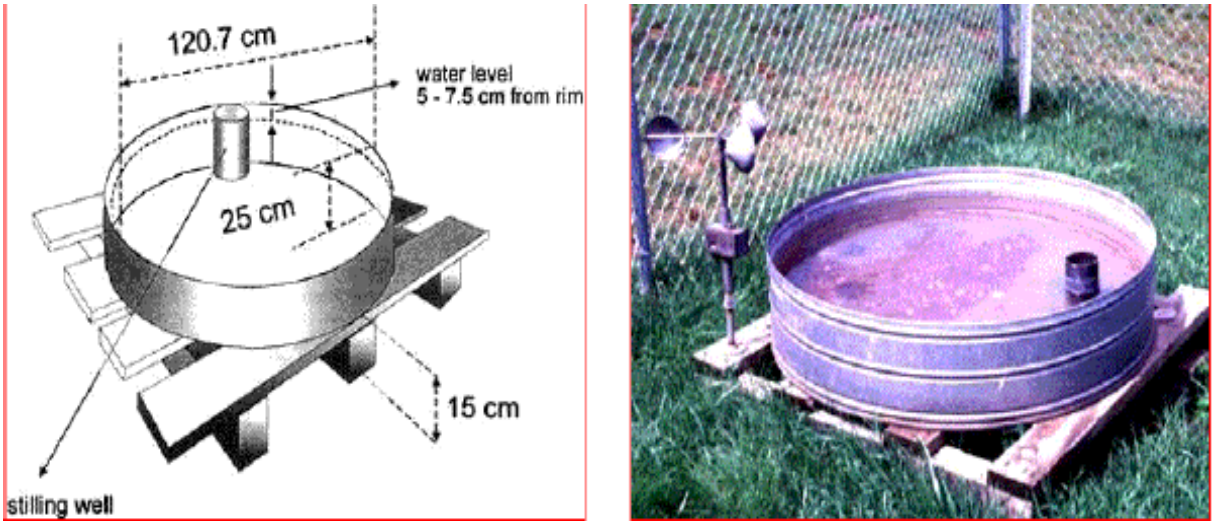


Fig. : USWB Class A Panevaporimeter

The irrigation scheduling is based on the cumulative pan evaporation and irrigation depth.

Irrigation at ratio of irrigation water (IW) and cumulative pan evaporation (CPE).

$$\text{IW/CPE} = \frac{\text{Depth of water to be irrigated (mm)}}{\text{Cumulative pan evaporation for particular period (mm)}}$$

For an example, if irrigation is scheduled at 0.7 IW/CPE ratios and the depth of irrigation water is 5.5 cm, then irrigation would be given when the CPE would reach at **78.6 mm**.

0.7 IW/CPE ratios with 5.5 mm irrigation water depth

$$0.7 = \frac{\text{Depth of water to be irrigated (mm)}}{\text{Cumulative pan evaporation for particular period (mm)}}$$

$$0.7 = \frac{\text{5.5 cm i.e.55 mm}}{\text{CPE (mm)}}$$

$$\text{CPE} = \frac{55}{0.7} = \frac{550}{7} = 78.6 \text{ mm}$$

When CPE value reached at 78.6 mm, then irrigation should schedule to a crop.

IW/CPE three things are keep in mind for scheduling of irrigation based on IW : CPE ratio

1. CPE = IW / Ratio
2. IW = Ratio x CPE
3. Ratio = IW / CPE

C. Plant Indices Approach

- **Visual plant symptoms**

In this method the visual signs of plants are used as an index for scheduling irritations. For instance, plant wilting, drooping, curling and rolling of leaves in maize is used as indicators for scheduling irrigation. Change in foliage colour and leaf angle is used to time irrigations in beans. Water stress in some crops leads to appearance of carotenoid (yellow and orange colour), which can be used as indices for scheduling irrigations to crops.

- **Plant Population**

In an alleviated area, one square plot is selected and crop is grown with four times thicker than normal seed rate. Because of high plant density, plants show wilting symptoms earlier than in the rest of the crop area, indicating the need of scheduling irrigation.

- **Canopy temperature**

Several studies have shown that plant temperature or canopy temperature adequately reflects the internal water balance of the plant, and can be used as a potential indicator for scheduling irrigation to crops. It can be measured by several instruments, which are commercially available viz., porometer, infrared thermometer etc.

For maize it is shown that if the canopy temperature rises to more than 0.7 ^{0}C over ambient temperature during 1330 to 1400 hour's irrigations need to be scheduled.

- **Critical growth stages**

The crop plants in their life cycle pass through various phases of growth, some of which are critical for water supply. In each crop, there are some growth stages at which moisture stress leads to irrevocable yields loss. These stages are known as critical period or moisture sensitive period. The most critical stage of crop growth is the one at which a high degree of water stress would cause maximum loss in yield. Or The stages of the crop at which moisture stress affects the yield significantly are called critical growth stages.

Scheduling of irrigations on the basis of critical growth stages is simple and easy for the farmers. However, it does not take into account the available soil water in the crop root zone depth. Excessive irrigations without significant soil/ plant water deficit could be harmful to crop plants and might reduce their yield under certain situations. The criterion may not hold well in long duration crops like sugarcane, cotton; crops requiring frequent irrigation's viz., potato or standing/nearly standing water (rice) and where there is interference by rainfall of different amounts.

Table : Critical growth periods of crops for water supply

Name of the crop	Critical stages
Wheat	CRI (most critical), tillering, jointing, booting, milking and dough
Paddy	Seeding, tillering, heading, flowering, milking
Maize	Vegetative growth, tesseling, grain setting
Sorghum	Late seedling, pre-flowering, milking and dough
Green gram	Branching, flowering, pod formation
Castor	Before flowering
Cotton	Pre-flowering, flowering, boll formation
Groundnut	Branching, flowering, peg initiation, peg penetration, pod formation and pod development
Sugarcane	Sprouting, grand growth period
Gram	Flowering, pod development
Potato	Stolenization to tuber initiation, tuber formation

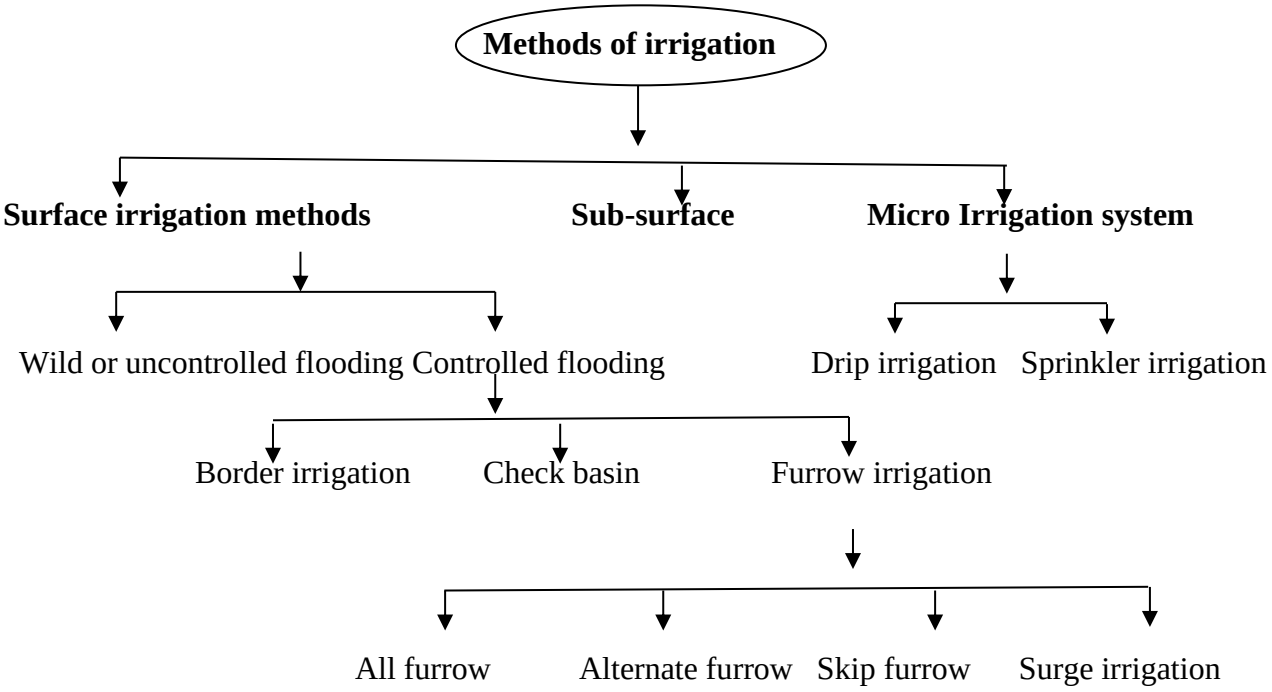
Topic 18: Methods of irrigation including micro irrigation system

There is a need to bring more and more cultivable land under irrigation for assuring crop production to meet the food requirement of our ever-increasing population. It is therefore, necessary to attain maximum efficiency in the application of the existing irrigation potential in the country. Although some improved methods of application of irrigation water like sprinkler system and drip system are being popularized yet, comparatively a larger irrigated area in this country is still irrigated by conventional surface methods.

Irrigation application methods are adopted in different conditions in order to achieve high irrigation efficiency in crop production. Each method differ has unique advantages and disadvantages depending upon (i) Initial cost (ii) shape and size of the field, (iii) soil characteristics, (iv) nature and availability of water supply, (v) climate, (vi) cropping patterns, etc.

Factors affecting the adoption of irrigation methods

1) Topography
2) Soil type and conditions
3) Crops to be grown, nature and its habit of growth
4) Value of the crop
5) Cultural practices are to be required
6) Season of the crops
7) Sources of water
8) Skill and expenditure involved in method and its operation
9) Cost of installation
10) Efficiency that can be achieved



A. Surface irrigation methods

Surface irrigation methods are being classified based on slope, shape and size of the field, the end conditions and how water flows into and over the field.

1. Wild or uncontrolled flooding

In this method water is applied over the smooth or flat field without much control over the flow or prior preparation. The water is applied into the field from the ditch excavated either on the contour or up and down the slope. The water distribution is quite uneven.

Advantages

- Minimum labour requirements
- System does not interfere for the use of farm implements in standing crop.
- Rough levelled field may also be irrigated under wild flooding

Disadvantages

(i) Wastage of water,

(ii) Non-uniform distribution of water,

(iii) Excessive soil erosion and

(iv) Require drainage arrangement to reduce flooding.

2. Controlled flooding

In this method, irrigation is applied by flooding but with some control as per demand of soil, crop and water supply. The following are most common methods used under field conditions:

1. Border irrigation

The land is divided into number of long parallel strips called borders. These borders are separated by low ridges. The border strip has a uniform gentle slope in the direction of irrigation. Each strip is irrigated independently by turning the water in the upper end. This method is suitable to all close growing crops like wheat, barley, fodder and legumes. A uniform moisture distribution can be achieved by this method with good water use efficiency.

Advantage

1. Border ridges can be constructed with simple farm implements like bund former.
2. Labour requirement in irrigation is reduced as compared to conventional check basin method.
3. Uniform distribution of water and high water application efficiencies are possible.
4. Due to longer strip size inter-cultivation is possible.

2. Check basin irrigation

Check basin irrigation is most common (popular) method of irrigation in India and in many other countries. The field is divided into smaller plots to bring unit area forming basins within which irrigation water can be controlled. The basins are filled to the desired depth and water is retained until it infiltrates in to the soil. The size and shape of the

check basin depends upon soil type, infiltration rate, size of stream and crop to be grown. The shape of check basin may be square or rectangular.

Basins for orchards (wide spaced crops) prepared generally in ring (circular around tree) and the rings are connected with water channel. The rings prepared in orchards are small during young stage.

Advantages

1. Simplest method
2. Helps in conservation of rainfall in the field and reduce erosion of soil due to run-off.
3. Helps in removal of salts from soil profile through leaching requirement.
4. Uniform distribution of water is possible.

Disadvantages

1. Wastage of land in preparation of bunds and channels is more over other surface methods.
2. Interfere in carrying out agricultural operations due to bunds and channel
3. Labour requirement is higher.
4. Not suitable for crops which are sensitive to wet soil conditions around the stem.

3. Furrow irrigation

In furrow irrigation method, water is applied through small stream running between the crop rows. This method of irrigation is suitable for row crops like sugarcane, tobacco, potato, cotton and some vegetable crops.

In general, small plants require small furrows, larger plants permits large furrows. Furrows of 7.5 to 12.5 cm depth are appropriate for vegetables, while some row crops and orchards require much deeper furrows.

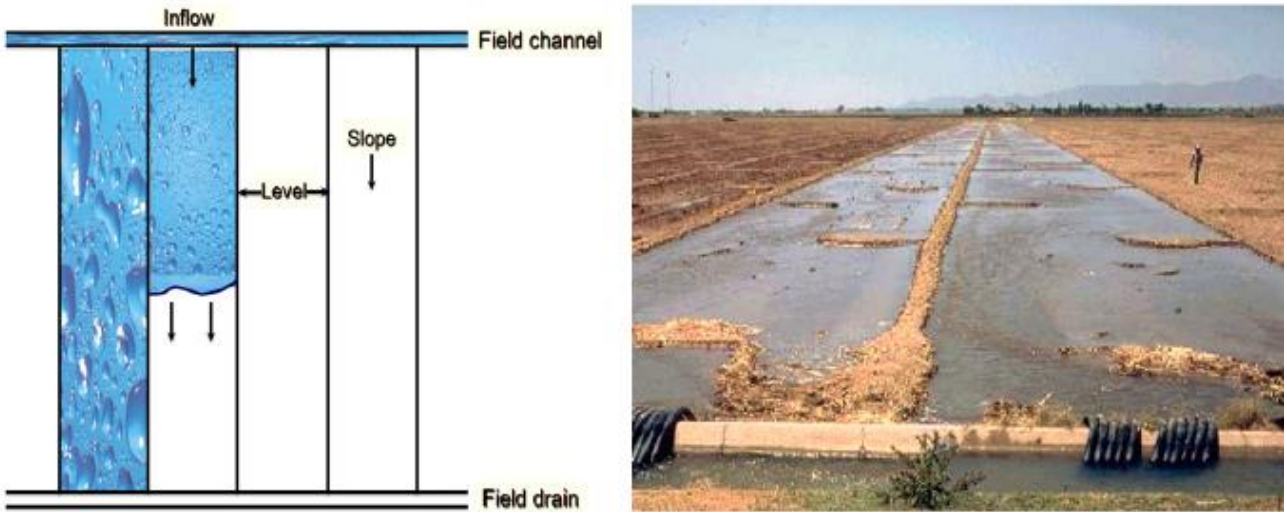


Fig.: Border strip method of irrigation

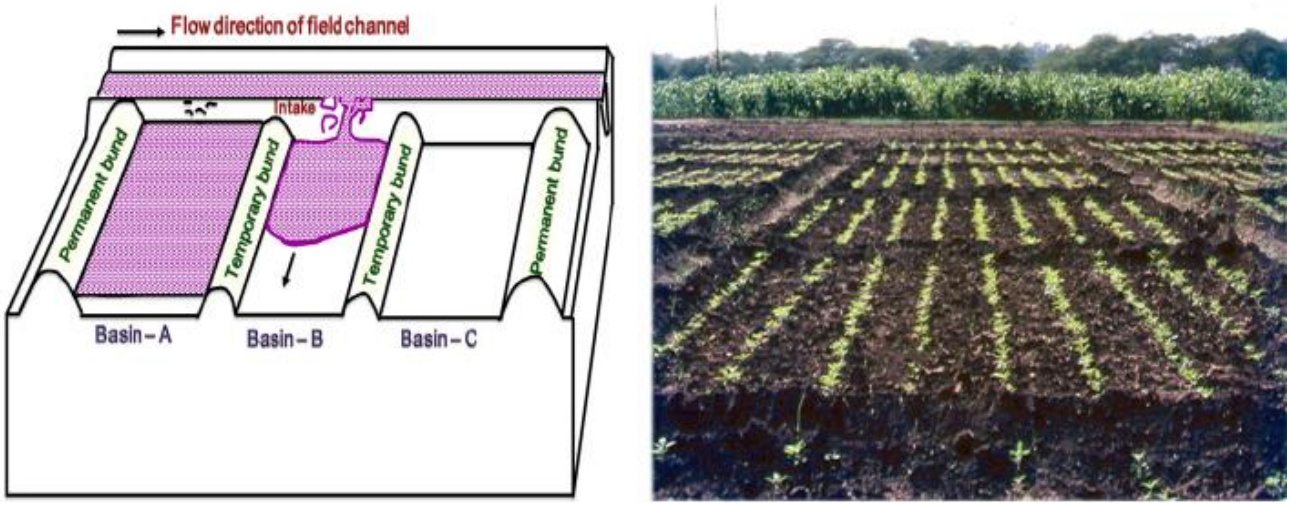


Fig. : Check basin method of irrigation

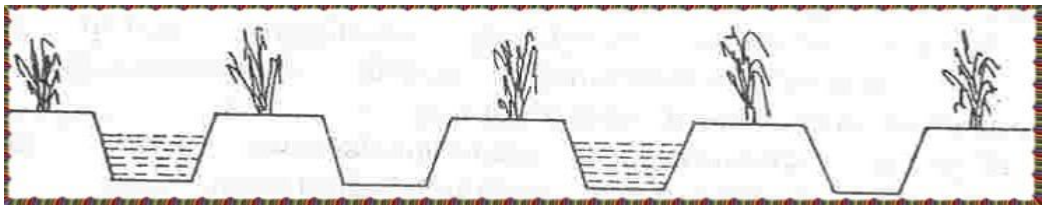
Advantages

- Both large and small streams can be used.
- The furrow can be used to disposed- off excess water of irrigation or run-off from rainfall rapidly.
- Wastage of land is very low.
- Labour requirement is very low for layout and application of water.
- Wastage of water is very low, only a limited surface of land is wetted and hence WUE is much high as compared to all other surface methods.
- Weeds can be controlled mechanically, between the beds, early in crop cycle.
- Less lodging occurs.

Type of furrow

A. All furrow irrigation: Water is applied evenly in all the furrows and are called furrow system or uniform furrow system.

B. Alternate furrow irrigation: It is not an irrigation layout but a technique for water saving. Water is applied in alternate furrows for eg. During first irrigation if the even numbers of furrows are irrigated during next irrigation the odd number of furrows will be irrigated.



C. Skip furrow irrigation: They are normally adopted during the period of water scarcity and to accommodate intercrops. In the skip furrow irrigation a set of furrows are completely skipped out from irrigation permanently. The skipped furrow will be utilized for raising intercrop. The system ensures water saving of 30-35 per cent. By this method the available water is economically used without much field reduction.

D. Surge irrigation: Surge irrigation is the application of water in to the furrows intermittently in a series of relatively short On and OFF times of irrigation cycle. It has been found that intermittent application of water reduces the infiltration rate over surges thereby the water front advances quickly, hence, reduced net irrigation water

requirement. This also results in more uniform soil moisture distribution and storage in the crop root zone compared to continuous flow.

B. Sub-surface irrigation

- In subsurface irrigation water is applied beneath the ground by creating and maintaining an artificial water table at some depth. Usually 30-75 cm below the ground surface.
- Moisture covers upwards towards the land surface through capillary action.
- Water is applied through underground field trenches laid 15-30 m apart.
- Open ditches are preferred because they are relatively cheaper and suitable to all types of soil.
- The irrigation water should be good quality to prevent soil salinity.

Advantage

1. Minimum water requirement for raising crops
2. Minimum evaporation and deep percolation losses
3. No wastage of land
4. No interference to movement of farm machinery

Disadvantages

1. Requires a special combination of natural conditions.
2. There is danger of water logging.
3. Possibility of choking of the pipes lay underground.
4. High cost.

C. Micro irrigation system

The term micro irrigation is commonly used to describe several low - pressure irrigation systems including drip/trickle.

1. Sprinkler irrigation

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil.

Components of sprinkler irrigation system

A. sprinkler system usually consists of the following components:

i) A pump unit

ii) Tubing's- main/sub mains and laterals

iii) Couplers

iv) Sprinkler head

v) Other accessories such as valves, bends, plugs and risers

Adaptability

- When water is a scarce (limited)
- Uneven topography of land
- Nursery of crops, which require rainfall type irrigation
- Sandy soils that have a high infiltration rate
- Most field crops except paddy and Jute

Advantage of sprinkler irrigation

1. Water saving to an extent of 35-40% compared to surface irrigation methods.
2. Sprinkler method is suitable for soils having high infiltration rate.

3. Land grading and land levelling is not essential
4. Suitable for high value crops, especially the fruits and vegetable.
5. Nutrients can be applied with the irrigation water, as per requirement of the crop, and hence increases the fertilizer use efficiency by more than 40%.
6. Controlled water application leading to higher application efficiency.
7. Irrigation is possible in area at higher elevation than the source.
8. Drainage problems eliminated

Disadvantages

1. High initial cost
2. Efficiency is affected by wind
3. Higher evaporation losses in spraying water
4. Not suitable for tall crops like sugarcane
5. Poor quality water cannot be used (Sensitivity of crop to saline water and clogging of nozzles)
6. Operation and maintenance require technical manpower.
7. Pollination of crop is adversely affected (Paddy and Jute).

Fig.: Sprinkler system

2. Drip Irrigation

Drip irrigation also known as trickle irrigation system is a technique by which water and fertilizer including chemicals can be placed at the direct disposal of the root zone with the help of a specially designed dripper. Water is applied as continuous drops or fine spray through emitters placed along a low pressure delivery system. Such system provides water precisely to plant root zones and maintains ideal moisture conditions for plant growths.

Components of drip irrigation

A. Head control unit:

i). Pump/Overhead Tank ii). Fertilizer Applicator iii). Filters (Gravel or Media Filter, Screen Filters, Disk Filters)

B. Distribution network:

i). Mainline ii). Sub-mains iii). Laterals iv). Emitters / Drippers (Online Pressure Compensating drippers, Online Non-Pressure Compensating drippers, In-Line Drippers or Inline tubes)

C. Accessories

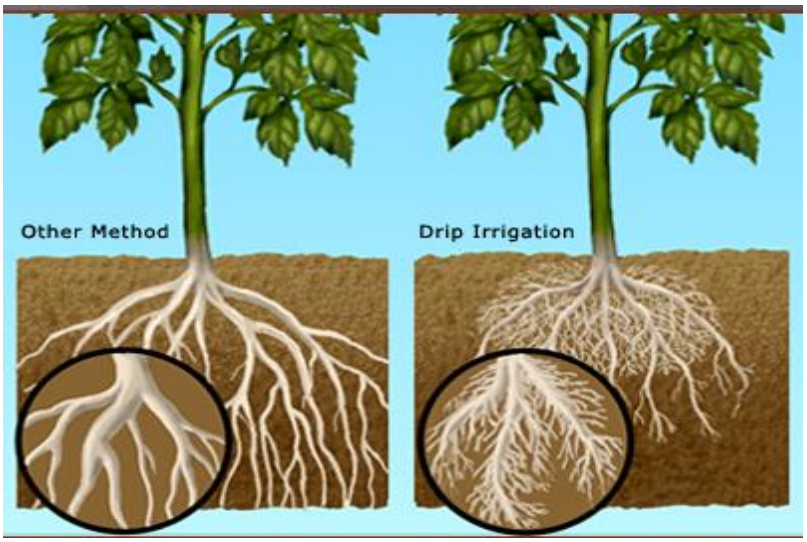
i) Gate valve ii) tee iii) elbow iv) end cap v) grommet take off

All these components are available in 4,10,12,16 and 20 mm sizes. These takeouts/starter and rubber grommet are used for taking out lateral lines from submain, Connector, tee, band and end caps are used in drip laterals.

Water use efficiency is always higher in trickle irrigation system as compared to other irrigation methods because water is applied drop by drop to the root zone areas directly with the emitters and hence, application losses, seepage, percolation and evaporation losses are negligible. The water is only applied as per the requirement and hence, crop growth is also more and not adversely affected. Operational cost is also low after installation. Fertilizers and pesticides (fertigation and chemigation) are directly applied to the root zone under this system has better utilization and leaching loss of

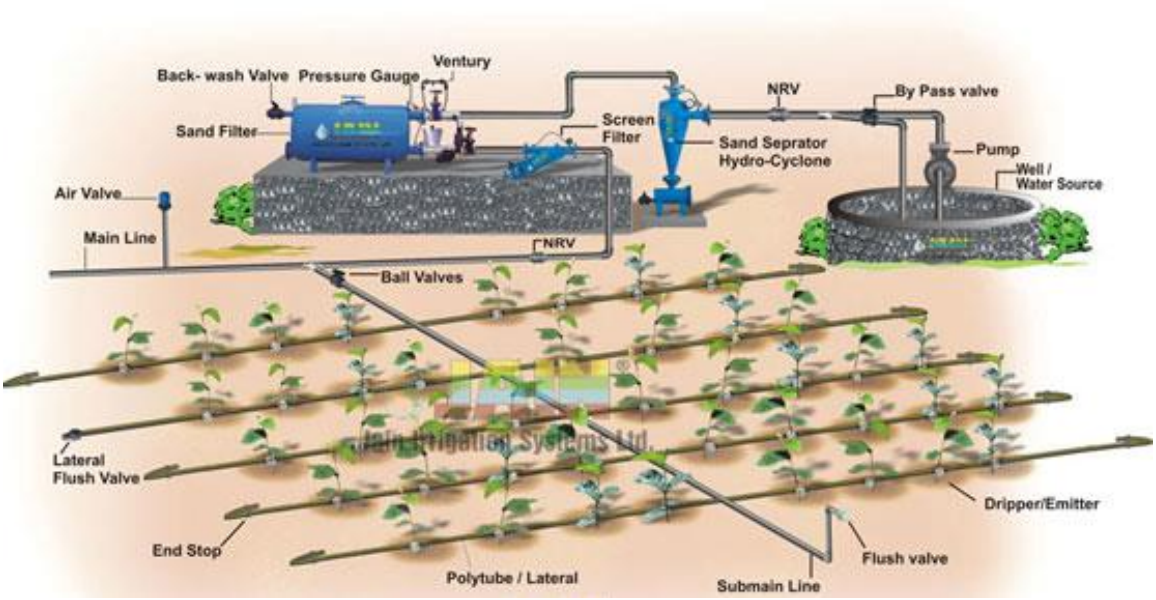
nutrient is very less. Considering all these factors, less water utilization, more water saving, results in higher water use efficiency.

Research experiments conducted on various crops indicated that drip system not only save irrigation water but also increase the net profit. Some of the research findings are given below in Table.



Name of the crops, water saving and production increased under drip irrigation system over traditional method of irrigation

Sr. No.	Crop	Water saving (%)	Increased production (%)
1	Sugarcane (Navsari)	47	48.4
2	Cotton (Rahuri)	43	40.0
3	Onion (Coimbatore)	60	20.0
4	Bottle guard ('')	12	46.8
5	Potato ('')	50	46.0
6	Tomato ('')	71	43.0
7	Chili ('')	62	44.0
8	Radish ('')	77	73.0
9	Beat ('')	80	73.0
10	Okra ('')	84	13.0
11	Okra (Rahuri)	39.6	16.1
12	Brinjal ('')	55.8	17.5
13	Brinjal (Anand)	24.6	---
14	Cabbage (Rahuri)	59.6	23.5
15	Karela (Rahuri)	52.7	13.5
16	Turia ('')	58.9	17.7
17	Potato (Hisar)	20	48.0
18	Potato (Udepur)	47	74.2
19	Beat (Hisar)	47	17.0
20	Onion (Hisar)	25	31.0
21	Bottle guard (Jodhpur)	12	47.0
22	Cabbage (Dharwad)	46	17.6
23	Water/musk melon (Jodhpur)	70	179
24	Tomato (Baroda)	50	45.0
25	Tomato (Navsari)	44	57.4
26	Potato (Deesa)	44	26.0
27	Santara (Vidarbh)	22	55.0
28	Banana (Yaval)	62	35.8
29	Banana (Navsari)	43	16.5
30	Banana (Coimbatore)	77	40.0
31	Papaya ('')	68	77.0
32	Lime (Baroda)	81	34.0
33	Grape (Parabhani)	55-63	40.0
34	G.nut (Baroda)	40	66.0
35	Grape (Coimbatore)	60	69.0
36	Mosambi (Parabhani)	55-63	40.0
37	Pomegranate (Rahuri)	44.6	30.0



Layout plan of Drip irrigation system

Advantages

i. Water saving

ii. Enhanced plant growth and yield of better quality

iii. Reduced salinity hazards to plants

iv. Fertilizer and other chemicals application

v. Higher efficiency of all chemicals

vi. Reduced weed growth

vii. Labour saving

viii. Highly suited to poor soils

ix. Efficiency in cultural operations

Disadvantages

i. High initial investment

ii. Clogging of drippers by suspended materials, salts oxides of iron, organic material

iii. Interferes with farm operations and movement of implements and machineries

iv. Operational difficulties: Installation, maintenance

v. Problem of theft, rodents etc.

vi. Not highly suited to closed spaced crops like wheat, rice etc.

Topic 19 : Quality of water, water logging

In irrigated agriculture, the quality of water used for irrigation should receive adequate attention. Irrigation water, regardless of its source, always contains some soluble salts in it. Raindrop reaches the surface on earth, different kinds of gases and suspended materials of the atmosphere mix with it.

Water being a universal solvent, many kinds of salts is dissolved in it. Apart from the total concentration of the dissolved salts, the concentration of some of the individual salts, and especially of those which are most harmful to crops, is important in determining the suitability of water for irrigation. Irrigation water contains 10 – 100 times more salt than rain water. Thus, each irrigation event adds salts to the soil.

The constituents usually determined by analyzing irrigation water are the electrical conductivity for the total dissolved salts, soluble sodium percentage, sodium absorption ratio, the boron content, pH, cations (calcium, magnesium, sodium, potassium) and anions (carbonates, bicarbonates, sulphates, chlorides and nitrates).

Quality of water refers to the degree of suitability for crop growth and it depends on the nature and amount of dissolved salts. The water contains dissolved and undissolved impurities. The undissolved impurities are organic matter, plant residues, sand, silt and clay. The minor impurities do not affect pH, EC but total salt concentration is decided by the Ca, Mg, Na and K (Cations) and CO_3, HCO_3, Cl and SO_4. The boron concentration >2 ppm also affects plant growth. Soil salinity and alkalinity of the soil is depends on quality of irrigation water as the salts present in water affects nature and properties of soil. If water contains hazardous limit of elements (salts) not only injurious to plant but may affect the soil productivity. Therefore, it is necessary to determine the quality of irrigation water before it is used for irrigation water.

❖ Criteria for water quality

The United States Soil Salinity Laboratory (USSSL) in 1954 proposed different criteria to determine the quality of irrigation water. The following characteristics of water are most important in determining quality of irrigation water.

1. Total concentration of soluble salts (Salinity hazards)
2. Relative concentration of Na^{+} to other cations (Sodium hazards)
3. Bicarbonate concentration as related to $Ca^{+2} + Mg^{+2}$ (RSC hazards)
4. Concentration of boron (Boron hazards)
5. Toxic effects of certain constituents (Other hazards)

1) Total salt concentration (Salinity hazards)

Total soluble salt concentration of irrigation water is expressed as electrical conductivity (EC) in µmhos/cm or dSm^{-1}. The water with high salt content is known as saline water. The salinity of the soil ultimately depends on the amount and kind of salt carried by irrigation water and that accumulated in the soil.

Rating of salinity hazard is as under

EC	**Low**	**Medium**	**High**	**Very high**
dS/m	< 0.25	0.25-0.75	0.75-2.25	>2.25
Water class	C_1	C_2	C_3	C_4
Water quality	Good	Medium	Poor	Very poor
Soil	Most of the soil is used	Safely used if leaching is possible	Adequate drainage is required, Agronomic management practices to be followed	Under special circumstances, Agronomical management practices to be followed, permeable soil

Adverse effects of saline water

Salt accumulation, increase in osmotic potential, decreased water availability to plants, poor germination, stunted growth with smaller, thicker and dark green leaves, leaf necrosis & leaf drop, root death, wilting of plants, nutrient deficiency symptoms and poor crop yields.

2) Alkali hazards (Sodium hazard) or Relative concentration of Na^+ to other cations

Water having high Na concentrations converted normal soil into alkali soils. The alkali hazard involved in the use of water for irrigation is determined by the soluble and relative concentration of the cations. If the proportion of Na is high, the alkali hazard is high and conversely, if Ca and Mg predominant, the hazard is low. It means that use of irrigation water having excess Na results in formation of alkali soils.

The physical condition of soil is deteriorated. The soils are characterized by poor tilth and low permeability. The sodium hazard of irrigation water is measured by the concentration of sodium (Na) relative to Ca and Mg called SAR (Sodium adsorption ratio). It is suggested by USSSL.

SAR Rating

SAR value	Symbol	Class of water	Preference
< 10	S_1	Low Na	Most soil with little damage of harmful Na level development
10-18	S_2	Medium Na	Sodium hazard likely in fine textured soil. High permeability of soil is required
18-26	S_3	High Na	May produce harmful level of ESP in most of the soil, Agronomical practices required, drainage, leaching and organic matter is also required.
> 26	S_4	Very high Na	Not suitable for irrigation except low to medium salinity under special management practices

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca+Mg}{2}}}$$

3) Bicarbonate concentration in relation to Ca + Mg (RSC hazard)

The sodium hazard of irrigation water as expressed by SAR does not take into account the effect of an ionic composition. In irrigation water containing high concentration of bicarbonate ions, there is a tendency for Ca and Mg ions to precipitate in the form of carbonate as the soil solution becomes more concentrated, thus resulting in increase of ESP of the soil. Eaton (1950) hence, suggested the concept of Residual Sodium Carbonate (RSC) for evaluating high carbonated water as the difference between (CO_3+ HCO_3) and (Ca + Mg).

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \text{ - Values in meq/litre}$$

$$Ca + 2HCO_3 = CaCO_3 + CO_2 + H_2O$$

R S C rating (Meq/litre)

RSC rating	Water class (Quality)
< 1.25	Good water, if RSC is negative, then water is of very good quality.
1.25 to 2.50	Marginal good, can be used on light textured soil with adequate leaching and application of gypsum
> 2.50	Not suitable for irrigation

4) Boron hazard

Boron at low concentration is not harmful to plants and may be beneficial. Water containing 1.0 ppm of boron can still considered as safe for most field crops. Boron is not uncommon in well water and toxic level may reach by irrigating with such waters. It does not affect the physical and chemical properties of soil but at high concentration it affects the metabolic activities of the plant (stunted growth). Permissible limit of boron (ppm) for several classes of irrigation water as suggested by USSSL are as under.

Boron water class	Born content (ppm)		
	0.3 to 1.0	**1.0 to 2.0**	**2.0 to 4.0**
	Sensitive crop	**Semi sensitive crop**	**Tolerance crop**
Excellent	< 0.33	< 0.67	< 1.0
Good	0.33 to 0.67	0.67 to 1.33	1.0 to 2.0
Medium	0.67 to 1.0	1.33 to 2.0	2.0 to 3.0
Unfit	> 1.25	> 2.50	> 3.75
Crops	Apple,Grape, Orange,Lemon, Grape fruit	Sunflower,Potato, Cotton,Radish, Fieldpea, Barley,Wheat, Corn,Sweet potato,	Palm, Datepalm, Sugarbeat,Lucerne, Onion,Turnip, Cabbage, Lettuce, Carrot

5) Other hazards

Chloride: If the chloride content is more in the irrigation water, keeping quality of the farm produce may affect.

Fluorine: Higher fluorine affects the human health.

❖ **Management practices for using poor irrigation water**

Some of the important management practices are

(1) Application of gypsum

(2) Alternate irrigation strategy

(3) Fertilizer application

(4) Methods of irrigation

(5) Crop tolerance

(6) Method of sowing and

(7) Other management practices

❖ Management practices for using poor quality water

Whenever, it is inevitable to use of poor quality water for crop production appropriate management practices helps to obtain reasonable yield of crops. Some of the important management practices are as follows:

a) Application of gypsum

Chemical amendments such as gypsum, when added to water will increase the calcium concentration in the water, thus reducing the sodium to calcium ratio and the SAR, thus improving the infiltration rate. Gypsum requirement is calculated based on relative concentration of Na, Mg &Ca ions in irrigation water and the solubility of gypsum. To add 1 meq/L of calcium, 860 kg of gypsum of 100% purity per ha m of water is necessary.
Due to its low solubility (0.25-0.30%) and cost, gypsum (hydrated calcium sulphate) is suitable for creating a favorable Ca: Na. Gypsum used for agriculture purpose should be 65% pure. Gypsum has to be powdered up to 0.5 mm size or passed through 30 mesh sieve.

b) Alternate irrigation strategy

Some crops are susceptible to salinity at germination and establishment stage, but tolerant at later stage. If susceptible stages are ensured with good quality water, subsequent tolerant stages can be irrigated with poor quality saline water.

c) Fertilizer application

Fertilizers, manures and soil amendments include many soluble salts in high concentrations. If it is applied too close to the germinating seedling or to the growing plant, the fertilizer may cause salinity or toxicity problem. Therefore, care should be taken in placement as well as timing of fertilization.

Application of fertilizers in small doses and frequently improve uptake and reduce damage to the crop plants.

d) Methods of irrigation

The method of irrigation directly affects both the efficiency of water use and the way salts accumulate. Poor quality irrigation water is not suitable for use in sprinkler method of irrigation. Crops sprinkled with waters having excess quantities of specific ions such as Na and Cl cause leaf burn.

High frequency irrigation in small amounts as in drip irrigation improves water availability and uptake due to micro leaching effect in the wetted zone.

e) Crop tolerance:

The crops differ in their tolerance to poor quality waters. Growing tolerant crops when poor quality water is used for irrigation helps to obtain reasonable crops yields. Relative salt tolerance of crops is given in Table.

Relative tolerance of crops to salinity			
Sensitive	**Moderately Sensitive**	**Moderately Tolerant**	**Tolerant**
Apple	Cabbage	Safflower	Barley
Carrot	Corn	Soyaben	Cotton
Lemon	Cowpea	Wheat	Date plam
Ladies finger	Grape		Sugar beet
Onion	Groundnut		
Orange	Potato		
Pulses	Rice		
	Sugarcane		
	Tomato		
	Raddish		
	Sesbania		
	Sorghum		

f) Method of sowing:

Salinity reduces or slows germination and it is often difficult to obtain a satisfactory stand. Suitable planting practices, bed shapes, and irrigation management can greatly enhance salt control during the critical germination period. Seeds have to be placed in the area where salt concentration is less. Salt accumulation is less on the slope of the ridge and bottom of the ridge. Therefore, placing the seed on the slope of the ridge, several cm below the crown, is recommended for successful crop establishment.

g) Drainage

In order to maintain a satisfactory salt balance in the root-zone excellent drainage of soil is most essential.

h) Other management practices

1. **Selection of seedlings:** Transplantation of rice with over aged seedlings results in better establishment in salt affected soil than normal aged seedlings. Closer planting has to be adopted for compensating the yield reduction caused by planting over aged seedlings. In case of other crops like finger millet, pearl millet etc. transplanting is the better method than direct sowing of these crops for proper establishment.
2. **Mulching:** Mulching with locally available plant materials help in reducing salt affected problems by reducing evaporation and by increasing infiltration. Salts are leached into lower layers even with rainfall by application of mulches.
3. **Soil management:** All soil management practices that improve the infiltration rate and maintain favorable soil structure reduce salinity hazard.
4. **Crop rotation:** Inclusion of crops such as rice in the rotation reduces salinity.
5. **Climate:** Temperature, rainfall and its distribution, wind velocity and relative humidity are all factors directly effecting duty of water. The duty of water in crops lessens during summer season.
6. **Time and number of ploughing:** The ploughing of the field and hoeing of soil at proper time controls weeds and there is lesser loss of water from the soil resulting in higher duty of water.

7. **Slope of the land:** In land having steep slope water is generally lost by run off which results in loss of moisture from soil and needs frequent irrigation. Hence duty of water is reduced in sloppy lands.
8. **Velocity of water in canal:** Duty of water is positively correlated to the velocity of the water in canal.
9. **Type of crops:** Different crops have variable water requirement and consequently different duties of water. Sugarcane needs more irrigation compared to wheat and maize. Crops like sugarcane and paddy etc requiring more water have lesser duty of water.
10. **Skill of the farmer:** Flow irrigation has more duty of water because it needs great labour on the part of the farmer to uplift water. Hence such water is used with great care by the farmer.

❖ Leaching requirement (LR)

The leaching requirement is defined as the fraction of the irrigation water that must be leached through the root-zone to control soil salinity at any specified level so that crop growth is not affected adversely.

Irrigation water, even if of excellent quality, is a major source of soluble salts. An annual application of 1000 mm water containing 250 mg / 1 dissolved salts will add 2500 kg salts in one hectare land. To avoid soil salinization, these salts have to be leached out of the root-zone by water percolating to the sub soil. This percolation water will cause the ground water table to rise and has to be drained off because a second source of salinization in irrigated areas is capillary rise from a water table. As ground water is often somewhat saline, even a small amount of capillary rise can add greatly to the salinity of the root-zone. Hence, drainage, either natural or artificial is a necessary complement to irrigation.

Leaching requirement (LR) is the extra fraction of water expressed as a ratio or as per cent, needed to leach the salt from the soil at a given level. It is calculated by the formula as given below.

$$LR = \frac{Dd}{Di} = \frac{ECi}{ECd}$$

Where,

LR = Leaching requirement

Dd = Depth of drainage water

Di = Depth of irrigation water

ECi = Electrical conductivity of irrigation water

ECd = Electrical conductivity of drainage water

❖ Water logging

Water logging refers to the saturation of soil with water. Soil may be regarded as waterlogged when it is nearly saturated with water much of the time such that its air phase is restricted and anaerobic conditions prevail **or**

When the conditions are so created that the crop root-zone gets poor of proper aeration due to the presence of excessive moisture or water content, the tract is said to be waterlogged.

❖ Causes of Water Logging

1. Seepage from canal
2. Over and excess irrigation

3. Accumulation of rainwater in low-lying area.
4. Overflow of tanks, canals, rivers etc.
5. Adoption of inefficient irrigation method
6. Poor permeability with fine textured soil.

❖ Disadvantages of water logging

Most of field crops are susceptible to water logging or higher water table.

1. Excess water within root zone or high water table creates unfavorable soil physical conditions and affect on air and moisture relationship.
2. It develops anaerobe conditions, which reduces O_2 (Oxygen) concentration and increase the concentration of CO_2 (Carbon dioxide).
3. Anaerobic condition reduce uptake of plant nutrients and it reduce root activity and growth.
4. **It reduces activity of favorable microorganisms, which are responsible for nitrification and decomposition of organic materials.**
5. It is a cause for development of salinity and alkalinity.
6. Leaching of plant nutrient.
7. Conversion of available nutrient into unavailable form.
8. Plant stand reduces considerably resulting into low yield.
9. Accumulation of certain toxic substances in soil eg, Ethanol.

❖ Measures to control the water logging problems

1. Construction of surface and sub-surface drainage.
2. Installation of pumping sets to pump or lift out excess water.

3. Installation (digging) of shallow tube well.
4. Lining of canals and subsidiary channels to reduce the seepage.
5. Use of efficient method of irrigation.
6. Application of required quantity of irrigation water.

❖ **To overcome the ill effect of water logging, drainage is required as the majority of the agricultural crops are susceptible to water logged situation.**

Drainage

Drainage is a process of removal of excess gravitational water (superfluous or free or excess or drainable water) from the root zone area of soil profile by artificial means to enhance better aeration and crop production.

Drainage is required under the following condition

a) High water table
b) Water pounding on the surface for longer periods
c) Excessive soil moisture content above F.C. not draining easily as in clay soil
d) Areas of salinity and alkalinity were annual evaporation exceeds rainfall and capillary rise of ground water occurs
e) Humid region with continuous of intermittent heavy rainfall
f) Low laying flat areas surrounded by hills

Characteristics of good drainage system

1. It should be permanent
2. It must have adequate capacity to drain the area completely
3. There should be minimum interference with cultural operations
4. There should be minimum loss of cultivable area
5. It should intercept or collect water and remove it quickly within shorter period

Benefits of drainage

1. Helps in soil aeration

2. Facilitates timely tillage operations
3. Better and healthy root growth
4. Favours growth of soil microorganism (better mineralization)
5. Warming up for optimum soil temperature maintenance
6. Promotes leaching and reduce water logging
7. Improves anchorage and reduce lodging
8. Improves soil structure and decreases soil erosion
9. Improves sanitary and health conditions and makes rural life happy

Topic 20: Weeds: definition, classification and characteristics

The first person to use the word **“WEED"** in the present day meaning was **Jethro Tull (1731).** Subsequently several definitions were proposed as listed below;

- A weed is a plant growing where it is not wanted.
- Weed is an unwanted plant.
- A plant out of place or a plant with negative value.
- A plant that is extremely noxious, useless, unwanted or poisonous.
- Any plant or vegetation interfering with the requirements of human.
- Weeds are plants that thrive best in an environment disturbed by man.

Classification of Weeds

Out of 2,50,000 plant species, weeds constitute about 250 species, which are prominent in agricultural and non-agricultural system. Under world conditions about 30000 species is grouped as weeds. Out of these 18,000 species can cause damage to the crops.

Though weeds can be classified in different ways, the important classification that helps in selecting weed control methods are based on life cycle, cotyledons number and morphological characteristics. Weeds can be grouped for the convenience of planning, interpreting and recording control measures against them.

Classification of weeds

1. Based on morphology	2. Based on life cycle / ontogeny
3. Based on habitat	4. Based on origin
5. Based on association	6. Based on nature of stem
7. Based on soils	8. Special classification

1. Classification based on morphology/ cotyledon characters

During 1940 2,4-D was discovered and it was a selective translocated herbicide. After the discovery of the herbicide, classification based on morphology has got strong recognition as it controlled broad leaved weeds. The morphological classification is most important and useful in weed control. Morphological characters of plant are closely reacted to herbicidal absorption, retention and translocation. The weeds belonging to the same group are likely to have same kind of response to specific herbicides or cultural or mechanical methods.

This is the most widely used classification by the weed scientists. So, weeds are generally divided into three groups

1) Grasses **2) Sedges** **3) Broad leaved weeds**

Based on cotyledon characters they are classified into

Monocots	Dicots
1. Narrow and upright leaves	1. Broad & horizontal leaves
2. Parallel venation	2. Reticulate venation
3. Retention of herbicide is less	3. Retention of herbicide is more
4. Adventitious root system	4. Tap root system.
5. Cambium (conductive tissue) is scattered Eg Grasses or narrow leaved weeds	5. Conductive tissue intact Eg: Dicots *Amaranthus spp.* *Chenopodium album* *Convolvulus arvensis* *Phyllanthus niruri* *Parthenium hysterophorus* *Xanthium strumarium*

Note : Cyperaceae and typhaceae are not grasses even though they are narrow leaved

Grasses	Sedges
1. Stem is hollow except at nodes	1. Stem Angular & solid
2. Ligulate	2. Does not posses ligules
3. Alternate or opposite leaves *Eg, Digitaria, Cynadon*	3. Leaves in whorls around the stem *Eg. Cyprus*

2. Classification based on life cycle / ontogeny

Depending upon their life cycle, weeds can be classified as:

(1) Annuals

(2) Biennials and

(3) Perennials

A. Annual weeds : Annuals weeds grow and mature within a year of their germination, but more commonly they complete their life cycle in one season and propagate by seeds, e.g. **Summer annual** *Trianthema* spp. and *Digera arvensis*, **Winter annuals** *Chenopodium album*.

Phyllanthus fratenus 'Niruri' completes its seed to seed cycle within two or four weeks. Such short – lived annuals are called ***Ephemerals***.

General characteristics of annual weeds

(i) Annual weeds reproduce by abundant seed production; however, some like *Allium* spp. viz., wild onion and wild garlic may grow also from bulbs and bulbils.

(ii) They fail to re-grow when they are cut close to the ground level. These are known as simple annuals.

(iii) Several annual weeds possess crown buds which sprout into new shoots soon after the mother plant is de-topped.

(iv) Easy to control. Such weeds must be destroyed before they set seeds.

(v) Weed seeds remain dormant for several years; this makes weed eradication almost infeasible. Therefore, a farmer must be particular about not allowing the weeds to set seeds on his land.

B. Biennial Weeds

They complete their life cycle in two years; in the first year they remain vegetative stage and in the second year they produce flowers and set seeds. They may propagate either by seeds or vegetative parts or by both.

The usual feature of biennial weeds to flower in the second year of growth limits their dispersal through seeds very much. It is so because they get harvested along with the crop plants before they get a chance to set seeds (*Launea nudicaulis)*. The biennial weeds must be controlled in the first year of growth before these have a chance to store food in their roots.

C. Perennial Weeds

Perennial weeds grow more than two years.

1. Usually, perennial weeds flower for the first time in the second year of their growth and thereafter flower each year regularly.
2. Besides seeds, they reproduce vegetatively from underground specialized organs.
3. In tropical areas these remain green throughout the year although in subtropical regions they may undergo dormancy during the low temperature periods.

The control of perennial weeds is much more difficult than that of annuals. Neither tillage nor the present day selective herbicides can reach their deep roots and underground modified shoot systems. Therefore, attempts to suppress such weeds are usually made during the fallow seasons by deep summer tillage alongwith the application of herbicides.

3. Classification based on habitat

Depending upon the place of their occurrence they are classified into terrestrial and aquatic weeds.

A. Terrestrial weeds are again classified into

1. Crop land weeds **:** Weeds in field. eg*. Echinocloa* in rice.
2. Non-crop land weeds **:** Weeds in waste lands. eg. *Tribulus terrestris, Xanthium strumarium.*
3. **Grass land weeds** **:** e.g. *Vernonia and Cyperus rotundus.*
4. **Weeds of lawns & public parks:** e.g. *Eleusine indica*.
5. Orchard or garden weeds **:** e.g. *Cynodon dactylon and Cyperus rotundus*
6. Parasitic weeds **:** e.g. *Loranthus, Striga, Orobanch etc.*
7. Road side weeds : e.g. *Euphorbia hirta, Lantana camera, Prosopis juliflora etc.*

B. Aquatic weeds **:** They are classified into

1.Sub merged weeds **:**e.g. *Hydrilla Verticillata*
2.Emerged weeds **:**e.g. *Typha Spp.*
3.Floating weeds **:**e.g. *Eichhornia crassipes*

4. Classification based on origin

Many of our weeds in India originated in some other parts of the world.

Indigenous weeds

All the native weeds of the country are coming under this group and most of the weeds are indigenous. e.g. *Sorghum halepense, Cynodon dactylon, Echinochloa colonum etc.*

Introduced or Exotic weeds or Alien

These are the weeds introduced from other countries by any means. These weeds are normally troublesome and become difficult to control. e.g. *Parthenium hysterophorus, Acanthospermum hispidum, Eichhornia crassipes, Argemone mexicana, Lantana camara etc.* When man aids in its introduction such Weeds are called as Anthrophytes.

The origin of some important weeds is given in Table here under.

Weed species	**Probable originated from**
Convolvulus arvensis	Eurasia
Cyperus rotundus	Eurasia
Eichhornia crassipes	Tropical America, Brazil
Lantana camara	Central America/ Tropical America
Orobanche spp.	Europe
Sorghum halepense	Southern Europe and Asia
Tribulus terrestris	Southern Europe/Africa

5. Classification based on association

When two plants are living together i.e called association. Based on association they are **season bound weeds, crop bound weeds and crop associated weeds.**

a. Season bound weeds

They are seen in that particular season irrespective of crop. These are either summer annuals or winter annuals. *Sorghum halepans* **(Perennial) is a summer perennial and** *Circium arvense is* **winter perennial.** *Phalaris minor and Avena fatua* are winter season annuals.

b. Crop bound weed

Weeds which usually parasite the host crop partially or fully for their nourishment i.e. parasitism also called as parasitic weeds. Those parasites which attack roots are termed as root parasites and those which attack shoot of other plants are called as stem parasites.

e.g. *Orobanche* (broom rape) in Tobacco, *Striga* spp (witch weed) in Sorghum

c. Crop associated weeds

These are also crop specific but they may be associated with certain crops for one of the following reasons:

Need for specific micro climate: Weed like *Cichorium intybus* requires for their best growth shady, cool and moist habitat which is amply available in crops like Lucerne and berseem.

Mimicry: - Wild rice in paddy field, *Phalaris minor* (canary grass) in wheat crop survive because of their similarity in morphology with host crops. This mechanism is called **mimicry**. A weed like *Avena fatua* (wildoat) tends to grow to the height of winter grains and adjust its ripening time to the crop over a wide varietal range. This kind of mimicry is called **phenotypic mimicry**.

Ready contamination of crop seeds with weed seeds : If the crop seed mature at the same time and same height of the crop, then it contaminates the crop (also morphologically same) easily. e.g. little seed canary grass (*Phalaris minor) and* wild onion, wild garlic (*Allium spp)*.

6. Classification according to the nature of stem

Depending upon development of bark tissue on their stems and branches weeds are classified into w**oody, semi-woody and herbaceous weeds.**

a. Woody weeds: Weeds include shrubs and under shrubs and are collectively called brush weeds. *Lantana camera, Prosopis juliflora* (mesquite) *Zizyphus rotundifolia* (wild plum) are examples for brush weeds.

b. Semi-woody weeds: *Croton sparsiflorus* is semi woody weed.

c. Herbaceous weeds: Weeds have green, succulent stems are of most common occurrence around us. e.g. *Amaranthus viridis and Chenopodium album*.

7. Classification according to soils

Of the several variables of soil, pH is implicated most frequently with the distribution of weed species over areas of similar agro climate.

On highly acid soils **acidophile** weed such as *Rumex acetosella* tends to dominate the weed flora, while on saline and alkali soils **basophile** weed like polygonum spp. is found. However the most of our common weeds are **neutrophiles**.

The texture of soil and consequently its water holding capacity also determines to a great extent the weed flora of a place. For example, *Tribulus terrestris* and *Euphorbia* spp. are dominant on course texture soils whereas, *Sorghum helepense* grows abundantly on heavy, moisture retentive soils. *Echinochloa colonum* requires wet soils for their best growth.

8. Special classification

Besides the various classes of weeds, a few others deserve special attention due to their specificity. They are **a. Poisonous weeds b. Parasitic weeds and c. Aquatic weeds**

a. Poisonous weeds: The poisonous weeds cause ailment on livestock resulting in death and cause great loss. These weeds are harvested along with fodder or grass and fed to cattle or while grazing the cattle consumes these poisonous plants. e.g. *Datura fastuosa* poisonous to animals and human beings.

b. Parasitic weeds: The parasite weeds are either total or partial which means, the weeds that depend completely on the host plant are termed as total parasites while the weeds that partially depend on host plant for minerals and capable of preparing its food from the green leaves are called as partial parasites. Those parasites which attack roots are termed as root parasites and those which attack shoot of other plants are called as stem parasites. The typical examples of different parasitic weeds are

1. **Total root parasite** **:** *Orabanche cernua* on Tobacco
2. Partial root parasite **:** *Striga lutea* on sugarcane and sorghum
3. Total stem parasite **:** *Cuscuta chinensis* on leucerne and onion
4. Partial stem parasite **:** *Loranthus longiflorus* on mango and other trees.

c. Aquatic weeds

Unwanted plants, which grow in water and complete at least a part of their life cycle in water are called as aquatic weeds. They are further grouped into four categories as submersed, emerged, marginal and floating weeds.

i. Submersed weeds*:* These weeds are mostly vascular plants that produce all or most of their vegetative growth beneath the water surface, having true roots, stems and leaves. e.g. *Ceratophyllum demersum, Hydrilla Verticillata* etc.

ii. Emerged weeds*:* These plants are rooted in the bottom mud, with aerial stems and leaves at or above the water surface. The leaves are broad in many plants and sometimes like grasses. These leaves do not rise and fall with water level as in the case of floating weeds. *Typha Spp .*

iii. Marginal weeds*:* Most of these plants are emerged weeds that can grow in moist shoreline areas with a depth of 60 to 90 cm water. These weeds vary in size, shape and habitat. The important genera that come under this group are; *Typha, Polygonum, Alternanthera, Ipomea*

iv. Floating weeds*:* These weeds have leaves that float on the water surface either singly or in cluster. Some weeds are free floating and some rooted at the mud bottom and the leaves rise and fall as the water level increases or decreases. Eg. *Eichhornea crassipes, Salvinia* etc.

(9) Facultative and Obligate weeds

Facultative weeds are those weed species that grow primarily in wild communities but often escape to cultivated fields, associating themselves closely with mans affairs e. g. O*puntia* spp. These are also known as **apophytes**.

Obligate weeds on the contrary occur only in cultivated or otherwise disturbed land. e. g. *Convolvulus arvensis*.

(10) Noxious and objectionable weeds

A noxious weed is a plant arbitrarily defined as being especially undesirable, troublesome and difficult to control. These weeds have immense capacity of reproduction and dispersal and they adopt tricky ways to defy mans' efforts to get rid of them. These are sometimes also referred **special problem weeds**, e. g. *Cyperus rotundus, Orobanche spp.*, *Striga* sp., *Parthenium* spp. and *Cynodon dactylon*

An objectionable weed is a noxious weed whose seed is difficult to separate once mixed with crop seeds, e. g. Jirado with cumin.

Special Characteristics of weeds

Weed possesses the following special characteristics.

1. **Abundant seed production**

   Weed produce large number of seeds per plant compared to crops. e.g. One plant of *Chenopodium* produces as much as 72000 seeds in one season, whereas one plant of rice produces about 1000 seeds. There is one slogan that **"One year seeding Seven year weeding."**

2. **Excellent viability of seeds**

   Most of the weeds seeds have dormancy. They germinate only when sufficient amount of rainfall is received for them to survive. They can remain viable for many years e.g. the seeds of *chenopodium* remain viable up to 40 years in soil.

3. **Ability to survive unfavourable condition**

   When the crop plants fails under adverse conditions, but weed plants can survive.

4. **Ability to reproduce vegetatively**

   Some weeds propagate vegetatively by rhizomes, stolons, bulbs etc. This helps to withstand under adverse conditions. e.g. Nut sedge, Dharo, Darbh etc.

5. **Dispersion/ spreading through various agencies**

   Weeds plants as a whole or seeds may disperse by various agents from one place to other place e.g. Wind, Water, Animals, Insects, Man; Manures etc. are the various agents.

Reference Books:

Sr. No.	Name of Books	Author
1	Agronomy of Field Crops	S. R. Reddy
2	Principles and Practices of Agronomy	S. S. Singh
3	Crop Management	S. S. Singh
4	Introduction to Crops of India	N. R. Das
5	Modern Concepts and Advance Principles in Crop Production	S. C. Panda
6	Science of Agronomy	U. S. Walia
7	Field Crop Production	Rajendra prasad
8	Principles of Agronomy	T. Y. Reddy and G. H. S. Reddy
9	Modern Techniques of Raising Field Crops	Chhidda Singh, Prem Singh & Rajbir Singh

Definition/ Explain: (Terminology related to course)

Agriculture: Agriculture is defined as an art of science of producing crops and livestock on a farm and their preparation and marketing for use by the human race.

Agronomy: Agros=Field, Nomous = to manage. Agronomy is a branch of agriculture that deals with the principles and practices of soil, water and crop management.

Crop: A crop is a species or variety that is grown to be harvested as food, livestock fodder, fuel or for any other economic purpose. **OR** It is assembly or aggregates of useful plants which man can know to use.

Seed: Seed is a dormant embryo with reserved stored food germinated under suitable climatic condition.

Row crop: Crops which are grown in rows with uniform spacing throughout the field eg. Cotton, castor

Cash crop: Crop grown for sale and brings money immediately eg. Cotton, tobacco.

Intercropping: It is the practice of growing two or more crops simultaneously in different rows in the field. The most common objective of intercropping is to produce a greater yield on a given piece of land by making use of resources that would otherwise not be utilized by a single crop.

Interculturing: Operations which are carried out in a standing crop with implements and hand tools are known as interculturing.

Multiple cropping: It is the practice of growing two or more crops on the same space/ field during a single growing season/ year.

Double-cropping: It is the practice, in which a second crop is planted after the first has been harvested.

Relay cropping: It is the practice, in which the second crop is planted in the first crop before it has been harvested.

Mixed cropping: It is the practice of growing two or more than two crops are together on the same piece of land at the same time eg. Mixing of seeds of Bajara + Cowpea + Green gram.

Sole cropping: It is the practice of growing one crop variety alone in pure stands at normal plant density.

Ratoon cropping: Ratoon cropping is the technique of allowing a crop to produce two crops of yield from one planting.

Cropping pattern: The yearly sequence and special arrangement of crops and fellow on a given area.

Cropping system: The cropping pattern used on the farm and their interaction with farm resources, other farm enterprises and available technology which determine their makeup.

Crop rotation: Is the practice of growing a series of dissimilar types of crops in the same area in sequential seasons for various benefits, such as to avoid the increase of pathogens and pests and efficient utilization of soil nutrients.

Fiber crops: The field crops grown for their fibers, which are traditionally used to make paper, cloth, or rope**.** eg. Cotton, Sunhamp

Forage crops: Crop grown primarily for livestock feed and it is harvested either for hay, silage, green feed or grazing eg. Lucerne, Fodder cowpea.

Field residues: The materials left in an agricultural field or orchard after the crop has been harvested. These residues include stalks and stubble (stems), leaves and seed pods.

Cereals: The grasses crops of the monocot families (Gramineae) cultivated and harvested for the edible grains and used as human food. eg wheat The fruit seeds of cereals is botanically, called a caryopsis.

Millets: The group of small-seeded species of cereal crops or grains, widely grown around the world for food and fodder.

Green manuring: Green manuring is the practice of ploughing or turning of undecomposed green plant tissues into the soil the for the purpose of improving physical structure as well as fertility of the soil.

Pulse: It is an annual leguminous crop yielding from one to twelve seeds of variable size, shape, and color within a pod used for food and animal feed. (Latin "puls", from greek "porridge")

Nitrogen fixation: Generally refers to the natural process, either biological or abiotic, by which nitrogen (N_2) in the atmosphere is converted into ammonia.

Dry farming: It is the profitable production of useful crops, without irrigation on lands that receive annually a rainfall of 500 mm or less.

Husk (or chaff): The outer cover of a grain of paddy, removed by threshing and winnowing which can be used for fuel.

Irrigation: Artificial application of water in field (other than rainwater) for cultivation of crops from groundwater or by diversion of surface water or from a storage tank or reservoir.

Puddling : Puddling is ploughing the land with standing water so as to create an impervious layer below the surface to reduce deep percolation losses of water and to provide soft seedbed for planting the paddy.

Transplanting : It is the practices of planting of the young seedling from nursery bed to well prepared field.

Parboiling : It is a process in which paddy is soaked in hot water and then dried in sun light for keeping moisture up to 14 per cent and milled.

Hull: The lemma and palea together are known as hull. The grain is tightly enclosed by the lemma and palea.

Seed rate: Amount or quantity of seeds in kg or gram required to sow the unit area of field.

Seed bed: The seed bed is the place where the seeds germinate and the medium from which the resulting plant through their roots secure moisture and mineral nutrients.

Planking: A tillage operation carried out before sowing the crops for smoothening and cover the seeds after sowing.

Ploughing: A tillage operation carried out with the help of tractor or animal drawn implements' plough" which involves turning over the top soil that helps to buries surface debris and loosens the soil, so that seeds can be sown

Germination: Process by which the plant embryo within the seed resumes growth after a period of dormancy and the seedling emerges under favourable conditions.

Earthing up: Earthing up is an operation carried out with the country plough or ridge plough or manually so as to form ridges at the base of the crops to provide extra support against lodging of crop.

Gap filling: Re-sowing or replanting or re-transplanting in sown, planted or transplanted field crops where gapping of plants found to maintain plant population.

Weed: A weed is an unsightly, useless or injurious plant growing where it is not desired and something else should grow.

Thinning : It is a removal of some excess plants, or parts of plants from thickly populated crop field to make space for the growth of individual plant.

Seedling: Young plant developing out of a plant embryo from a seed.

Tassel: The male portion of the maize flower is called the tassel.

Fertilizers: Fertilizers are artificial made soil amendments in which nitrogen, phosphorus, potassium and other micronutrients nutrients are added in smaller amounts which are applied to soil for plant growth.

Drainage: It is the natural or artificial removal of surface and sub-surface water from an area to improve agricultural production or to manage water supplies.

Vapsa condition: It is a optimum moisture condition in the field for carrying out different agricultural operations easily and efficiently.

Drilling: It is the process where a seeddrill sows crop seeds into rows in the soil, before covering them up.

Diblling: It is the method of sowing of crops with the help of labour or dibbler when specific spacing and number of plants are to be maintained between two rows and within the rows.

Nursery: It is a place where plants are propagated and grown to usable size.

Rice bran: The outer layers of the grain of cereals such as wheat, removed during the process of milling and used as a source of dietary fiber.

Retting : Retting is a process by which the fibres in the bark get lossened and separated from the woody stalk. It is a microbial process affected by various aerobic and anaerobic micro-flora.

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(A) CEREAL CROPS

The word Cereal derives from Ceres, the name of the Roman goddess of harvest and agriculture. Cereals are grasses (members of the monocot family Poaceae, also known as Gramineae) cutivated for the edible components of their grain (botanically, a type of fruit called a caryopsis), composed of the endosperm, germ and bran. Cereal grains are grown in greater quantities and provide more food energy worldwide than any other type of crop, they are therefore staple crops.

1 RICE

Botanical name: *Oryza sativa* L.

Family : Rice belongs to genus *oryza* of gramineae (poaceae) family

Origin : Rice is regarded as a first cultivated crop of Asia. Preserved rice grains were found in China around 3000 B.C. Paddy grains found during excavation at Hastinapur (India) around 1000-750 B.C., considered as a oldest sample in the world. Vavilov (1926) concluded that south- west Himalaya has various types and varieties and indicated probable center of origin. Thus, based on all these archaeological evidence, India is considered center of origin of Rice.

Area and distribution

Important rice growing countries in the world are India, China, Bangladesh, Korea, Japan, Pihilippines, Burma and Srilanka etc.

Among the rice growing countries, India has the largest area (41.92 million hectares, 2010-11) followed by China and Bangladesh. In respect of production, India ranks second with 89.09 million tonnes of paddy next to China. Average rice yield of India was only 2125 kg/ha (2010-11).

In India, rice is grown in almost all the States. Kerala, Andhra Pradesh, Orissa, Bihar, Uttar Pradesh, Madhya Pradesh, Punjab and West Bengal lead in the area, while West Bengal and Punjab have the highest rice production. The average yield per hectare was the highest (4014 kg/ha) in the Punjab state during the year 2010-11.

In Gujarat, rice is grown in about 7.0 to 7.5 lakh hectares, of which 53 % of the total area is under drilled and 47 % area is under transplanted rice crop. It is grown throughout state except Kutch district. Saurashtra and some parts of the State is growing rice as drilled, while transplanted rice is taken in South and middle Gujarat, where assured irrigation facilities are available because transplanted rice requires submerged conditions (standing water). These both regions have assured irrigation facilities in summer season also and hence summer paddy cultivation is popularized in these regions (Valsad, Surat, Khedaand and Navsari districts).

Drilled paddy is known as upland paddy and transplanted paddy is known as low land paddy. The average productivity of rice in Gujarat was 1548 kg/ha during 2012-13.

Economic important

Rice is the staple food of more than 60 per cent of the world's population. About 90 per cent of all rice grown in the world is produced and consumed in the Asian region (southeastern Asia). The protein content of milled rice is usually 6 to 7 per cent. Rice grain also contains as much Vitamin B as contained in wheat. Milled rice looses valuable proteins, Vitamins and minerals in the milling process, during which the embryo and aleurone layer are removed. Much of the loss of nutrients can be avoided through parboiling process, in which paddy is soaked in hot water and then dried in sun light for keeping moisture up to 14 per cent and milled. Steam paddy is known as parboiling.

The by-products of rice milling are used for a variety of purposes. Rice bran is used as cattle and poultry feed. Rice hulls can be used in manufacture of insulation materials, cement, and cardboard and are also used as litter in poultry keeping. Rice straw can be used as cattle feed as well as litter during winter, manufacturing of mat rope and for covering the thatched houses.

Hull: The lemma and palea together are known as hull. The grain is tightly enclosed by the lemma and palea.

Climatic requirements

Rice is a heat and water loving plant requiring high temperature and adequate moisture supply. For germination, a minimum of 10 ºC and for flowering a temperature of 22-25ºC is considered as an optimum. Grain formation takes place at 20-21ºC. Low temperatures particularly during 10-11 days before heading causes considerable loss in grain yield because of sterile spikelets. A ripening temperature should be in between 20-25 ºC. It is best suited in regions having high humidity, prolonged sunshine and an assured supply of water. The average temperature required throughout the life period of the crop ranges from 21 to 37 ºC. The crop requires higher temperature at the time of tillering than for growth.

Photo periodically rice is a short day, thermo sensitive plant but there are many varieties developed which are thermo insensitive. It is mainly grown in areas receiving 1000-1500 mm rain. Crop needs heavy rains (125 mm) during vegetative phase and 200 mm monthly rain for low land and 100 mm for upland rice. In India, it is grown from 8 to 35º north latitude and from sea level to the mountainous region up to 3000 meters. Heavy winds especially after heavy rainfall or heavy irrigation results in severe lodging. Where winter temperatures are fairly low, only one crop of rice is taken during *kharif* season. There are

three seasons for growing rice in India but in Gujarat, now days rice is taken in *kharif* and summer seasons where assured irrigation facilities are available. The rice variety IR 28 is a non-sensitive to the photoperiod and is grown in any temperature and time period.

Soil

Soils having good water retention capacity with good amount of clay and organic matter are ideal for rice cultivation. Clay or clay loams soils are most suited for rice cultivation. Rice being a semi-aquatic crop grows best under submerged conditions. A major part of rice crop in the state is grown under low land conditions. It grows well in soils having a pH range between 5.5 and 6.5 including alkaline and acidic soils.

Nursery raising for transplanted Paddy:

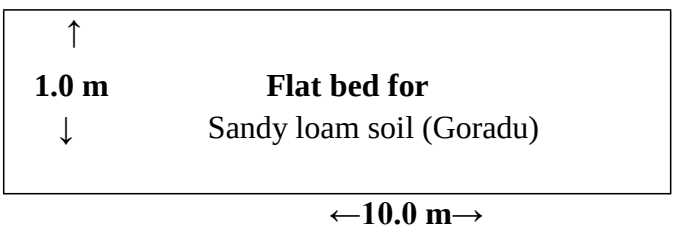
Seed and seed treatment:

- Select the certified seed for sowing
- For fine grain varieties, 20-25 kg seed and for coarse varieties, 25-30 kg seed would be required to raise seedlings in 10 Guntha areas, which is enough for one hectare.
- **Dry seed treatment:** Seeds should be treated with thiram or carbendazim 25 S.D. @ 3 g/kg seed.
- **Wet seed treatment :** Soak the seeds (25 kg) in streptocycline@ 6g/24 lit water for 10 hours. After soaking the seeds, they should be dried for sowing.

Nursey

- Select the well drained and levelled field having better irrigation facilities
- Usually nursery area for rice is about one tenth of the main field area. About 1000 sq. m. area of nursery is sufficient to transplant one hectare.
- Flat type of beds is prepared easily in sandy loam type of soils. Whereas, raised type of beds are mostly preferred in heavy black soils which have poor drainage capacity. The basal measurement of beds should be 10 m x 1m. Length of beds should be kept according to the slope of nursery.

In between the raised beds, a drainage channel of about 30 cm width is provided. The surface of the bed is smoothened with gradual inclination towards both sides to facilitate easy drainage of water.



	←10.0 m→	
1.0 m→	**Raised bed for black soil**	←Channel
	0.3m channel	

- Apply the manures and fertilizers as below for bed of **10 sq.m.**

Sr. No.	Fertilizer application	For 10 sq.m. of bed	For 1000 sq. m. (10 Guntha) of nursery area
1	Basal **:**		
	Well decomposed F.Y.M.	20.000 kg	2000 kg
	castor cake	1.000 kg	100 kg
	Ammonium Sulphate	0.250 kg	25 kg
	Single Super Phosphate	0.500 kg	50 kg
2	**Top dressing : (15 DAS)**		
	Ammonium Sulphate	0.250 kg	25 kg

- Keep the nursery wet by sprinkling water with water cane or give light irrigation till the germination of seeds.
- Weeding in time is the important operation. Spray pendimethalin @ 1.0 kg/ha or oxadiazon o.5 kg/ha or pretilachlor @1kg/ha with sand after 3 days of sowing for control of weeds.
- Application of Carbofuran 3G @ 10 kg / 10 Guntha 15 DAS
- After care should be taken for plant protection measures.

Time of seeding in nursery and T.P. in field

Sr. No.	Seasons	Time of seeding in nursery	T.P. time in field	Age of seedlings
1	***Kharif***	First fortnight of June	First fortnight of July	25-30 days
2	**Summer**	Last week of November to First week of December	First fortnight of February	50-55 days

Dapog Nursery:

- This method of raising nurseries has been introduced in India from Philipines.
- This involves growing seedlings on a concrete floor or on a raised bed of soil covered with polythene sheets or banana leaves.
- The polythene sheets prevent entry of roots into the soil.
- The dapog beds should be about 1- 1.5 m wide and its length depends on the area to be planted.
- Pre-germinated seeds are sown on the top of the sheets @ 2.0 kg/sq.m.of nursery.
- Water is sprinkled and the seeds are pressed gently with hand or with a wooden flat board twice a day for the first 3-6 days.
- This helps the roots to remain in contact with water retained on the surface and prevents drying.
- After 6 days, the seed beds are watered upto a depth of 1-2 cm.
- In about 14 days, seedlings are ready for transplanting. Besides, the seedlings are thin, slender and short in height.
- The main merit of this method is that less area (30-40 sq.m.) is needed to raise seedlings sufficient for planting one hectare.
- By this time, the roots are well developed and intertwine with one another so that the nursery can be cut into stripes, rolled and transported easily to the planting site.
- Loosen the interlocked roots carefully before transplanting.

Field preparation:

Before carrying out the field operations, green manure crops like dhaincha (50 kg seeds/ha) or sannhemp (100 kg seeds/ha) should be sown in last week of May and it should be buried in the soil 35-40 days after sowing before flowering with disc harrow or tractor drawn plough. For rapid decomposition of green manure crop, full dose of phosphatic fertilizers should be applied in the soil and about 4-5 cm of water should be given in the field which helps in easy decomposition of green manure as well as weed plants and stubbles of the previous crop. Before transplanting, the field should be puddled by three to four runs of puddler in 4-5 cm standing water followed by planking for levelling.

Advantages of puddling

1) Drainage can be reduced as the sub soil layer may become impermeable.
2) Seedlings can set easily in soil.
3) Weeds can be destroyed.
4) Manures and fertilizers can be well mixed in the soil.

Method of transplanting

Generally two seedlings / hill are recommended at 20 cm x 15 cm distance under normal conditions. When old seedlings are to be transplanted, more seedlings i.e. 3 to 4 seedlings/hill should be planted, because older seedlings produce less number of tillers.

There are two methods of transplanting in vogue (1) random (30-35 seedlings/sq.m.and (2) line sowing - 20 cm x 15 cm or 15 cm x 15 cm (1-2 seedlings/ dibble). Gap filling should be completed within 8 to 10 days after transplanting.

In reclaimed salt affected coastal soils of south Gujarat, transplant 9 seedlings/hill at 15 cm x 10 cm for higher yield as this type of soil affects tillers.

Depth of transplanting

Tillering takes place at the first stem node above the root. If the seedlings are planted deeper than 5 cm, tillering takes place at a node near the soil surface 2-5 nodes above the first stem node. The tillers arise from the upper nodes are generally weaker than those from the lower nodes, besides there is a delay in the formation of tillers. Therefore, planting at medium depth i.e. 3 to 5 cm is preferable as compared to deeper planting as it ensures a fairly good set of ancillary attributes which contributes to high grain production in coastal reclaimed saline-alkaline soil.

Manures and fertilizers

Farmyard manure @ 10 t/ ha should be given at the time of field preparation.

Fertilizers

(1) For early maturing varieties

N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Stage of application
20	25/30	0	Basal at the time of puddling (25% N)
40	0	0	At tillering (50 % N)
20	0	0	Earhead emergence (25 % N)
80	25/30	0	Total

(2) For mid late maturing varieties

N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Stage of application
25	25/30	0	Basal at the time of tillering (25 % N)
25	0	0	At tillering (25 % N)
25	0	0	Jointing stage (25 % N)
25	0	0	One week before earhead emergence (25% N)
100	25/30	0	Total

(3) For late maturing varieties

N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Stage of application
30	25/30	0	Basal at the time of puddling (25 % N)
30	0	0	At tillering (25 % N)
30	0	0	Jointing stage (25 % N)
30	0	0	One week before earhead emergence (25% N)
120	25/30	0	Total

Note : 25 kg P_2O_5 / ha for middle Gujarat and 30 kg P_2O_5 / ha for south Gujarat

25 % higher fertilizer dose for salt affected soil

Apply 10 t/ha green azolla as green manure at the time of first weeding under middle Gujarat conditions. In south Gujarat conditions, broadcast 1 tonnes green azolla after 1 week of transplanting and buried it into soil (after growth) at the time of first weeding or broadcast 10 kg blue green algae/ha before transplanting, if azolla is not available.

Nitrogenous fertilizers are highly soluble and in mobile form so easily lost by leaching, volatilization and denitrification. The efficiency of chemical fertilizers N is 30-35 % in rice, 45-60 % in wheat, 18-63 % in maize and 18-35 % in cotton. These figures indicate that about 50 to 75 % of the applied N to the soil never became available to the crop plants. Therefore, it is always desirable to place the nitrogenous fertilizers at a depth of 10 cm i.e. into the reduced zone so that the loss of N through volatilization can be reduced. The highest rate of volatilization occurs during the first 2-3 days of fertilizers application.

Secondly, the low efficiency is through losses due to leaching of nitrate nitrogen with the heavy irrigation on sandy soils or through denitrification in the form of elemental N in water logged conditions. To overcome this loss of N, ammonium sulphate or Neem Coated Urea (NCU) should be preferred over application of urea alone. To reduce denitrfication losses, ammonical N should only be given to soils having low pH (< 4).

Generally nitrogenous fertilizers are applied in the form of ammonium sulphate or urea. Before application of N fertilizers in the form of urea, the water is drained away from the field and again the field is filled in with water after 2-3 days of fertilizer application. **Zn deficiency:**

Usually Zn deficiency is observed in salty and sandy soils, so apply 25 kg ZnSO4 in the soil before transplanting or if it is observed in the field crop, spray 0.5 % ZnSO4 solution on leaves.

Irrigation

Continuous submergence irrigation water reduced the grain yield so water should be filled 5-7 cm depth upto flowering stage in the field. Alternate submergence and drainage are followed during this stage.After this stage,the field should be submergenced to a depth of 5-7 cm. Water must be drained out 2-3 weeks before harvest of crop to hasten ripening of grains and to promote favourable condition for harvesting. Rice being a semi-aquatic plant requires more water during life period so that it is also known as water loving plant.

Interculturing and weeding

First 40 days are critical for crop-weed competition. So weeds should be controlled at 30 days after transplanting with the help of hand rotary or Japanese paddy weeder. Weeding should be done before top dressing of N fertilizers. For chemical weed control, pendimethalin @ 1.0 kg/ha or oxadiazon @ o.5 kg/ha or pretilachlor @ 1kg/ha in 500 liters of water should be sprayed as pre-emergence or broadcast by mixing with 100 kg sand within 3 days of transplanting. Broadcasting of herbicide should be done only if the water is stagnated in the field. The field should not be disturbed for 10-15 days after applying the herbicide. Hand weeding should be carried at 30 days of transplanting.

Cropping system:

Rice – Wheat, Rice, Rice (S), Rice – Gram

Rice – castor (Semi-rabi), Rice – Groundnut (S)

Rice – Mustard, Rice – Cumin

Rice – Indian bean

Rice – Lucerne (Anand 2) (Fodder + seed production)

Crop Rotation: Rice – Banana/ Sugar cane

Plant protection measures

Pests

Jassids, Stem-borer, Gall midge, Rice hispa, Leaf roller, Army warm, Mole cricket, and Plant hopper

Diseases

Paddy blast, False smut, Brown spot, Stem rot, Blight, Kolat (yellowing of seedling).

Varieties for Transplanting

1 Early maturing varieties (80-100 days)

Sukhvel 20, GR 3, GR 4, GR 6, GR 7, GR 12,Gurjari, IR 28,GAR 2,GAR 3 and Mahisagar

2 Midlate maturing varieties (100-120 days)

GR 11, Jaya,IR 22,GR 103, GAR 13, GAR 1(Scented),Dandi, SLR 51214 (Salt resistant)

3 Late maturing varieties (130-140 days)

(i) Non- scented : Masuri

(ii) Scented : GR 101,GR 102, Narmada and GR 104

Following varieties have been released by Navsari Agril. University.

NAUR 1,GNR 2,GNR 3,GNR 4 (Bio fortified for high iron and dietary fiber content),GNR 5 (Salt resistant), GNR 6

Hybrid rice

Hybrid rice is a land mark technology development in China.Professor Yuvan Long Ping, the father of hybrid rice revolution in China,developed the first hybrid rice.With the advent of male sterile lines, efforts to develop hybrid rice technology has been successful during last four to five years with release of hybrids for commercial cultivation. Rice hybrids APHR-1, APHR-2 and BRRH-1 for AndhraPradesh, UPHR-17 for UttarPradesh, MGR-1, CORHI-1 and ADTRH-1 for TamilNadu, KRH-1 and KRH-2 for Karnataka, CNHR-3 for West Bengal and KJTRH-1 for Maharashtra have been already releases by the state as well as Central variety release committee. Rice hybrid viz., GNRH 1(2016) was developed by NAU.

Low cost technology of paddy cultivation with sprouted seeds

This is an alternate method of paddy transplanting developed by International Rice Research Institute, Philippines and later on recommended for middle Gujarat and south Gujarat.

Advantages of this method

This method saves labour, time and cost of nursery raising and gives about 30-35 % more profit as compared to transplanted paddy. It also saves about 20 % of water and 30 % labour cost besides giving 10-15 % (1 tonne) more yield than TP paddy. This method helps in maturing the crop 10-20 days early than TP paddy.

WET LAND SUMMER RICE CULTIVATION

Summer rice is being cultivated in the districts of Surat, Valsad and Kheda where assured canal irrigation facilities are available. The area under summer rice is increasing year after year.

Selection of variety

GR 11, IR 22, IR 28, GR 3, GR 4, GR 103, Jaya, Gurjari, GR 7 and GAR 13 (For middle and south Gujarat)

(A) Raising nursery

(1) Sowing should be done in last week of November to first week of December.

(2) Seedling should be raised as per transplanted rice.

(3) For early germination, sprouted seeds should be used.

(4) Nursery area should be covered by plastic sheet or gunny cloth for the protection against cold wind and 3-4 lines of windbreak crop (Sevari) is grown on all the sides of the nursery area.

(5) Seedling growth is suppressed due to cold condition; therefore, single super phosphate is applied for enhancing the root growth.

(B) Transplanting

(1) Puddling should be done before transplanting.

(2) Transplant 50 - 55 days old seedlings.

(3) Transplant 2-3 seedlings per hill.

(4) Transplanting is done at 15 cm x 15 cm distance.

(5) Transplanting should be done in first fortnight of February.

(C) Manures

Apply well decomposed FYM or compost @ 10 t/ha in the soil before puddling.

(D) Fertilizers

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
60	25/30	0	At puddling
30	0	0	At tillering
30	0	0	At panicle initiation
120	25/30	0	Total

Note : 25 kg P_2O_5 / ha for middle Gujarat and 30 kg P_2O_5 / ha for south Gujarat

25 % higher fertilizer dose for salt affected soil

(E) Irrigation

Scheduling of irrigation for bumper yield of rice is as under:

Stage of Crop Growth	Depth of standing water in kyari (cm)
Transplanting for establishment of seedlings	2 to 3
Panicle initiation to before week of harvesting	5 to 7

(E) Plant protection

Generally stem borer and wilt disease are observed in summer paddy.

Drilling method is also practiced for low land rice cultivation.

DRILLED/UPLAND/RAINFED RICE CULTIVATION

Area under drilled paddy in Gujarat is about 4.0 lakh hectares.

(1) Selection of variety**:** Select early maturing and moisture stress resistant varieties like GR 3, GR 5, GR 8, GR 9, Sukhvel 20, Purna, Ashoka 200-F, AAUDR 1 (DDR 97), IR 28

(2) Seed rate: 50- 60 kg/ha

(3) Spacing: 30 cm between rows.

(4) Manures and fertilizers: Well decomposed FYM @ 10 t/ha should be applied. Out of 50 kg N and 25 kg P_2O_5/ha, 25 kg N and full dose of P_2O_5 should be applied before sowing the crop when there is sufficient moisture present in the soil. Remaining 25 kg N/ha should be applied through Ammonium Sulphate at 30-40 DAS.

If moisture stress occurs, second top dressing of N is not applied under prolonged drought condition. Plant protection measures and other field operations are carried out as per *kharif*-transplanted rice.

Research Stations:

World : IRRI International Rice Research Institute, Manila, Philippines

India : CRRI Central Rice Research Institute, Cuttak, Orissa

Gujarat : MRRS Main Rice Research Station, Nawagam,Dist: Kheda and Navsari

Sub Research Station**:** Vyara, Dabhoi, Derol, Ubharat and Waghai

System of Rice Intensification (SRI)

SRI was developed in Madagascar by a French priest, Father Henri de Laulanie S.J., who spent 34 years (1961-1995) working with farmers there to improve rural livelihoods through increased rice productivity. The main practices of SRI were synthesized by the mid-1980s.Using the SRI methodology, yields are increased by 20-50 % or more, while reducing inputs: seed by 90%, irrigation water by 30-50%, chemical fertilizer by 20-100 % (Prasad, 2006) and usually reduced need for pesticides. For the farmer, SRI brings greater returns to labour, land and capital. So, SRI was referred to as 'Transformed Rice Cultivation'.

Details of SRI Technology

1. Land preparation : Apply 5 t FYM ha^{-1} and plough the field
2. Suitable varieties Any variety / hybrid
3. Seed rate 5 kg seed /ha
4. Nursery raising Apply layer of fine manure on seed bed. Distribute pre- sprouted se seeds and cover with them with layer of fine manure. Seed bed should be mulched with paddy straw. About 100 sq. m. area of rs nursery is sufficient to transplant one hectare
5. Age of seedling 1 12 -14 days old seedling (Two leaves stage)
6. Transplanting : Transplant one seedling per hill (25 cm x 25 cm). The root of the seedling should not be disturbed. Transplanting should be done a day after puddling the field having no standing water. Transplanting should be done from last fortnight of June to First fortnight of July.
7. Nutrient Management :

Fertilizer dose : 25 % RDN through chemical fertilizer and remain 75 % through organic manure

Bio-fertilizer : Liquid biofertilizer @ 1 lit/ ha each of *Azotobactor* and PBS after mixing with 50 kg well decomposed & sieved FYM, broadcast it equally at the time of transplanting.

8. Weed Control : Use cono-weeder/ rotary weeder 4 times at an interval of 10 DATP for weed control.
9. Water Management : A light irrigation should be given after transplanting when hair like crack of soil has been seen. Keep standing water (5 cm) from 50 % flowering to maturity stage.Water should be drained 10-15 days before

A healthy plant in SRI is because of ……..

- Large root volume
- Profuse and strong tillers
- Non loding
- More and well filled spikelets with higher grain weight

GENETICALLY MODIFIED RICE (Golden rice)

- Half of the world population's main food source is rice. In Asia, white rice is eaten three times a day.
- The main concern about white rice is that it has insufficient concentrations of vitamin A.
- It has been suggested that rice could be fortified to reduce the level of nutritional vitamin A deficiencies.
- Golden rice was originally created by Dr. Ingo Potrykus and his team in Zurich, Switzerland.
- This genetically modified rice is capable of producing beta-carotene in the endosperm (grain) which is a pre cursor for vitamin A production.
- In addition, Golden rice had increased iron content.
- Potrykus's goal is to distribute the rice to poor countries whose citizens suffer blindness and even death from a lack of vitamin A.
- Currently, the company SynGenta owns the license for commercial distribution of golden rice.

AEROBIC RICE

Aerobic rice is a new production system in which rice is grown in nonpuddled, nonflooded soil with the use of external inputs such as supplementary irrigation and fertilizer with the aim to obtain high yield.

The ecology for this type of rice is intermediate between upland and favourable shallow low lands. Varieties suitable for aerobic condition should have early seedling vigour, deep root system, erect leaf and early in maturity.

Yield obtained with aerobic rice varieties varied from 3.5 to 6.0 t ha^{-1}, which is almost double that obtained with upland rainfed varieties

	Upland rice		Aerobic rice
1.	Upland rice is grown in rainfed, naturally well-drained soils with bunded or unbunded fields without surface water accumulation	1.	The aerobic rice system is targeted at more favorable environments and have access to supplementary irrigation if rainfall is not sufficient
2.	Upland rice varieties are drought tolerant, but have a low yield potential	2.	Combines features of high yielding irrigated lowland and drought tolerant upland cultivars
	Sathi-34-36, GR-3, Sukhvel-20		ARB-6, MAS 946-1, APO (IR 55423-01), CT- 6510- 24-1-2

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2 M A I Z E (C O R N)

Botanical Name: *Zea mays* L.

Family: Gramineae (Poaceae)

Origin: Central America and Mexico. It has introduced into India by the Portuguese during the seventeenth century.

Area and distribution

Maize, popularly known as corn is one of the most important cereals of the world. The important maize growing countries are U S A, Brazil, China, Mexico and India.

In the world, maize is cultivated in about 115 million hectares with the production of about 290 million tonnes of grains. Whereas in India, this crop was grown in about 9.4 million hectares during 2013-14. In terms of area and production, it ranks next only to rice, wheat, jowar and bajra.

The cultivation of maize in India is confined mainly to the States of Orissa, AP, Punjab, Karnataka, Uttar Pradesh, Bihar, Rajasthan, Madhya Pradesh and Gujarat.The highest productivity of maize was in Uttar Pradesh during 2015-16. In Gujarat, maize was grown in about 3.73 lakh hectares with an annual production of 6.25 lakh tonnes of grains. It is grown in the districts of Panchmahals, Sabarkantha, Banaskantha and part of Vadodara and Kheda.

Economic Importance

Over 85 per cent of its production in the country is consumed directly as human food in various forms such as chapaties (commonest preparation), green roasted cobs (ear heads) and popcorn. It is also a good feed for poultry, piggery and other animals. Maize crop furnished huge quantities of green fodder for cattle. Maize crop supplies raw materials to various industries for manufacturing starch, alcohol, glucose, acetic acid, dyes, synthetic rubber, resin etc. Maize grain contains about 10 % protein, 4 % oil and has significant quantities of Vitamins A and E. Types of maize based on the composition and endosperm, maize is divided into following groups.

1) Dent corn (*Zea mays indentata,* sturt)

Dent corn is the most widely grown type in the USA, Canada and Australia. It is characterized by a depression or dent on the top of seed, which has soft starch. The sides of the seed have hard starch. Rapid drying and shrinkage of soft starch results in denting.

2) **Flint corn (*Zea mays indureta)***

Flint corn is widely grown in Europe, Asia, South America and Central America. The kernels are hard and smooth containing soft starch surrounded by hard starch. Often-earlier maturity and earlier vigor and more tillers than dent.

3)* Sweet corn (*Zea mays saccharata sturt)

Translucent and wrinkled kernels characterize sweet corn maize when it matures. It is grown primarily in USA where cobs (ears) are picked green for canning and table use as they contain about5 % sugar as compared to 2 per cent in dent type and 2.3 % in flint type (Cv.Madhuri).

4)* Pop corn (*Zea mays awerta sturt)

Popcorn is an extreme form of flint containing a very small proportion of soft starch surrounded by hard starch. The ability to pop seems to be conditioned by the hard starch where the starch grains are embedded in a tough calcite colloidal material, which confines and resists. The steam pressure generated within the grain upon heating until it touches explosive force. It contains even higher percentage of hard starch than flint corn (cv. Amber).

5)* Flour corn or soft corn (*Zea mays amylacea)

The endosperm consists largely of soft starch with little or no hard starch

6) W*axy corn (*Zea mays ceretina kulesh)

The kernels appearance is waxy. A starch molecule differs considerably from that of other types and resembles glycogen. The starch is gummy and has some of the characteristics of tapioca.

Climatic requirement

Maize is essentially a warm weather crop. It is grown under extremely divert conditions, (wide adaptability) ranging from tropical to temperate regions. It is widely cultivated from the sea level upto altitude of 2500 m. It can be successfully grown where the night temperature does not go below 15.6^0 C (60^0 F). It cannot withstand frost at any stage of its growth.

Extreme high temperature and low humidity during flowering, damage the foliage, desiccate the pollen and interfere with proper pollination resulting into poor grain formation. Fifty to seventy five centimeters of well-distributed rain is sufficient for proper growth. Maize is very sensitive to stagnant water, particularly during its early stages of growth.

Soil

Maize requires fertile, well-drained and leveled field having medium loam to heavy loam soils. However, it can be grown on any type of soil, ranging from deep heavy clay to light sandy. Water stagnation is extremely harmful to the crop. Therefore, proper drainage is a must for the success of the crop especially during *kharif* season. It can be grown successfully in soils having pH ranges from 5.5 to 8.0.

Preparation of land

Successful maize cultivation requires good seedbed. Seed should be placed in contact with the moist soil. The first ploughing should be done with soil inverting plough so that at least 20 to 25 cm deep soil may become loose. It should be followed by two to three harrowing or three to four cross ploughing with local plough. Planking should be done after each ploughing and field should be leveled for good water management.

Seeds and sowing

For getting maximum yield, use certified seeds of improved varieties and new hybrid seeds every year of hybrid varieties. In case of composite varieties, use seeds from own composite crop for next year provided that no mixture has been allowed in the field and at threshing floor. Change seeds of composite varieties after three to four years.

Sowing time

Where irrigation facilities exist, *kharif* maize should be grown between second week of June by giving one pre-sowing irrigation. In rainfed situation, sowing of maize is generally done with onset of rains. Thus early sown maize plants are able to face and tolerate most of the diseases and attack of insect start with onset of monsoon showers.

Method of sowing

Maize is sown by two methods 1) Sowing seed behind the plough or drilling - Seeds are drilled with the help of seed drill or behind plough with help of funnel in rows after applying fertilizers. This is the most common method for sowing of the composite varieties.

2) Dibbling – Two seeds per hill should be dibbled for hybrid varieties.

Seed rate: 20 to 25 kg/ha

Spacing

For hybrid and composite varieties: 60 cm x 20-25 cm

Seeds should be sown 5-7 cm deep. Plant population of 80-85 thousand plants/ha should be maintained for achieving the maximum yield.

Manures and fertilizers

Manures

Well decomposed FYM or compost @ 10 t/ha should be incorporated into the soil before sowing.

Fertilizers

(1) For hybrids and composite varieties

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
10	50	00	As basal
20	-	-	At 4 leaf stage
30	-	-	At 8 leaf stage
30	-	-	At tasseling & flowering stage
10	-	-	At grain filling stage
100	50	00	Total

(2) For local improved varieties

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
6	40	00	As basal
12	-	-	At 4 leaf stage
18	-	-	At 8 leaf stage
18	-	-	At tasseling & flowering stage
6	-	-	At grain filling stage
120	60	00	Total

Irrigation

Maize is very susceptible both to excess water and moisture stress. Therefore, suitable drainage should be provided for removal of excess rainwater from the field. In case of soil moisture deficiency occur due to dry spell at tasseling, silking and milking stages, irrigation becomes necessary other-wise yield is reduced substantially. A good crop of maize requires about 460 to 600 mm of water during its life span.

Depending upon availability of irrigation water, following irrigation schedule is recommended.

Number of irrigations at critical growth stages

Six	Five	Four
Leaf stage	Leaf stage	Leaf stage
Early knee-high stage	Late knee-high stage	Late knee-high stage
Late knee-high stage	Tasseling stage	Tasseling stage
Tasseling stage	50 % silking stage	50 % silking stage
50 % silking stage	Dough stage	---
Dough stage	---	---

The farmers of middle Gujarat Agro-climatic Zone-III (AES-II) are advised to adopt drip method of irrigation in maize (Sweet corn var. Madhuri) to get higher green cob yield and income. The drip system should be laid out at a lateral distance of 0.90 m and dripper (4.0

lph) spacing of 0.60 m. The system should be operated for 2 hours at a pressure of 1.2 kg/cm^2 on alternate day during the crop period.

Interculturing and Weeding

Sometimes due to continuous rains during the early period of maize growth, it is not possible to enter in the field. In such situations, the only effective way to control weeds is the use of herbicides. Mixture of pendimethalin @ 0.25 kg / ha + atrazine @ 0.50 kg / ha as pre-emergence for effective weed control (Twice inter culturing and hand weeding (20 and 40 DAS) is also equally effective for weed management in k*harif* Maize.Field should not be disturbed for initial three weeks after spraying. If pulse crop sown as inter crop in maize, pendimethalin 750 ml/ha should be disolved in 500 litres of water and spray as pre emergence.

Thinning

Thinning should be done within 15 to 20 days after sowing by keeping only one healthy plant per hill by keeping one plant 20 - 25 cm apart in rows.

Earthing up

Five weeks after sowing, when the plants attain knee-high stage, earthing up should be done with the help of local plough or hoe. This provide safe guard against lodging which is likely to occur at cob formation stage due to high wind velocity and also helps to drain out water during rainy season as maize crop can not withstand stagnation of water.

Watching

The crop requires protection against parrots, crows and human beings when crop comes in tasseling and cob formation stage as they attack on tassels and green cobs. Watching should be continued till crop is harvested. Shooting away the birds from manchas prepared in the field and beating drums are effective methods. Most of the new high yielding hybrids have thick covers and birds cannot do much damage.

Cropping system:

(A) Intercropping

i Maize (Farm Sameri) + Pigeon pea (BDN-2) (1 : 1) for Panchamahals and Dahod districts of Middle Gujarat.

ii Maize + Green gram or Black gram (1 : 4) iii Maize + Castor (2 : 2)

(B) Crop sequences

i Maize – Wheat - Pulses

ii Maize - Mustard

iii Maize – Potato – Bajra (S)

(C) Crop rotation

i Maize – Pulses ii Maize – Cotton iii Maize – Castor

Plant protection

Insect and pest: Stem borer, Army worm, Hairy cater pillar

Diseases: Leaf blight, Late wilt and Charcoal Rot

Harvesting

Harvest maize crop when husk of the cobs has turned into yellow or brown in color (cob sheath becomes dry) and grains become hard enough to crack when pressed under your teeth or having less than 12-15 % moisture. Do not wait for stalks and leaves to dry because they remain green in most of the hybrid and composite varieties.

The cobs are picked from standing crop by removing of dry husk and then dry them in sun for seven to eight days. Thereafter, grains are removed (separated) either by beating the cobs by sticks or with the help of maize Sheller. The separated grains should be sun dried and use for storage.

Varieties

Sr. No.	Varieties	Productivity (kg/ha)	Recommended zones	Maturity days	Grain colour
1	Gujarat Maize 2	3000-3500	North Gujarat	85-90	Yellow shine
2	Gujarat Maize 4	3500-4000	Middle & South Gujarat	80-85	White shine
3	Gujarat Maize 6	3000-3500	Middle & South Gujarat	75-80	White shine
4	Narmada moti	4500-5000	Middle & South Gujarat	80-85	White shine
5	Madhuri* (Sweet corn)	12000-14000 (Green cob)	Entire Gujarat	70	Pale yellow
6	Vin orange (Sweet corn)	14000-15000 (Green cob)	Entire Gujarat	70	Pale yellow
7	Amber (Pop corn)	2500-3000	Entire Gujarat	80-85	Yellow
*****Isolation distance for Madhuri **:** 300 m or sowing of common maize should be done at 20-25 days interval					
Hybrid varieties					
8	GAYMH 1	4200-5000	Middle, North & South Gujarat	80-85	Yellow
9	GAWMH 2	4000-4500	Middle & South Gujarat	80-85	White
10	HQPM 1 **(For quality protein)**	4000-4500	Middle & South Gujarat	95	Yellow

Research Stations

World: CIMMYT (International Center for Wheat and Maize Research),Mexico

Gujarat (Main): Main Maize Research Station, Godhra (Panchmahals district) & Bhiloda (Arvalli district)

(Sub): Devgadh Baria (Panchmahals dist.), Khedbrahma (Sabarkantha dist.)

Yield: Composite varieties: 3000 to 5000 kg /ha, Hybrid varieties**:** 4000 to 6500 kg /ha

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3 S O R G H U M (Great millet)

Botanical name: *Sorghum vulgare* L. *moench*

Family: Gramineae (Poaceae)

Origin: East Central Africa

Area and Distribution

Sorghum is the fourth in importance among world's leading cereals. It is cultivated in an area of about 51 millions hectares with a total production of about 67.3 million tonnes. Among sorghum growing countries, India ranks first in acreage but second in production. USA is the largest producer in the world. Other important sorghum growing countries are China, Nigeria, Sudan and Argentina.

In India, it was grown in an area of 7.79 million hectares with total production of about 6.70 million tonnes. The highest productivity (1267kg/ha) was in Madhya Pradesh during (2010-11). Maharashtra, Andhra Pradesh, Karnataka, Madhya Pradesh, Gujarat, Tamil Nadu, Rajasthan and Uttar Pradesh are important sorghum growing states.

In Gujarat, about 2.16 lakh hectares area is under sorghum cultivation with total production of 2.6 lakh tonnes. It is cultivated in almost all districts of the state. The Main Sorghum Research Station is located at Surat.

Economic importance

Millions of peoples living in Africa and Asia depend on sorghum, as it is a staple food. In addition to this, fodder and stover are fed to millions of animals providing milk and meat for human being.

Sorghum ranks third in the major food grain crops of our country. The greatest merit with sorghum is that it has capacity to withstand against drought. It does well even in low rainfall areas. It makes comparatively quick growth and gives not only good yields of grain but also very large quantity of fodder.

Human beings in India eat sorghum grain by breaking the grain and cooking it in the same way as rice or by grinding it into flour and for making chapaties. It is also eaten as parched and popped grain to some extent. Grain is also fed to cattle, poultry and swine. Sorghum grain contains about 10-12 % protein, 3 % fat and 70 % carbohydrates.

Climatic requirements

Sorghum requires warm climate and grown from sea level to as high as 1500 meters. Sorghum plants can tolerate high temperatures throughout their life cycle better than any other cereal crops. It can tolerate drought conditions very well because it remains dormant

during moisture stress conditions and resumes growth when favorable conditions reappear. It can also tolerate water logged conditions better than any other cereal except rice.

Sorghum is a short day plant and flowering is hastened by short day and delayed by long day. The time of heading in sorghum is influenced by temperature as well as photoperiod.

Soils

Clay loam or loamy textured soils having good water retention capacity are best suited for sorghum cultivation. It can grow in the soils having pH 6.0-8.5 as it tolerates considerable salinity and alkalinity.

Field preparation

In black cotton soils, ploughing should be done with soil turning plough so that 10 to 15 cm deep soil may become loose followed by two to three harrowing and planking to break clods and to level the field. But in other soils, land is cultivated only with blade harrow.

Time of sowing

Timely sown crop escape from damage of shoot flies, while delay in sowing increases its infestation. So sowing should be done within two weeks of onset of monsoon.

Seed rate: 8 - 10 kg/ha

Seed treatment

For minimizing the losses in the germination percentage occurred due to attack of the cricket ants, seeds should be treated with 5 g Carbofuran 50 % SP dust with mixing of castor oil. Treated seeds should be sown immediately.

Spacing: 45 x 10-15 cm i.e. 1.8 to 2.0 lakh plants/ha.

Manures and fertilizers: Well decomposed FYM @ 10 t/ha

(1) For rainfed *kharif* cultivation for entire state

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
40	40	0	At the time of field preparation
40	0	0	At 30-35 DAS
80	40	0	Total

(2) For dry farming area of Saurashtra region (Var. CSH-6)

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
45	30	0	At the time of field preparation
45	0	0	At 30-35 DAS
90	30	0	Total

Irrigation

Sorghum is usually grown as a rainfed crop; however, irrigation should be provided whenever rains are not received. At the time of earhead formation and milking stages, crop requires more water and at these stages, plants should not be allowed to wilt otherwise yield is affected. Suitable drainage conditions should be provided for removal of excess rainwater from the field.

Under water scarce conditions, four irrigations should be given at just after the harvest of first crop, knee-high stage, earhead emergence stage and at grain formation stage.

Interculturing and Weeding

For weed control in sorghum, spray atrazine 1.5 kg/ha in 500 litres of water evenly on the soil surface as pre-emergence treatment. There should be enough moisture in the soil at the time of spray. Field should not be disturbed for initial 3-4 weeks after spraying. One hand weeding should be done after 30-35 days of sowing.

Thinning

For maintaining desired plant population, thinning should be done at 10-15 and 20-25 days of sowing. All disease and insect infested plants should be removed at the time of thinning.

Cropping system:

(A) Crop Rotation

i Sorghum – Cotton

ii Sorghum - Pulses

iii Sorghum – Castor

(B) Intercropping

i Sorghum + Pigeon pea (BDN-2) (1 : 1) for dry farming area of Saurashtra

ii Sorghum + Karingada (5 : 1) for dry farming area of Banaskantha and Kutch

iii Sorghum + Black gram

(C) Crop sequences

i Sorghum – Wheat - Mung

ii Sorghum – Mustard

iii Sorghum – Gram/ Pea

iv Sorghum - Wheat

v Sorghum – Potato – Bajra (S)

Plant protection

Insect Pests : Shoot fly, Sorghum midge and Ants, Stem borer, Leaf minor, Sorghum earhead fly, Earhead borer.

Diseases : Sugary disease, Charcocal stem rot, Grain moulds, Leaf spot, Smut

Harvesting

Kharif ratoon is ready for harvest in the month of November-December. Harvested earheads from standing crop are carted & transported in threshing yard for complete drying. After drying, grains are separated by trampling under bullock feet. Storage should be done after complete drying of seeds. Fodder is harvested after harvesting of earheads. Improved variety takes 100 to 110 days for maturity.

Transplanting of sorghum seedlings

Timely sowing is not possible in heavy rainfall areas, so 24 days old seedlings are used for transplanting. The varieties viz., CSH1, GJ35, GJ36, and CSH5 are used for transplanting purpose. Transplanted crop gives 20-30 per cent higher yield than direct sown crop.

Package of practices for ratoon crop

(1) Cutting: After harvesting of first crop by keeping 8-10 cm height, dried diseased leaves and tillers from the field should be removed.

(2) Fertilizer : 80 Kg N and 40 Kg P_2O_5/ha, of which entire quantity of P_2O_5 and half quantity of N should be drilled in both sides of the rows as basal and remaining half quantity of N should be applied after 30 days.

(3) De tillering : Keep only the same aged tillers in the ratoon crop. All small tillers should be removed.

(4) Interculturing & weeding

Interculturing should be done after first irrigation at Vapsa conditions. One or two interculturing should be done as and when required. At the time of last interculturing operation, earthing up should be done. Weeding is done as and when required.

(5) Irrigation :In south Gujarat areas, seven irrigations are given as follows during the critical stages of the crop, just after harvesting, 4-5 leaf stage, knee high stage, flag leaf stage, flowering stage, grain filling stage and milking stage.

Varieties :

Sr. No.	Variety	Maturity days	Sowing time	Area of sowing	Remarks
High yielding varieties					
1	CSH 1	110-115	2nd week after onset of monsoon to end of August	Entire state	Suitable for ratoon crop, 33 % more yield than CSH-6
2	CSH 5	105	Up to the end of August, within two weeks after sufficient rain	Dry farming areas of the state	’’
3	CSH 6	105	Upto the end of August	Dry farming areas of the state	Suitable for ratoon crop, 33 % more yield than CSH-6
4	GJ 35	110-115	As CSH-1	Entire state	’’
5	GJ 36	110-115	For late cultivation in *kharif* season	For south Gujarat and Vadodara	For grain, ratoon crop and TP crop. Resistant to smut.
6	GJ 37	100-105	AS CSH-1	Entire state except south Gujarat	Grain as well as fodder
7	GJ 38	100-110		For Vadodara	Grain and fodder
8	GJ 39	95-100	July-August	North Gujarat, Saurashtra, Kutch	Suitable for low rainfall areas
9	GJ 40	104-108	’’	South Gujarat	
10	GJ 41				
11	GJ 42				
12	CSH 13	110-115	Upto end of Aug.	South Gujarat	
For specific areas					
1	Gundari	130-140	End of September	Ghed area (coastal area of Junagadh	Grain and fodder
2	Solapuri	150-160	’’	Bhal area	’’
Improved varieties					
1	C-10-2 (Chhachhatiya)	110	June-July	A'bad,Mehsana	Grain and fodder
2	BC 9, Striga resistant	160	July-August	South Gujarat	Grain purpose, Late maturing
5	Malvan	170	’’	South Gujarat and Saurashtra	Grain purpose
6	S 210	170	’’	’’	’’
7	S 213	160	’’	’’	’’
***Rabi* varieties**					
1	GJ 8				
2	GJ 9				
3	CSH 8				

GNJ 1 (2016) has been released by NAU.

Research stations: Main: Surat

Sub : Deesa,Viramgam

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4 P E A R L M I LL E T

Batanical name *Pennisetum glaucum*

Family Gramineae (Poceae)

Origin The primary center of origin of pearl millet is Africa from where it spread to India and other countries.

Area and distribution

The important pearl millet growing countries are India, China, Nigeria, Pakistan, Sudan, Egypt, A*rabi*a and Russia. International Crops Research Institute for Semi-Arid Tropics (ICRISAT) located at Hyderabad (AP) is undertaking research on five crops viz., pearl millet, pigeon pea, sorghum, chickpea, and groundnut.

In India, pearl millet was grown over an area of 8.9 million hectares with total production of 6.51 million tonnes with average productivity of 731 kg/ha (2010-11). Pearl millet is grown almost everywhere except in high rainfall areas like Assam, West Bengal and Orissa. States of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana account for 87 % of the total area. About 73 % of the production comes from Gujarat, Rajasthan, Uttar Pradesh and Haryana. The production of pearl millet fluctuates with the vagaries of monsoon and incidence of diseases.

In Gujarat, *kharif* pearl millet was cultivated in about 3.34 lakh hectares with productivity of 1037 kg/ha.The area under hot weather was about 2.65 lakh hectares. The average productivity of pearlmillet was 2634 kg/ha (2012-13) during summer season. Which was 2.6 times higher productivity in summer season. Banaskantha, Bhavnagar, Mehsana, Kutch, Kheda, Surendranagar, Jamnagar, Amreli, Rajkot and Junagadh are major pearl millet growing districts, while it is not grown in Valsad, Dangs, Surat, Navsari and Bharuch. The Main Pearl millet Research Station is located at Jamnagar.

Economic importance

Pearl millet is one of the major coarse grain crops, which does well even under adverse conditions of weather. It provides staple food for the poor in a short period in the relatively dry tracts of the country. It is the most drought tolerant crop among cereals and millets.

Pearl millet grain contains about 11.6 % protein. Pearl millet grains are cooked like rice or “Chapaties" are prepared from flour. It is also used as feed for poultry and green or dry karbi for cattle.

Climatic requirements

Pearl millet is a rapid-growing warm weather crop suitable for areas with 40 to 75 cm of annual rainfall. During the vegetative growth of the crop, moist weather is useful. The rainfall at flowering time is harmful as it washes off the pollen and consequently there is poor seed setting. It has a high degree of resistance for drought conditions. The crop does best under conditions of light showers followed by bright sunshine. The best temperature for the growth of pearl millet is between 20 to 28 ºC.

Soil requirements

It does best on well-drained sandy loam soils. Pearl millet is sensitive to water logging and acidic soils.

Field operations

Field should be cultivated either by tractor drawn cultivator twice or by country plough followed by harrowing to make the soil friable. While leveling the field, care should be taken to ensure that rainwater does not stagnated but drain out easily.

Sowing time

Sowing should be done with onset of monsoon i.e. 15th June to 15th July. Summer pearl millet should be sown in the second week of February to second week of March. Timely sowing reduces the incidence of insect-pests and diseases and results in higher yield. In case sowing is delayed, there is a drastic reduction in yield due to more incidences of diseases like downy mildew and ergot, due to restricted vegetative growth of the crop, high mortality and poor grain setting.

Method of sowing

Sowing is done by (1) seed drill (2) broadcast method (3) sown behind plough and (4) transplanting. Sowing with the help of seed drill in lines about 4 cm deep is the best method, which provides good germination and ultimately uniform plant population.

Transplanting of seedlings – Timely sowing of pearl millet may not be done due to several unavoidable reasons such as late harvesting of preceding summer crop. In case sowing is delayed, transplanting has been found to give higher yields as compared to direct sowing. It has the following distinct advantages.

1) Crop matures earlier and the low temperature late in the season has no adverse effects on grain setting.
2) It produces more tillers and ears owing to better growth.
3) Optimum plant population is ensured.
4) Crop gets a better start because three weeks age old seedlings are able to withstand frequent rains.
5) Downy mildew infested seedlings are rejected at the time of transplanting.

Raising seedlings

Prepare flat seed beds of 1.2 x 7.5 meters, the seeds should be sown in rows 10 cm apart and at 1.5 cm depth. About 2 kg seed of pearl millet is sown in 5 to 6 are in nursery to get seedlings for one hectare. To give better start to the seedlings, apply 5-10 kg N in the nursery. The seedlings are uprooted and transplanted after three weeks. While uprooting the seedlings, keep the nursery wet just to avoid root injury. Remove top portion above the growing point so as to minimize the transpiration from the seedlings. This also helps in preventing the lodging of the seedlings. Transplanting should be done preferably on rainy days. Irrigate the field to help seedlings to establish if there is no rain. Transplant one seedling per hill by following spacing of 50 x 10 cm. Transplanting from third week of July to second week of August gives good results.

Seed rate: 3.75 kg/ha

Seed treatment

If there is a possibility of ergot being mixed with seeds, dip the seeds in 20 % salt solution (NaCl). The ergot-infested seeds would float on the surface that should be removed and burnt. The sound seeds that settle at the bottom should be washed thoroughly with fresh water and dried in shade. After drying the seeds, it should be treated with Thiram @ 3 g per kg of seed. Use certified seeds only. Pearl millet seeds should be inoculated with Azotobacter or Azospirillum culture, which can save about 40 % of the recommended dose of nitrogen.

Spacing

45 cm x 15 cm

Manures and fertilizers

Well decomposed FYM or compost @ 10 t/ha should be applied and incorporated in the soil during field preparation.

Fertilizers (For *kharif*)

N kg/ha	P_2O_5 kg/ha	K_2O kg /ha	Stage of application
40	40	00	As basal in furrows 7 to 8 cm deep before sowing
25	00	00	21 days with seed drill 7 to 8 cm deep and 8-10 cm away from the rows. This should be done after thinning and weeding
15	00	00	At earhead formation stage (sufficient moisture should be in the soil)
80	40	00	Total

Fertilizers (For summer)

N kg/ha	P_2O_5 kg/ha	K_2O kg /ha	Stage of application
60	60	00	As basal in furrows 7 to 8 cm deep before sowing
60	00	00	At 21 to 30 days of sowing
120	60	00	Total

Fertilizers (For north Gujarat – Loamy sand soil)

N kg/ha	P_2O_5 kg/ha	K_2O kg /ha	Stage of application
80	60	00	As basal in furrows 7 to 8 cm deep before sowing
50	00	00	At 21 to 30 days of sowing
30	00	00	45 DAS
160	60	00	Total

Irrigation

Generally this crop is grown under rainfed conditions; hence, there is hardly any need for irrigation. Irrigate the crop if there is no rain during ear head emergence as this stage is considered as most critical stage for water requirement. Pearl millet does not tolerate waterlogged condition so proper arrangement to drain excess water from the field must be done.

The farmers of north Gujarat growing summer pearlmillet (GHB 558)are advise to irrigate their crop through drip system (1.0 PEF)on alternate day and fertilizer with 100 % RDF (120- 60- 00 N,P_2 O_5, K_2O kg/ha) as fertigation for obtaining higher grain yield and net profit as well as 8% water saving as compared to surface method of irrigation(1.0 IW/CPE ratio with 100% RDF).

After care

Thinning and Gap filling

Thinning and gap filling should be done 21 days after sowing, when there is sufficient moisture in the soil. Gap filling should be done with thinned plant if gaps are found in the field.

Interculturing and Weeding

Pearl millet is being a rainy season crop suffers from infestation of weeds. The weed infestation is severe during 3-5 weeks after sowing. Therefore, timely control of weeds is essential to get higher yield. For this, two to three interculturings should be done at an interval of 15 days up to earhead formation stage and two hand weedings at 20 and 40 days

after sowing proved beneficial. Timely manual weeding becomes difficult due to excess moisture in the field or unavailability of labours. Under such circumstances, effective way to control weeds is use of herbicides. Atrazine @ 0.5 kg/ha in 500 litres of water as pre-emergence application can effectively control most of the monocot and dicot weeds.

Cropping system:

Cropping system has been proved alternative in different Agro-climatic zones of Gujarat stae are as under:

(A) Crop Rotation

I Pearlmillet – Cotton

ii Pearlmillet – Castor

iii Pearlmillet – Groundnut

iv Pearlmillet – Pulses

(B) Crop sequences

I Pearlmillet – Wheat – Greengram

ii Pearlmillet – Mustard

iii Pearlmillet – Groundnut

(C) Intercropping: It has been followed in dry farming areas.

I Pearlmillet + Pigeon pea (1 : 1)

ii Pearlmillet + Casstor (3 : 1)

iii Pearlmillet + Cluster bean (2 : 1)

iv Peralmillet + Greengram (1 : 3)

Plant protection

Insect-Pests

White grub, Hairy cater pillar, Grass hopper, Shoot fly, Stem borer, Earhead worm and Bristle bittle

Diseases : Downy mildew, Ergot, Smut, Rust

Harvesting and threshing

Harvesting is done by cutting the whole plant or by nipping the earheads first and then cutting the plants later on. The earheads should be dried and then grains are separated either by beating the earheads with stick or by trampling under the bullock feet. The threshed grain should be cleaned and dried in sun to bring the moisture content down to 8-10 % for safe storage.

Yields 1) 2700 to 3400 kg/ha grain in case of improved cultural practices under irrigated conditions

2) 1800 -2000 kg/ha grain in case of rainfed crop

(**Summer** crop yields: 4500-5000 kg grain/ha, 7000 - 8000 kg straw/ha)

Varieties

Sr. No.	Hybrid varieties	Year of release	Area of recommended	Maturity days	Yield (Kg/ha)
1	GHB 558	2002	Entire Guj. & India	80-85 days	2800-3000
2	GHB 538	2004	Entire Guj., dry areas of Rajasthan & Haryana	70-73 days	2700-3000
3	GHB 719	2006	-do-	72-75 days	2800-3200
4	GHB 732	2007	Entire Guj. & states of north India	78-82 days	3000-3400
5	GHB 744	2007	-do-	75-80 days	3000-3200
6	GHB 757	2007	Entire Guj., dry areas of Rajasthan & Haryana	70-73 days	2800-3000
7	GHB 905	2012	Entire Guj. & states of north India	75-80 days	3100-3300

For **summer** cultivation varieties viz., GHB 526, GHB 538 and GHB 558 should be selected.

Research Station

Main : Main Pearl millet Research Station, Jamnagar

Sub : Rajkot, Talaja, Anand, Sardar Krushinagar, Kothara

Summer pearl millet give more yield than monsoon crop because (1) taken under assured irrigation facilities, (2) occurrence of diseases is less (3) efficient use of fertilizersand (4) seeds dropping, lodging of the crop and seed germination on the earhead is not possible as it happens in monsoon crop.

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7 FINGER MILLET (BAVTO/ RAGI/ NAGLI)

Botanical name: *Eleusine coracana* Gaertn.

Family: G*ramineae*

Origin: India and Africa

Finger millet is also known as Ragi in Telugu, Tamil and Kannada, Marua in Hindi, Marwa in Bengali, Mandia in Oriya, Nagli in Marathi, Mandhuka in Punjabi and Bavto in Gujarati.

Area and distribution

India, Africa, Srilanka, Malaysia, China and Japan are the important finger millet growing countries in the world.

In India, it was cultivated in about 2.65 million hectares with an annual production of 2.90 million tonnes.

The important finger millet growing States in India is Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra, Orissa, Bihar, Uttar Pradesh, Himachal Pradesh and Gujarat.

In Gujarat, it was cultivated in an area of about 45000 to 50000 hectares with an annual production of about 50000 tonnes. It is mainly cultivated in the districts of Dangs, Surat, Valsad, Panchmahals and Kheda and in very small area in Sabarkantha district. The Main Hill Millet Research Station is located at Surat with its sub centres at Waghai and Dahod.

Economic importance

It is important minor millet grown in India. It is a staple food for hard toiling class in many hilly areas of the country. It is very useful to persons suffering from diabetes. The grains are rich in protein (9.2 %) and provide minerals and vitamin A and B. The grains are eaten as chapaties. In South India, grains are malted and fed to infants (pregnant women). It is a nutritive food for adults of different ages. It can be stored for many years, as insect-pest cannot damage it during storing period. Finger millet stalk is considered to be good fodder for animals, green straw is suitable for making silage.

Climatic requirements

Finger millet requires tropical and sub-tropical climate and grown up to altitude of 2100 metres. It is very well grown under moderately hot and humid regions and tolerate drought and heavy rains from 500 to 100 cm. In regions of higher rainfall, it can be grown as transplanted crop on well-drained soil.

Soil

It is most suited to light red, red and poor to fertile soils. It also does well on well-drained sandy loam or clay loam soils. But clayey soils, heavy black cotton soils, gravely and stony

soils with poor fertility and drainage are not suitable for raising this crop. It tolerates salinity better than other cereals.

Field preparation

As the seeds are small, it needs well prepare field. After harvesting of previous crop, one or two cross ploughing or one to two tractor cultivations are sufficient for preparation of good seedbed. Stubbles and weeds should be removed from the field.

Sowing time: Onset of the monsoon

Seed rate: 5 kg/ha for transplanting of one hectare area.

Sowing methods

It is sown by two methods.

(1) Drilling - seeds are drilled in furrows 3-4 cm deep

(2) Transplanting – 3-4 weeks old seedlings should be transplanted in the puddled field. Puddling is done with plough when rains occur with light showers followed by planking. Before pulling out the seedlings, the nursery should be irrigated. In absence of the rains, transplanted field should be irrigated regularly till seedlings are well established.

Spacing: 30 cm x 7.5 cm, one seedling/hill

Manure and fertilizers

Manures: 10 t FYM/ha

Fertilizers

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
30	20	0	At transplanting
10	0	0	At 30 Days after transplanting
40	20	0	Total

Apply bio fertilizer @ 4 kg /ha (Azospirillum + Phosphobacteria) in addition to 40 kg N/ha.

Raising seedlings

For getting higher yield, it should be transplanted like paddy crop. Seedlings should be raised on raised beds in heavy rainfall areas and on flat beds in low rainfall areas.

1) Time of sowing: Seedlings are raised in June after receiving the first rain
2) Seed rate: 5 kg seeds/ha for 10 are area for transplanting of one-hectare land
3) Manures: Apply 1 tonne well decomposed FYM
4) Field preparation: Soil is prepared for nursery by one deep ploughing followed by planking.
5) Bed preparation: Beds of 1 m x 1 m as per slope should be made. Clods should be broken and make the surface of the beds fine and friable. The nursery beds may be of

any length depending upon the slope of the land but the width should be 1.0 meter. The beds should be about 15 cm higher than surrounding land. To ensure easy drainage of excessive water, channels in between the seedbeds should be provided. Nursery beds should be uniformly leveled and compacted.

6) Sowing method: Open 3-5 cm deep furrows at 10 cm apart with the help of kudali and drill the seeds in the furrows and cover the furrows with soil by hand. This facilitates germination of the seeds and easy weeding as compared to broadcasting method.
7) Aftercare: Remove weeds after 10-12 days of sowing, if necessary, second weeding should be carried out as and when required.
8) Fertilizers: Apply 5 kg ammonium sulphate for quick growth.

Interculturing and weeding

Interculturing and weeding should be carried out as and when required.

Harvesting

The crop is ready for harvest after 120 to 135 days of sowing. Matured earheads are harvested from standing crop and dried on threshing floor for few days. Straw is cut close to the ground later on. Grains are separated by trampling earheads under bullock feet.

Plant protection

Insect-pests: Stem borer, Hairy cater pillar, Grass hopper, Earhead cater pillar

Diseases: Blast, Blight and Root rot, Wilt or Foot rot, Smut

Yield: 2500 to 3000 kg grain/ha

5000 to 8000 kg fodder/ha

Varieties

1 Gujarat Nagli 1 - Released in 1976 gives 10.6 % higher yield than local variety. Average yield is 2000 kg/ha.
2 Gujarat Nagli 2 - Released in 1983, gives yield of 2200 kg/ha, attractive seed colour and comparatively larger seed size and gives 10 % higher yield than Gujarat Nagli–1.
3 Gujarat Nagli 3 - Evolved from a cross of GN-2 x KM-13 and released in 1991, gives yield of 2365 kg/ha.
4 Gujarat Nagli 4 - Released in 2006, it gives yield 2934 kg/ha.
5 Gujarat Nagli 5 - Released in 2009
6 Gujarat Navsari Nagli 6 (GNN 6) - Released in 2013
7 Gujarat Navsari Nagli 7 (GNN 7) - Released in 2016
8 Gujarat Navsari Nagli 8 (GNN 8) - Released in 2018 (Early variety, mature in 110 days)

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B PULSE CROPS

Pulses may be defined as the dried edible seeds of cultivated legumes. They belongs to the family of peas, beans and lentils (Family : Fabaceae). English word pulse is taken from the Latin Puls,meaning pouage or thick pap. The pulses are a large family and various species are capcble or surviving in very different climates and soils.

Role of pulses in Indian agriculture

India shares about 35 - 36 % and 27 - 28 % of the total area and production of pulses in the world. In India, 17 % of the total cultivated area (23 million hectares of land) is under pulse crops. The productivity is very low that is 500 kg/ha. The productivity of pulse crops became stagnated since last three decades because of less success in getting improved varieties and less area under cultivation.To meet the requirement of ever-increasing population of our country, it is necessary to increase the productivity of the pulse crops. Pulses play a vital role in human and animal and in agricultural economy by many ways:

For balanced diet, daily 85 - 104 gm of pulses/capita is required. According to WHO report, per capita availability come down to 33.19 gm per day/capita as compared to 74.1 g during 1955 against minimum requirement of 85 gm per day. According to economic survey of 1995 of Central Government of India, per capita availability of pulses in 1961 was 69 gm, which reduced to 37 gm in 1995. The average availability of pulses in Gujarat is 17 gm/day (Only 20 % of the requirement). Gujarat had an area of kharif pulses of 4.46 lakh hectares with 3.82 lakh tones production and average productivity 857 kg/ha (2012-13).

1) Pulses being an excellent source of high quality protein to the predominantly vegetarian population of our country.
2) Pulses also provide/supply nutritive feed to the poultry, piggery and other animals (Milch)
3) Pulses provide huge quantity of green as well as dry fodder to the cattles.
4) Being deep-rooted crop, they tolerate drought much better than cereals and millets and they can extract nutrients and moisture from the deep layer of the soil and hence they are considered as most important crops of the dry farming areas.
5) By virtue of their unique plant height, such as maturity, duration and low water and nutrient requirement they find a place in crop mixtures, multiple cropping and rotation.
6) Pulses have got the capacity of fixing atmospheric nitrogen by symbiotic process through root nodules. Thus, they require less quantity of nitrogen, which is a costly fertilizer.
7) Pulses can easily be grown in marginal and sub marginal soils with minimum care.

8) Pulse crop leaves considerable amount of residual nitrogen for the succeeding crop.

9) Pulses are best suited for green manuring.

10) They improve the physical condition of the soil.

11) They help in preventing soil erosion.

12) The cost of cultivation is also less as compared to other crops.

Some of the reasons for low productivity of pulse crops

1) Non availability of high yielding varieties and efficient and short duration plant type.

2) Cultivation of pulses on marginal and sub marginal soils only (Relatively poor soils).

3) The farmers are not applying proper nutrients to pulses and hence they give low productivity.

4) In addition to major nutrients, application of sulphur is beneficial in crops like pigeon pea, chick pea, green gram and black gram, if the soils have less than 9 ppm sulphur in the soil.

5) Lack of adequate resistant varieties to major diseases, insect - pests.

6) Insufficient weed management practices and irrigation

7) All pulses are grown under rainfed condition and on marginal soils; hence the average yield is about 500 - 600 kg/ha. However, with adopting of high yielding early disease resistant varieties having good quality seeds, yield can be increased upto 1000 to 1200 kg/ha under irrigated condition on productive soil.

Differences

Pulses		Legumes	
Sr. No.	Particular	Sr. No.	Particular
1	Pulses are always leguminous	1	Legumes may or may not be pulses
2	Always consumed as human food in form of Dal	2	Mostly used as cattle feed
3	Rich in protein	3	They contain protein and oil both
4	Green gram, black gram,pigeon pea, kidney bean, cowpea, cluster bean	4	Soybean, sunnhemp, fenugreek, groundnut, lucerne

***Rhizobium* stains used for the seed treatment to pulses**

Name of the strain	Crop
Rhizobium leguminosarum	Pea
Rhizobium japonicum	Soybean
Rhizobium phaseolus	Bean
Rhizobium spp	Cowpea

Nitrogen fixation by *Rhizobia* in some of the crops

Name of crop	Quantity fix in soil	Name of crop	Quantity fix in soil
Pea	65 kg/ha	Black gram	61 kg/ha
Cowpea	200 kg/ha	Green gram	200 kg/ha
Pigeon pea	200 kg/ha	Chickpea	225 kg/ha

NB: Fixation of atmospheric nitrogen is depending on the specific strain, moisture, temperature, crop oxygen, pH and organic matter present in the soil.

MULLaRP

M = Mungbean (Greengram) U = Urdbean (Blackgram) L = Lentil (Masur) La = Lathyrus (Lang) R = Rajmah P = Peas

8 PIGEON PEA (R E D G R A M, Arhar, Tur)

Botanical name: *Cajanus cajan* L. (Millsp.)

Family: Leguminoseae (Fabaceae)

Origin: It seems that Africa is the probable place of origin and the plant might have been introduced into India by ancient traders trading on the routs between Zanzibar, India and Shrilanka. However, according to Vavilov, India is the place of origin of pigeon pea.

Synonyms: Red gram commonly known as arhar, pigeon pea or tur etc.

Pigeon pea is commonly known as pigeon pea. It is important and old crop in our country. It is grown in wide range of agro ecological situations because of its deep root system and due to this characteristics, it is drought tolerant and is useful in the areas of low and uncertain rainfall on lighter soils. It is grown as sole as well as mix or inter crop. Traditional long duration varieties of pigeon pea that take 240-270 days to mature are of low potential and susceptible to different diseases and pests and are also damaged by frost. Recently some short duration varieties (120 - 125 days) have been developed having high yield potential (20-30 q/ha) and harvested by end of November. These varieties fit very well under double cropping systems with wheat and other *rabi* crops.

Classification pigeon pea

Cultivated pigeon pea may be classified into two groups. Species differed according to height, colour, shape and size of pod and seed and time of maturity.

1) *Cajanus cajan* var. *bicolor*

Mostly late maturing varieties included in this group, plants are tall, bushy with yellow flowers, purple streaped, pods dark colored containing four to five seeds, extensively cultivated in northern India.

2) *Cajanus cajan* var. *flavus*

This group is early maturing, comparatively small plants, yellow flower, and pods containing only two to three seeds, grown in southern India.

Area and Production

Pigeon pea is grown throughout tropical countries like Africa, West Indies, Shrilanka, Australia and Malasia. It is grown over an area of 3.9 millian hectares with a production of 3.3 MT having the productivity of 848 kg/ha (2013-14). The crop is extensively grown in Maharashtra, Uttar Pradesh, Madhya Pradesh, Karnataka, Andhra Pradesh and Gujarat. Uttar Pradesh alone contributing about 40 % of the total pigeon pea production in the country. In Gujarat, it is grown in about 2.28 lakh hectares with production of about 2.70 lakh tonnes with the productivity of 1185 kg/ha (2012-13). This crop is grown in almost all the districts of the state except in areas receiving low rains and light soils in Saurashtra region. Major pigeon pea growing districts are Bharuch, Baroda and Surat.

Economic importance

Pigeon pea is a backbone of nutritional security of our country. India produces about 90 % of the world total production. After gram, pigeon pea is the second most important pulse crop in the country, stands first in Gujarat. It is rich source of protein (23.1 %) and supplies a major share of the protein requirements of the vegetarian population of the country. It is mainly eaten in the form of Dal. Seeds of pigeon pea are also rich in iodine and essential amino acids like lycine, cystine and arginine. The outer covering of its seed together with part of the kernel provides a valuable feed for milch cattle. The husk of pods and leaves constitute valuable cattle feed, woody parts of the plant are used for fuel as well as roofing purpose. It is a legume crop and consequently possesses valuable properties as restorer of nitrogen into the soil. It profusely adds the organic matter in the soil due to shattering of the leaves. It is a tap-rooted crop having indeterminate habit in flowering so it can withstand the adverse weather situation. Extensive cover of this crop prevents wind and water erosion of the soil

Climatic requirement

Pigeon pea grows well in warm tropical and sub-tropical climate. The crop prefers a fairly moist and warm climate during the period of its vegetative growth. During the flowering and ripening stages, it requires bright sunny weather for the setting of fruits. It is highly

susceptible to frost at the time of flowering. Cloudy weather and excessive rainfall at flowering time damage the crop to a great extent. Flowers are dropping in the cloudy weather. It tolerates moisture stress due to its deep root system.

Soil

It does well on fertile, well-drained sandy loams to black soils. It is also grown on sandy to clay soils. The saline-alkaline and water logged soils are unfit for its cultivation as they adversely affect nodulation.

Field preparation

Being a deep-rooted crop, it requires a deep and well-pulverized field, which is free from weeds and clods. Deep ploughing (15 cm) with soil turning plough followed by two to three cross harrowing and proper levelling should be done to ensure uniform irrigation and proper drainage. Planking should follow each ploughing**.**

Sowing time

Immediately after onset of monsoon. For timely sowing of succeeding crop, it should be raised by applying pre-sowing irrigation.

Method of sowing: With the help of seed drill or sown behind the plough

Seed rate

Sole crop : 12 to 15 kg/ha for early maturing varieties

: 10 to 12 kg/ha for mid late varieties

Mixed crop : 6 to 7 kg/ha

Seed treatment

Rhizobium bacterial culture is given before sowing because leguminous crops have root nodules with capacity to fix atmospheric nitrogen in the soil, which helps in minimizing the N requirement of the crop. Nitrogen is therefore require as starter dose, latter on the crop takes N fixed by *Rhizobium.*

Spacing

1) Early maturing varieties: 60 cm x 15 cm

2) Mid late varieties: 90 cm x 15 cm

3) Inter crop: Early maturing varieties of greengram/ blackgram/cowpea should be sown in between rows of pigeonpea at 75 cm / 120 cm.

Spacing should be kept 120 cm x 45 cm and 120 cm x 30 cm for AGT 2 and Vaishali varieties, respectively.

Manures and fertilizers

Manures

FYM @ 8- 10 t/ha should be applied and incorporated in the soil at the time of field preparation. Apply 250 kg gypsum/ha under north Gujarat conditions, while 150 kg/ha under middle Gujarat conditions in addition to recommended dose of fertilizer (25:50:0 N:P:K kg/ha).

Fertilizers

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Time of application
25	50	0	As basal before sowing

Application of gypsum and zinc sulphate @ 200 kg/ha and 25 kg/ha are found beneficial if the soils are deficient in sulphur and zinc, respectively. If soil is deficient in micro-nutrients, they should be applied accordingly.

Interculturing and weeding

The period of first 60 days is very critical in the life cycle of pigeon pea. Two interculturings and hand weedings, first at 30 days and second at 45 days after sowing should be carried out. Under scarcity of labours, pendimethalin @ 1.0 kg/ha as pre-emergence should be applied in north Gujarat zone.

Irrigation

Being a rainy season crop, it does not require irrigation but in case of prolonged drought during the reproductive period of growth, one or two irrigations may be needed. If irrigation facilities are available, two irrigations are given after cessation of rainy season at flowering and grain formation in pods that resulted into double yield.

Crop rotation

Development of short duration varieties maturing in 130-160 days has made it possible to grow a second crop during rabi season. Several crops like wheat, gram, lentil, sugarcane etc. may be grown after pigeon pea crop.

Intercropping

a) Three rows of groundnut + one row of pigeon pea (3:1) b) Two rows of pearl millet + one row of pigeon pea (2:1) c) Three rows of pearl millet + one row of pigeon pea (3:1)

Plant protection

Insect- Pests: Aphids, Jassids, Pod borer and Pod fly

Diseases: Wilt and Sterility mosaic

Harvesting: When leaves dried, fall down and most of the pods (75 %) are dried, harvesting should be done by cutting the whole plant. Threshing should be done by beating the plants with sticks and grains are separated and cleaned.

Varieties

Sr. No.	Variety	Maturity days	Area of sowing
1	BDN 2	150-160	All pigeon pea growing areas, resistant to wilt disease, mid late maturity
2	ICPL 87	120	Early maturing variety, red colour seeds, pod seting in bunch, pods matures at a same time, feasible for narrow spacing
3	Manak	120-125	Early maturing, seeds small, semi spreading, suitable for double cropping, popular in northwest plains, developed at Hisar.
4	GT 100	125-140	Early maturing variety and for intercropping, pod setting in bunch, seed and vegetable purpose
5	ICPH 8	125-140	’’, yield 2500 kg/ha,red colour seeds, hybrid variety
6	GT 1	150-160	Vegetable variety, 5100 kg green pods/ha
7	C 11	-	South Gujarat for *rabi* cultivation, Released in1998
8	GT 101	130-140	Individual pod setting and big size seeds
9	GT 103	-	1496 kg grain /ha
10	SVT 1	125-140	Released by GSFC, Vadodara for vegetable purpose
11	Banas	130-140	Resistant to Fusarium wilt, seed size medium

Research Stations

Main Pulse Research Station - Sardar Krushinagar

Sub Stations – Vadodara, Anand,Bharuch, Navsari and Junagadh

Yield : 800 - 1000 kg seeds/ha

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9 GREEN GRAM (MUNG BEAN or MOONG)

Botanical name: *Vigna radiata* L. Wildzek

Family: Leguminoseae (Fabaceae)

Origin: India and Central Asia

Area and Distribution

Green gram is cultivated in the countries of India, Burma, Srilanka, Pakistan, China, Fiji, Queens land and Africa.

India is the major producer of green gram in the world and grown in almost all the States. It is grown in about 36 lakh hectares with the total production of about 17 lakh tonnes of grain with a productivity of about 500 kg/ha. The important green gram growing states in the country are Orissa, Maharashtra, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan and Bihar.

In Gujarat, it was cultivated in total area of about 1.15 lakh hectares with the production of 0.52 lakh tonnes with an average yield of 452 kg/ha (2012-13). It is mainly cultivated in the districts of Kutch, Banaskantha, Sabarkantha, Mehsana, Surendranagar and Ahmedabad, however, almost all districts are growing green gram in the State.

Economic importance

Greengram is an excellent source of high quality protein (25%) having high digestibility. It is consumed as whole grains as well as "Dal" in a variety of ways in our food. Sprouted green gram is used in the preparation of curry or a savory dish (South India). It is supposed to be easily digestible and hence the patients prefer it. It is also a good source of Riboflavin, Thiamine and Vitamin C (Ascorbic acid). When green gram is sprouted, seeds synthesized remarkable quantity of ascorbic acid (Vitamin C). Green gram is also used as green manure crop. It being a leguminous crop has capacity to fix the atmospheric nitrogen (30-40 kg N/ha). It also helps in preventing soil erosion. Being a short duration crop, it fits well in many intensive crop rotations. Green gram can be used as feed for cattle. After harvesting the pods, green plants are uprooted or cut from the ground level and chopped into small pieces and fed to the cattle. The husk of the seed can be soaked in water and used as cattle feed. It is self-pollinated crop. In North India, it is cultivated in both *kharif* and summer seasons and in South India, it is cultivated in *rabi* season.

Climatic requirement

Green gram is best suited to areas having an annual rainfall of 60 to 75 cm. It requires a hot and warm climate. Greengram is considered to be hardiest among all pulse crops and can tolerate drought to a great extent. Hence, it is successfully grown in any adverse conditions

and particularly in drought prone areas during *kharif* season. However, water logging and cloudy weather are harmful for the crop. It is grown in all the three seasons in the country.

Soil

Green gram can be grown on a variety of soils ranging from sandy loam to black cotton soils having good drainage capacity. Saline and alkaline soils are not suitable for green gram cultivation. Green gram is very sensitive to water logging conditions.

Field preparation

Field is prepared by one or two ploughing followed by two or three cross harrowing and planking. The field should be well leveled and free from weeds and stubbles.

For summer season crop, pre-sowing irrigation should be given immediately after harvesting of the previous crop Field is prepared at Vapsa conditions by giving two or three ploughing by local plough or harrow. Each ploughing/harrowing should be followed by planking to make the field levelled and to minimize the loss of moisture by evaporation from the soil. Planking operation is important in summer season to prevent the losses of moisture from the soil.

Time of sowing

Sowing is done on onset of the monsoon in *kharif* season and during second fortnight of February to first fortnight of March in summer season.

Method of sowing

Sowing should be done behind the local plough or with the help of seed drill.

Seed treatment

Before sowing, seeds should be treated with Thiram or Captan@ 2 to 3g/kg of seeds. It is also desirable to treat seeds with suitable *rhizobium* strain if crop is taken in the field first time.

Spacing: 45 cm x 10 cm (*kharif*); 30 cm x 10 cm (*rabi* and summer)

Seed rate: 15 to 20 kg/ha (kharif season)

20-25 kg/ha (*rabi* and summer seasons)

Seeds should be sown at a depth of 5-7 cm.

Manures and fertilizers

Well decomposed FYM @8-10 t/ha should be incorporated into soil at the time of preparation of the soil.

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Remarks
20	40	0	As basal application

Irrigation

For rainfed crop, irrigation is not needed but drainage is very important because this crop is very much sensitive to water logging.

For summer season crop, five to six irrigations may be given. First irrigation should be given at 20-25 DAS and subsequent irrigations should be given at an interval of 12-15 days. Irrigation should not be given at full bloom stage of the crop. Late flowering and early pod filling stages are critical stages for irrigation.

Interculturing and weeding

Application of pendimethalin 30% EC 0.9 lit/ha followed by imazethapyr 10% SL 0.75 kg/ha PE followed by hand weeding at 25-30 DAS or pendimethalin 1.0 kg/ha PE followed by quizalofop-ethyl 50 g/ha at 15-20 DAS to control weeds effectively in mungbean.

Cropping system

Early maturing varieties mature in 60-70 days and they can be fitted between *kharif* and *rabi* season crops. Green gram is grown as mixed crop with pearl millet, sorghum, maize and cotton. Green gram is taken in a crop sequence of sorghum-wheat-green gram, sorghum-potato- Bajra (S)

Plant protection

Pests: Aphids, Jassids, White flies and Pod borer

Diseases

green gram or pearl millet-wheat-green gram.

Yellow mosaic, Mosaic mottle, Leaf crinkle, Leaf curl, Seed and Seedling rot, Cercospora leaf spot. Mosaic is transmitted by whiteflies (Vector) and hence, it should be controlled by spraying of systemic insecticides.

Harvesting

When pods are turned into black colour, two to three pickings are done. Pickings should be carried out only during morning hours. Threshing should be done in threshing yard and seeds are separated and cleaned.

Varieties

Variety	Maturity days	Recommended area for sowing
Gujarat moong 3	70 – 75	Yield 1200-1300 kg/ha, Entire state for only summer season
Gujarat moong 4	60-65	Yield 1200 –1300 kg/ha. *Kharif* and summer seasons. Resistant against micophomina blight. Synchroneous maturity.

K 851	65-70	Entire state for summer cultivation also and pods are matured at the same time having synchronous maturity and hence field can be harvested at the same time. Yield 1000-1200 kg/ha. Kharif and summer seasons.
GAM 5		For summer cultivation, Released by AAU
GAN 6, Guj. Black Moong 1		Released by NAU

Research Stations: 1) Main Pulses Research Station - SardarKrushinagar

2) Sub Stations - Vadodara, Anand, Navsari and Junagadh

Yield : *Kharif* season : 600 - 700 kg/ha ; Summer season : 1100 - 1300 kg/ha

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10 BLACK GRAM (URD BEAN)

Botanical name*: Vigna mungo* (L.) Hepper

Family: Leguminoseae

Origin: India

Area and distribution:

Black gram is grown in the countries of India, Bangladesh, Pakistan, Burma and Srilanka. In India, it is mainly grown in the states of Maharashtra, Orissa, Rajasthan, Bihar, Madhya Pradesh, Andhra Pradesh, Gujarat and Uttar Pradesh. In India, it is cultivated in an area of about 30 lakh hectares with production of 10-12 lakh tonnes with an average productivity of about 500 kg/ha. In Gujarat, it was cultivated in an area of 0.94 lakh hectares with production of 0.60 lakh tonnes grains, productivity is being 638 kg/ha (2012-13). In Gujarat, it is more or less grown in almost all districts and its cultivation is mainly centered in Panchmahals,Sabarkantha and Vadodara districts.

Economic importance:

It is used as a food in form of "Dal" in both the ways i.e. whole or split, husked and de-husked. It is a chief constituent of "Papad". Also used in "Dosa", "Idali", "Halwa" and "Imarati sweets". It is also used as nutritive fodder for milch animal. It acts as soil binder due to deep rooted system prevent soil erosion and also used for green manuring purpose. It has high nutritive value 24 % protein, 60 % carbohydrates and richest in phosphoric acid, 5 to 10 times richer than others. It contains 1.5 % amino acids, vitamins and minerals etc. The crop also builds soil fertility by fixing about 70-90 kg N/ha.

Climatic requirement

It is a hot weather crop grown in kharif season in north and central India. In eastern states, it can be grown in winter, whereas, in southern India, it can be grown both in rabi and kharif seasons. Heavy rainfall at flowering is harmful. Crop is sensitive to photoperiod and does well under short day conditions.

Soil : Does well on the soils ranging from sandy loam to heavy clay except alkaline and saline soils.

Soil preparation

One ploughing followed by two to three harrowing and planking should be carried out.

Sowing time: Onset of monsoon

Spacing: 45 cm x 10 -15 cm

Manures and fertilizers

FYM @ 8-10 t/ha and 10-20-00 kg NPK/ha as basal. Application of sulphur @ 20 kg/ha is found beneficial if the soils are deficient in sulphur.

Irrigation

During *kharif* season, irrigation is not required but good drainage is essential. For summer season crop, 4-6 irrigations are required at an interval of 10-15 days depending upon weather conditions and soil type. Flowering and pod filling stages are critical stages for irrigation.

Interculturing and Weeding

One or two hand weeding and interculturing should be carried out upto 40 DAS to check weeds. Application of Pendimethalin @ 1.0 kg/ha as pre-emergence in 500 litres of water controls the weeds in this crop.

Cropping system

Black gram is grown as either mixed or intercropped with other *kharif* crops sorghum, maize, pearl millet, pigeonpea and cotton.

Plant protection

Pests: Jassids, Aphids, Whitefly and Pod borer

Diseases : Yellow mosaic, Powdery mildew and leaf spots

Yellow mosaic is transmitted by whiteflies,hence spray systemic insecticide for controlling it.

Harvesting

The crop is harvested when most of the pods turned into black colour. Harvesting is done by cutting the whole plants and allowed to dry on threshing floor for few days. After complete drying, threshing is done manually or by trampling under bullock feet. Cleaned seeds are stored having 8-10 % moisture.

Yield: 800-1000 kg/ha

Varieties

Sr. No.	Variety	Maturity days	Remarks
1	T 9	75-80	Entire state for *kharif* and summer season and synchronous maturity, photo-insensitive, yield 800-1000 kg/ha cultivation, hairs on stem, branch, leaves and pods
2	TPU 4	70-75	More height, bold seed and synchronous maturity, yield 1200 to 1500 kg/ha, Medium plant height, no hairs on stem, branch, leaves and pods
3	Pusa-1	80-85	Resistant to yellow mosaic, photo-insensitive, yield 1200 to 1500 kg/ha
4	Guj. Urd 1	70	Released during 2004. Seeds are greenish black. Yield 1100-1200 kg/ha, 14 % higher yield over T-9, hairs on stem and pods only.

Research stations : **Main :** Sardar Krushinagar

Sub : Vadodara and Navsari

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12 G R O U N D N U T (P E A N U T)

Botanical name: *Arachis hypogea* L. *Arachis hypogea* is derived from two Greek words "Arachis" meaning to legume and "hypogea" meaning below ground, referring to the formation of pods in the soil.

Family Leguminoseae (Fabaceae)

Origin: Botanical survey has indicated that Brazil in South America is the most likely center of origin of this plant. In India, Jesuit Father (Missionaries) introduced it in first half of the 16th century. It was introduced in Gujarat by Shri Padmabhai Patel of Pipaliya village (Rajkot) in 1910 from Tamil Nadu.

It is also known as peanut, earthnut, monkey nut, manilla nut, pinda, goober and kingpin of oilseeds, unpredictable legume and energy capsule.

Area and distribution

World production of groundnut reached a record of about 21 million tonnes. The most important groundnut producing countries in the world are India, China, USA, West Africa, Sudan, and Nigeria etc. India ranks first in the world in area (8.5 million hectares contributes about 40 % of the total world's area) and production (8.4 million tonnes contributes about 33 % of the total world's production). The average productivity of India is only about 988 kg/ha as against 2995 kg/ha in USA, 2688 kg/ha in China, 1379 kg/ha in Brazil, 1360 kg/ha in Indonesia and 1145 kg/ha in Nigeria.

Among all oilseed crops, groundnut accounts for more than 40-50 % in area and 60 to 70 % in production in the country. Among oilseed crops, groundnut has first place in the country. In India, it is grown in an area of about 85 lakh hectares with the total production of 84 lakh tonnes. Its cultivation in India is mainly confined to the States of Gujarat, Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, Uttar Pradesh, Rajasthan, Punjab and Orissa. About 80 % of the total area and 84 % of the total production in the country are confined to first five States. The highest productivity of groundnut (1604 kg/ha) is in State of Tamil Nadu, while in Gujarat the productivity is about 1190 kg/ha.

Table shows the position of the States with respect to area, production and productivity

Area	Production	Productivity
Gujarat	Gujarat	Tamil Nadu
Andhra Pradesh	Tamil Nadu	Gujarat
Karnataka	Andhra Pradesh	Punjab
Maharashtra	Karnataka	Andhra Pradesh
Tamil Nadu	Maharashtra	Uttar Pradesh

In Gujarat, groundnut is grown in an about 20 lakh hectares area with total production of about 26 lakh tonnes annually. In Gujarat State, groundnut is grown mainly in the districts of Junagadh, Amreli, Rajkot, Bhavnagar, Jamnagar and Sabarkantha etc. Saurashtra is the heart of the Gujarat and India for groundnut production.

Economic importance

Groundnut kernel contains about 47-49 % oil and 20 % protein. Its kernel as a whole is highly digestible. The kernels are eaten as either roasted or fried and salted. The biological value of the groundnut protein is among the highest of the vegetable protein and equals that of casein. Groundnut oil is famous for use in human diet and Gujarati peoples like it more in preparation of their foods as compared to other edible oils. Groundnut oil is primarily used in the manufacturing of vegetable ghee. Groundnut is a good source of all B vitamins except B_{12}. They are a rich source of thiamin, riboflavin, nicotinic acid and vitamin E. 1 g kernel supplies 5-8 food calories.

The oil cake obtained after the extraction of the oil is a valuable organic manure and animal feed. It contains 7-8 % N, 1.5 % P_2O_5 and 1.5 % K_2O. It is a good rotation crop being legume as it build up the soil fertility by fixing atmospheric nitrogen through root nodules which adds about 12 to 40 kg N/ha and also act as a efficient cover crop for land exposed to soil erosion. The per capita consumption of edible oils in India is about 5 kg/annum, which is far less than the world average of about 13 kg and one fourth of 20 kg/capita consumption in developed countries. Plant haulm used as valuable foods. Shell is used for fuel, thus it is four fold crop i.e. food, fodder, feed and bio-fertilizer.

Groundnut is classified according to Waldron or Growth habits.

(1) The erect or bunch type: include *Arachis hypogea* sub species *fastigiata* short duration (95-105), early manuring, and high yielding and almost free from dormancy, high germination percentage (90-95).

(2) The spreading or trailing type: include *Arachis hypogea* sub species *procumbens. Lal.* Long duration (110-120 days), late maturity, high yielding ability and have dormancy (60-75%), low germination per cent (85-90).

Characteristics of main axis and laterals

Main and laterals	Erect	Bunch	Spreading	Semi-spreading	Trailing
Main axis	Short and erect	Long and erect	Very short and erect	Intermediate between bunch and spreading	Medium length and erect
Laterals	Erect, slightly oblique to main axis but almost parallel to it.	Oblique to main axis	Spread horizontally along the ground usually an inch above ground except the tips.	Prostrate up to a few internodes and then begin to ascend in a bow shaped pattern.	Trail along the ground they are flat on the ground up to the extreme tip.

The groundnut as such can be classified as erect or bunch, spreading, semi-spreading and trailing types.

Climatic requirement

Groundnut is a tropical plant requires a long and warm growing season. It grows well in areas receiving 50 to 125 cm of well-distributed rainfall during growing season, abundance of sunshine and relatively warm temperature. Soil temperature is an important factor and its effects are critical on seed germination, emergence of seedlings, early plant growth, rate of flowering, and pod development. When soil temperature goes below 19 ºC, emergence of seedlings is low. The optimum temperature for vegetative growth of groundnut is ranging in between 26 to 30 ºC depending on the cultivar. Reproduction growth is maximum at 24-27 ºC. The maximum rate of growth of pods between 30 to 34 ºC as it requires about a month of warm and dry weather. Light influences both photosynthesis and respiration in groundnut. The opening of flowers and number of flowers both depend on light.

In India, groundnut is generally sown in four seasons

Kharif: About 85 % of the total groundnut in India is sown in the kharif season under rainfed conditions.

Rabi: Groundnut is grown in rabi season on a limited area where winter is not severe and night temperature do not go below 15 ºC. This crop is usually cultivated in rice fallow field and utilizes the residual moisture after harvest of rice or with minimal irrigation (5-9). Rabi groundnut is raised on coastal regions, river deltas of Krishna, Godavari and Kaveri aand other irrigated areas in part of Tamil Nadu, Andhra Pradesh and Karnataka.

Summer: Summer cultivation of groundnut is mainly taken in the states of Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat and Maharashtra states (9-12 irrigations).

Spring: Spring cultivation of groundnut is taken in the states of Uttar Pradesh, Punjab and West Bengal etc.

Soil :

Groundnut does well in the well drained, light textured, loose, friable and sandy and sandy loam soils which help in easy penetration of pegs and their development and also harvesting. Clay or heavy soils are not suitable for this crop as they interfere in penetration of pegs and make harvesting quite difficult. Groundnut is sensitive to soil salinity. It gives good yields in the soil having the pH between 6.0 to 7.5, well supplies with calcium and a moderate amount of organic matter.

Field preparation

Although the groundnut is a deep rooted crop, but looking to its underground pod forming habit, deep ploughing should be avoided, because it encourages development of pods in deeper layers of soil which makes harvesting difficult. Adequate rains at sowing are necessary for proper germination and good plant growth and well-distributed rainfall during the crop period ensures normal vegetative growth, increased flowering and proper development of pods. One ploughing with soil turning plough followed by two harrowing would be sufficient to achieve a good surface tilth up to 12-18 cm depth.

Seeds and sowing

Bold and filled pods should be selected and shelled by using either hand or power operated decorticator just before sowing. Form the shelled seeds, small, shriveled, damaged and broken seeds should be removed and only bold ones should be used for sowing.

Seed treatment

For control of seed borne diseases, treatment of groundnut seeds with Thiram (3 g/kg of seeds), Mancozeb (3 g/kg of seeds) or carbendazim (2 g/kg of seeds) is recommended. Thereafter, seeds should be inoculated with proper strain of Rhizobium culture particularly in those fields where groundnut is to be grown first time. Seed are treated with chlorphyriphos 20 EC @ 25 ml/kg of kernels for control of white grubs. To break the seed dormancy of spreading type varieties, give the seed treatment of etharel.

Some times rodents and crows are noticed to take away the seed from the field; therefore, use of repellent like Pinetar and Kerosene for seed treatment are recommended to keep the intruders away but the care should be taken to avoid any injury to the kernels.

Sowing

Usually groundnut sowing is undertaken with the onset of monsoon. But where irrigation facilities are available, pre-monsoon sowing should be done in the last week of May or in the first week of June with pre-sowing irrigation, which increased the yield by 46 % in Gujarat and in Punjab, shifting of sowing date from normal time of first week of July to

20th June increase the pod yield of about 19 %. Early sowing helps in best utilization of monsoon by the crop because germination of all seeds will take place before rains start and the field is also vacated in time for the sowing of the winter (rabi) crop. Rabi crop is sown from September to December depending upon vacate of the rice fields. The summer crop is sown in the last week of January (second fortnight of December to first week of February depending upon the temperature prevails in the regions) to first week of February. The spring crop is sown from the second fortnight of February to first week of March after harvest of toria and potato crops.

Sowing method

Seeds should be sown about 5 cm deep with the help of country seed drill or they are sown behind the country plough. Dibbling of seeds by keeping 60 cm distance in row to row and 10 cm distance in plant to plant for spreading type and 45 cm x 10 cm in bunch type helps in saving the seed requirement and also increased the yield as the sufficient space is provided around the plant for its better growth and development.

Groundnut is generally sown in flat beds with 30 cm x 10 cm spacing. In Saurashtra region of Gujarat, set furrow system of groundnut cultivation is still practice by the farmers.

In set furrow system, farmers use same furrows (90 cm) year after year for groundnut cultivation.

In cross method of sowing, total seed lot is divided in to two parts, first half of the seed lot is sown in one direction by adopting recommended row to row spacing and second half lot is used for perpendicular sowing just to first direction by adopting same row spacing. This method of sowing helps in maintaining optimum plant population and found advantageous where groundnut cultivation is succeeds by rice cultivation.

In paired row sowing method, two pairs of rows are spaced at 45-60 cm with a spacing of 22.5-30 cm within the pair. This method also gives about 20 % higher yield than line-sown crop.

Broad bed and furrow method is useful in high rainfall area having deep vertisol where drainage of excess water is a problem. In this method, stored moisture in the furrows are utilized effectively by the crop and gives about 15 % higher yield than flat bed method.

Spacing

Spreading varieties: 60 cm x 10 cm

Bunch type varieties: 45 cm x 10 cm

Selection of seeds

Quality of seeds is of prime importance for establishing the optimum plant stand. Pods for seed purposes should be stored unshelled in a cool, dry and well-ventilated place. For seed purposes, pods should be shelled by hand 1 week before sowing time. Hand shelling insures little damage to seeds. Pods shelled long before sowing time are liable to suffer from loss of viability and storage damages. Discard shriveled, small and diseases kernels. Only bold seeds should be used for sowing to get good stand.

Seed rate

Seed rate is always depends on the spacing, type of seeds and germination percentage. Use of optimum seed rate is the key factor for maintaining recommended plant population

Spreading type varieties: 80-100 kg/ha according to the size of kernels

Bunch type varieties: 100-125 kg/ha according to the size of kernels

Manures and fertilizers

Manures 10 t/ha well decomposed FYM or compost/ha

Fertilizers

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
12.5	25.0	50.0 +	As basal application

\+ **In Potash deficient soil**

The pod formation and development of groundnut is greatly influenced by fertilizer application. Lime application accuse better nodulation.

The entire quantity of phosphorus should be applied about 4-5 cm in the side of the seed and 4-5 cm below the seed level before sowing. N may be applied preferably in the form of ammonium sulphate as it contains sulphur, which is directly involved in biosynthesis of oil. Phosphorus fertilizer is very much important as it promotes root growth and development of rhizobium and helps the crop to tide over moisture stress. Single super phosphate is the best source of phosphorus as it contains 16 % phosphorus besides 19.5 % calcium and 12.5% sulphur. Gypsum is the cheapest source of calcium (24 %) and sulphur (18.6 %). Well powdered gypsum may be applied to the crop @ 125 kg/ha when it is in peak flowering stage on the soil surface as close to the base of the plant as possible because calcium is picked up by the peg and the developing pod. Calcium too has pronounced effect on proper development of pods and kernels. Groundnut being a legume and oilseed crop has greater requirement for sulphur and phosphorus. P is a constituent of enzymes, phospholipides and protein, while S is a constituent of S containing amino acids and helps in

fatty acid synthesis. Calcium is another important mineral for groundnut production. Groundnut has unique characteristics of absorbing about 75 % of S and Ca through gynophores and developing pods.

Due to ever increasing cost of chemical fertilizers, greater emphasis has been given on the use alternate and renewable source of fertilizers. Rhizobium inoculation is found beneficial in the areas where groundnut is introduced first time. It has been reported that 15-30 % and 15-50 % yields can be increased in summer and *kharif* cultivation of groundnut by inoculating the seeds.

Yellow leaf deficiency (Fe deficiency) is corrected by spraying of 1 % $FeSO_4$ + 0.01 % Citric acid (15 g $FeSO_4$ + 1.5 g Citric acid in 10 liters of water). Yellowing of veins (Zn deficiency) is corrected by spraying of 0.2 % $ZnSO_4$ or basal application of $ZnSO_4$ once in three years @ 50 kg/ha. Unfilled pods (boron deficiency) are corrected by 0.1 % borex.

Irrigation

Groundnut being a rainy season crop, it does not require irrigation unless the dry spell period prolonged and irrigation facilities are available. If dry spell occurs, irrigation may become necessary during critical stages. Flowering, peg formation and pod development stages are critical for irrigation in groundnut. Life saving irrigation during the critical stages of the crop growth results in an increase in pod yield to the extent of 63 % in Gujarat, shelling is increased by 5 %. However, lack of soil moisture at these stages was found to be most crucial factor holding up groundnut production. Hard soils are irrigated before harvest to facilitate easy harvest.

It is recommended to spray 4 % kaolin on groundnut plants when dry spell occur.

Aftercare operations

1) Interculturing and weeding

Weeds result in severe competition with the crop and cause a considerable reduction in yield to the extent of 25 to 50 % based on nature of weed infestation in the field. Weed problem is very severe in the initial stage due to slow growth of the crop. The critical period of weed competition was found to be from 28 to 42 days after sowing. The Crop should be kept absolutely weed free up to 60 days of sowing by following 2-3 interculturing operations followed by hand weeding but care should be taken that soil should not be disturbed at pegging and pod formation stage. The earthing up should also be taken up simultaneously with interculturing operations. Basic idea of earthing up is to promote easy penetration of pegs in soil as soil also to provide more area to spread.

For efficient weed control following herbicides could be sprayed in groundnut.

Name of herbicides	Doses	Remarks
Pendimethalin	1 **kg /ha**	As pre emergence
Oxyflourfen	240 g /ha	- do-
Imazethapyr	75 g /ha	As post emergence
Quizalofopethyle **or** Fenoxaprop-p-ethyl	100 g /ha	- do-

Application of MH (Maleic hydrazide) near maturity results in inducing dormancy in the pods for about 20-30 days which checks the germination of matured pods even if they get water. Thus it helps in easy harvesting of the crop. If the soil has dried the field may be irrigated and the crop can be harvested by the help of plough harrow or cultivator. Application of growth hormone like planofix or vardhak at the time of flowering have been found to reduce excessive vegetative growth and flowering period which ultimately increases the number of effective pods/plant, test weight and the yield/unit area. The most ideal time for hormonal application in groundnut is 40 to80 days after sowing and the best concentration is 20 ppm.

Plant protection measures

Pests : Aphids, Jassid, Thrips, Whiteflies, Leaf miner, White grub, Army warm and Heliothis etc.

Diseases : Tikka, Stem rot, Rust, Leaf spots

Intercropping

In Gujarat following inter cropping systems are possible.

Groundnut + Castor (3:1 ratio)
Groundnut + Pigeon pea (3:1 ratio)
Groundnut + sunflower (3:1 ratio)
Groundnut + Sesamum (6:1 ratio)

Other crop rotations are

Maize (summer)- groundnut- gram or sarson
Groundnut – onion or garlic
Green gram - Groundnut – wheat
Maize - groundnut – pea
Lobia - groundnut –wheat

Harvesting

The prominent symptoms of maturity are yellowing of foliage, spotting of leaves and dropping of old leaves. The pod is mature when it becomes hard and tough and when there is dark tint on the inner side of the cells. Harvesting before maturity lowers the yield due to shrinkage of seeds when they dried.. Delaying in harvesting germinate the seeds in the filed it self due to dormancy in bunch type of varieties. In spreading varieties, more pods remains in soil due to broken of roots, which reduce yield and increase labour cost for picking up the pods from the soil.

In case of bunch type of groundnut, the plants are harvested by pulling. Harvesting of spreading type of groundnut is done by local plough or with the help of blade harrow. Leave the harvested crop in small heaps for two to three days for curing and drying. After drying, collect the crop at one place and detach the pods either by hand or by using pucker or thresher for separating the pods from the plants. The dried fodder, which is also known as haulm, is used in cattle feed.

Drying and storage of pods

The pods for storage must contain moisture less than 9 % and kernels 8 % as the higher moisture level in the produce are congenial for the production of aflatoxin caused for lever cancer of our body.

Yield

1500 to 2000 kg/ha (spreading type), 1000 to 1500 kg/ha (bunch type). Ratio of the kernels to pods is 70:30 (kernels and shell).

Varieties: Important characteristics of the improved groundnut varieties in Gujarat State are given below in Table.

Sr. No.	Name of variety	Year of release	Area recommended for cultivation	Pod yield kg/ha	Oil %	Days to maturity	Shelling %	Remarks
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	GG-2	1986	Gujarat	1336	49.6	98	72.8	Early maturing and high yielding
2	GG-11	1987	Gujarat	1430	48.6	110-114	72.6	Suitable for pre-monsoon sowing
3	GG-12	1991	Gujarat	1437	49.6	112-115	71.2	Early maturing and suitable for rainfed conditions
4	GG-20	1991	All Gujarat except North Gujarat	1960	50.7	109	73.4	High yield and oil Suitable for HPS
5	GG-13	1994	Gujarat	1511	49.6	120	69.2	Suitable for pre - monsoon sowing& High yield
6	GG-5	1996	Saurashtra	1270	49.2	100	73.7	Bold seeded
7	GJG-HPS-1	2008	Saurashtra& South Gujarat	2125	47.9	110-120	67.6	High yield and Suitable for HPS and confectionary uses
8	GJG-9	2010	Gujarat	1632	48.1	103	72.5	High yielding
9	GJG-22	2011	Saurashtra& South Gujarat	1770	51.6	118	72.5	High yielding tolerant to collar rot
10	GJG-17	2011	Gujarat	1798	48.5	120	66.2	High yielding tolerant to stem rot

In addition to the above varieties, TAG 24 (Trombay Akola Groundnut 24), TG 26, TG 37 –A and TPG 41 (Trombay Parbhani Groundnut 41) are also recommended.

S U M M E R G R O U N D N U T

Summer groundnut cultivation is presently confined to six states in the country. In order to the importance, they are Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra, Karnataka and Orissa.

The area under irrigated summer groundnut accounts for about 16 % of the total area and contributes to about 28 % of the total production. The yield level of summer groundnut is almost double than those of kharif groundnut. The average productivity of summer groundnut in the Gujarat was around 2287 kg/ha as against 502 kg/ha in *kharif* season. Summer cultivation in Gujarat was about in 0.66 lakh hectare with the production of 1.51 lakh tonnes. (2012-13). Since the irrigated crop is not subjected to vagaries of monsoon rains and is less exposed to pest and disease complexes, there is an immense possibility of increasing productivity and stabilizing production of groundnut. Weeds infestation is also less in summer season as compared to *kharif* and they are easily controlled, as the rain is not interfering in the intercultural operations. Besides these, the crop is highly responsive to irrigation and gives maximum water use efficiency.

Time of sowing

Third week of January to first week of February is most suitable period for sowing of summer groundnut. Early sowing affects the germination due to low temperature results in lower yield and delay in sowing damaged the pods as it is matured at the time of onset of monsoon. The time of sowing for summer groundnut is depend upon the soil and atmospheric temperature. The minimum temperature in the top layer of soil should not be less than 18 ˚C. If it is goes below 18 ˚C, emergence of groundnut seedlings is slowed down resulting in poor plant stand and ultimately gives lower yield.

Soil

The crop does well in the well-drained, sandy loam soils. Groundnut is sensitive to soil salinity.

Varieties

Sr. No.	Name of variety	Year of release	Area recommended for cultivation	Pod yield kg/ha	Oil %	Days to maturity	Shelling %	Remarks
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	GG-2	1984	Gujarat	1947	49.0	120	70.5	High yielding
2	GG-4	1993	Gujarat	2007	50.8	119	74.4	- do -
3	GG-6	1999	Gujarat	2782	50.3	119	73.0	- do -
4	GJG-31	2010	Gujarat	3483	49.2	117	70.6	- do -

Life period

Summer groundnut varieties require 110-120 days for maturity, which matures within 90-100 days in *kharif* season. The reason for delay in maturity during summer season is due to the fact that in summer it requires 10 to 15 days for its germination as compared to 4-5 days for germination in *kharif* season.

Seed rate

100 kg/ha healthy kernels should be used for sowing for getting appropriate plant population because plant population is one of the limiting factors for groundnut production. Seed rate is depends upon the size of the kernels. The farmers are using less seed rate because of its high cost.

Seed treatment

As per *kharif* season crop

Spacing

The spacing should be 30.0 cm between the rows and 10 cm between the plants. Cross sowing can also be used but there was no any remarkable difference in yield was observed in cross and line sowing crop of groundnut.

Fertilizers requirement

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
25	50	50 +	As basal

+ In Potash deficient soil

Well powdered gypsum @ 300 kg/ha should be applied at the time of peg formation (when it is in peak flowering stage (40 DAS) on the soil surface as close to the base of the plants as possible) as it contains 24 % calcium and 18.6 % sulphur, which help in oil synthesis.

Weed control

Two hand weedings or interculturing twice or thrice between the rows till the crop permit (up to flowering only) should be carried out for controlling the weeds. In scarcity and unavailability of labour, herbicides should be sprayed as per *kharif* crop.

Irrigation

Generally 8-9 irrigations are required for the crop season. After the crop is established, it is necessary to withheld the irrigation for about 25 days and create stress which will encourage early flush of heavy flowering, root development, nodulation and checks excessive vegetative growth.

Furrow method is the most effective with maximum water use efficiency of 3.71 kg/ha-mm and also saves about 2-3 irrigations as compared to border strip and check basin irrigation methods.

Harvesting

The bunch variety matures in about 110-120 days. Harvesting before maturity lowers the yield. Hard soils are irrigated before harvest to facilitate easy uprooting of the plants. Generally in bunch variety, harvesting is done by hand pulling of the whole plants a day after light irrigation. The fresh and matured pods are picked up manually in the field itself and dried in the threshing yard depending upon the weather conditions otherwise the plants are allowed to dry it along with the pods in the field and then carted at the threshing yard and pods are separated with the help of thresher. The pods are allowed for drying in the threshing yard till they contain 9 % moisture for good storage. The dry haulm (fodder) is used as cattle feed.

Research Stations

- ICRISAT (International Crop Research Institute for Semi-Arid Tropics), Patancheru, Hyderabad (AP)
- ICAR- Directorate Groundnut Research, Junagadh, Gujarat
- **Research Stations in Guj. : Main :** Junagadh

  Sub : Talod, Anand and Vyara

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13 C A S T O R

Botanical name: *Ricinus communis* L.

Family: Euphorbiaceae

Origin: According to available literature, castor is indigenous to Eastern Africa and most probably originated in Ethiopia. It is also possible that castor is originated in the tropical belt of both India and Africa. In India, castor is known from very early days and is referred to in Sanskrit literature.

Area and distribution

Castor is grown under varied conditions of climate including tropical, sub tropical and temperate. However, its cultivation is largely confined to the countries lying between 52' N to 40' S latitude. The major countries growing castor are India, China, Brazil, USSR and Thailand, Africa,Philippines and Pakistan.

India ranks first in the world in respect of acreage (10.4 lakh hectares) and production (17.33 lakh metric tonnes) in the world(2014-15). It contributes about 66 % of the world's acreage and 83 % of total output. Following Brazil, India occupies the next prestigious market position in the world's castor market and each year exports substantial part of its total produce to earn foreign exchange. The major castor growing states in the country are Gujarat, Andhra Pradesh, Tamil Nadu, Orissa and Rajasthan. It is also grown in the states of Uttar Pradesh, Mahrashtra, Karnataka, Madhya Pradesh and Bihar.

The Gujarat state ranks first position in the country with respect to area and production and productivity among all major castor growing states in the country because majority of farmers are adopting hybrid varieties and cultivating this crop as irrigated crop (In river belt and dry farming areas, it is taken as rainfed crop). In Gujarat, it is grown in an area of about 7.15 lakh hectares with an annual production of about 14.56 lakh tonnes of castor seeds (2014-15).The most important castor growing districts in Gujarat are Mehsana, Sabarkantha, Banaskantha, Kutch, Ahmedabad, Kheda, Vadodara, Rajkor, Jamnagar and Gandhinagar. In other districts except Valsad, Dangs and Navsari districts, it is cultivated in more or less area. Gujarat developed the hybrid variety first in the world.

Economic importance

Castor is an important industrial non-edible oilseed crop. Castor seed contain 45-47 % non-edible oil, which is used as domestic, medicinal and industrial purposes. Castor oil is used as a lubricant in all moving parts of the machinery and particularly high speed engines and aero planes. Hydrogenated castor oil is used in polishes, varnishes, transparent paper, linoleum, plasticizers, ointments, waxes, printing ink, cosmetics, hairdressing, soaps etc. In dyeing

industries and disinfectants, it is used for the preparation of Turkey red". Castor oil is also used as purgative. It is used in many veterinary uses. It is also used for medicinal and lighting purposes. It is use externally as an emollient and also used as soothing medium when dropped into the eyes of animals after removal of foreign bodies. Oil received from small seeded variety is of very good quality and specially used as a medicine, while oil received from bold seeded variety is used for lightening and lubrication etc.

Because of its deep root system, drought hardiness and quick growth, it finds a place of prestige in the cropping systems of dryland agriculture in semi-arid zones of India. The castor cake is valuable manure for field crops but due to the presence of poison "Ricin", it is not feed to the cattle. It is useful as a trap crop because root contain "ricin" (poisonous alkaloids) which kills nematodes entered into roots. It is used as windbreak crop for sugarcane, papaya and banana crops. In eri silk-producing areas, leaves are fed to eri worms. The plant stalks are used for fuel purpose or as that ching material or for preparing paper pulp.

Castor plant is also grown on the border of the nursery for natural insect control. The prodenia (leaf eating cater pillar) may lay the eggs on the lower side of the leaves of the castor, which can be destroyed by picking the leaves, and buried into the soil. This crop is also helpful as a trap crop as roots of plants trap the nematods.

Dry leaves of castor contain 24 % crude protein along with "ricin alkaloid which is poisonous but green mature leaves can be fed to the cattle with proper care i.e after washing them into the water.

Castor seed and castor cake are highly poisonous to man and animal because it contains a toxic alkaloid ricinine and ricin. But the castor cake is a good source of organic manure as it contains 4.5 % N, 1.75 % P_2O_5 and 1.5 % K_2O and also control white ants and nematodes.

Climatic requirement

Castor requires a moderately high temperature 20 to 27 ˚C with low humidity throughout the growing season. It grows best in areas where there are clear warm sunny days. Prolonged cloudy weather with high temperature at the time of flowering resulted in poor seed setting, which is known as sex reversion.High temperature above 41 ºC at flowering time even for as short period results in blasting of flowers.

The plant is considered to be very resistant to drought but even than about 80-100 mm evenly distributed rainfall is required for optimum growth. Heavy rainfall at flowering reduces the yield. Castor plant is very susceptible to frost but some annual cutivars can grew even an

altitude of 1200 to 2100 m, e.g. Nilgiris, if sown in March- April, perennial varieties are grown at still higher altitude for shade in coffee estates.

Soil

Castor can be successfully grown on any type of soils except clays as the castor crop is highly susceptible to water logged conditions. It is generally grown on red loam soils in peninsular Indian and on light alluvial soils in northern states. Inferior soils not fit for valuable commercial and food crops are often used for raising castor crop. The crop cannot tolerate alkalinity of soil but withstand slight to moderate acidity of soil. Its cultivation should however be confined to upland areas as this crop is highly susceptible to water logged conditions.

Field preparation

Castor being a deep-rooted crop requires well-prepared seedbed (deep rooting medium). Deep ploughing in summer is necessary to break up any compact layer in the soil so that roots can penetrate deep in the soil to obtain moisture from deep layer of the soil during dry periods. Deep ploughing will also increase water-holding capacity of the soil. Disc harrowing should be done followed by ploughing to break clods, level the seedbed and destroy weeds. The seedbed should be moist to a depth of 15-20 cm.

Sowing time

1. For rainfed crop - onset of the monsoon i.e.Second fortnight of July
2. For irrigated crop - July end to 15th August

- For GCH 5 **:** 15th August to first fortnight of September

: 15th October (As a *Rabi* crop)

Seed rate

1. For irrigated crop - 5 to 6 kg/ha (For dibbling method)
2. For rainfed crop - 10 to 12 kg/ha

Seed treatment

Seeds should be treated with 1g Bavistin or 3 g Thiram/kg of seeds for controlling seed and soil borne diseases.

Spacing

For irrigated crop **:** 90-150 cm x 60-75 cm

For unirrigated crop **:** 90-120 cm x 45-60 cm

The seeds may be sown at 8 cm depth behind the plough or by seed drill for rainfed crop.Gap filling should be done within 10-12 days and keep one plant per dibble for irrigated crop.

Manures and fertilizers

Manures

Well powdered FYM @ 10 t/ha or Castor cake @ 1 t/ha

Fertilizers

For rainfed crop

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
40	40	00	
20	40	00	As basal application
20	00	00	At flowering stage i.e. 45 DAS

For Irrigated castor

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
120	25	00	
40	25	00	As basal application
40	00	00	40- 50 DAS
40	00	00	70-80 DAS

For GCH 7

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
180	37.5	00	
45	37.5	00	As basal application
45	00	00	35-40 DAS
45	00	00	65-70 DAS
45	00	00	95--100 DAS

Integrated Nutrient Management (INM)

75 % N through fertilizer + 25 % N through FYM or Castor cake or Green manuring **OR**

75 % N through fertilizer + 25 % N through FYM + Azospirillum seed inoculation

(50 g culture/ kg seed)

In sulphur deficient soil, 20 kg S /ha should be applied through gypsum @125 kg/ha.

Irrigation

Castor is mostly raised under rainfed conditions. However, it has been observed that it responds very well to irrigation. Castor being a deep-rooted crop can extract water from considerable depth in the soil. Irrigations may thus be relatively heavy and less frequent. For higher yields, wherever, possible 2-3 heavy irrigations may be given. In case of soil moisture deficiency at flowering stage, essentially one irrigation be provided. In heavy rainfall areas, proper drainage is most essential.

Under irrigated conditions, 3-4 irrigations at an interval of 15 to 20 days should be given after cessation of monsoon.

Advantages of Drip Irrigation system

Sr. No.	Name of zone	Water saving	Higher castor yield as compared to surface irrigation method
1	North Guj.	24 %	36 %
2	South Saurashtra	29 %	43 %

Interculturing and weeding

Conditions during kharif season are conducive to rapid and luxurious growth of weeds. Weeds compete with the plants in the early stage of growth. Weed competition period is found initial 45 Days. To control the weeds, 2 hand weedings, one at 30 days of crop growth and the other after 60 days of crop growth should be given. Two interculturings should be carried out before flowering stage.

Under poucity of labourers, farmers of north Guj. and south Saurashtra are advised to apply pendimethalin 0.9 kg/ha as pre-emergence to control the weeds.

Relay cropping

The farmers of north Guj. Agro-climatic zone are advised to adopt relay cropping systems of castor in greengram for minimizing the risk. Greengram should be sown in paired row(30-60-30 cm) and castor should be sown in between two pairs as a relay crop before harvest /picking of the greengram.

The farmers of middle Gujarat are recommended to adopt soybean-castor relay cropping system for getting castor equivalent higher yield and net return. Soybean NRC 37 is to be sown 45 cm apart in first fortnight of July and castor GCH 7 in second fortnight of August wherein, skip one row for sowing of castor after two rows of soybean.

Crop rotation

To save the crop from fusarium wilt, crop rotation is non-monetary input and take it after three years.

Plant protection measures

Pests: Semi looper, Capsule borer, Jassids, Thrips and Whiteflies

Diseases : Bacterial leaf spot, Wilt, Root rot and Blight

Nipping of axillary buds

If all axillary buds on the main shoot are nipped soon after emergence of the primary spike and thus a single main spike is allowed to develop, not only the duration of the crop is reduced but also yields are increased substantially (This practices are followed for local varieties only).

Harvesting

It takes 145-280 days to mature. Harvesting is done when capsules turn yellowish and approximate 15 to 20% capsule dried. However, all the capsules do not mature at the same time. The central spike on the main rachies mature first and then after the spikes on the side branches start maturing. Therefore, generally two to three pickings may be needed for harvesting the entire crop. The spikes should be dried in the sun light for four to five days and then threshed by beating the dried capsules with wooden sticks or trampling under the bullock feet or with the help of electrical thresher. The main spike is ready for harvest at 90 to 100 days and remaining spikes should be harvested at an interval of 15 days according to their maturity. Shattering should be eliminated. Harvesting of pre-maturing spikes lead to poor yield and ultimately oil yield with poor quality. Harvested capsules should allow drying under sun light for 5 to 6 days before threshing.

Yield : 1500 kg/ha (Rainfed crop)

3500 kg/ha (Irrigated crop)

Research Stations: AICRP on Castor: Sardar Krushinagar, Junagadh and Anand

Varieties

Varieties	Year of Release	Parents	Av. yield (kg/ha)	Remarks
GAUC 1	1973-74	VI 9	1242	Unirrigated, Double bloom,Greenish stem
GAUCH 1	1973-74	VP 1 x VI 9	1518	Irrigated and Unirrigated, Greenish stem, Triple bloom
GCH 2	1984	VP 1 x JI 35	1747	Irrigated and Unirrigated, Resistant to root rot, Triple bloom
GCH 4	1986	VP 1 x 48-1	1985	Irrigated, Triple bloom, Pinkish stem,
GC 2	1994	1-21 x VI 9	1707	Irrigated and Unirrigated, Pinkish stem, Triple bloom
GCH 5	1995	Gita x SH 72	2826	Pinkish stem, Double bloom, Suitable for late sowing, Irrigated and Unirrigated
GCH 6	1999	JP 65 x JI 96	2325	Pinkish stem, Resistant to root rot, Unirrigated
GCH 7	2006	SKP 84 x SKI 215	3000	Irrigated, Pinkish stem, Triple bloom, Resistant to root rot and nematod
GC 3	2007	(JP 65 x JI 96) x 48-1	2050	Irrigated and Unirrigated, Pinkish stem, Triple bloom, Resistant to wilt
GCH 8	2018	JP 96 x DCS 89	3680	Notified as new hybrid variety, developed by SDAU Oil content: 49.7%, 16.1% higher yield than GCH 7, Resistant to Fusarium wilt and moderately resistant to Macrophomina root rot
GCH 9	2017	Identified as new hybrid variety, developed by JAU		

NAU and AAU developed varieties GNCH 1 and GC 101, respectively.

The bloom or waxy coating found on the stem and certain parts of the castor plants is a natural protection to the plants both from pests and diseases and drought**.**

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15 S O Y B E A N

Botanical Name: *Glycine Max* Merril.

Family: Leguminoseae (Fabaceae)

Origin: North-East China

Soybean is reported to have originated in Eastern Asia or China. There is no available record of introduction of soybean into India. However, it has been traditionally grown in Northern hills and several other scattered pockets in the country and has become an essential part of the daily diet in these regions.

Area and distribution

Soybean is one of the important crops of the world cultivated over an area of 71.85 million hectares with a production of 154.32 million tonnes. The important soybean growing countries are USA, China, Brazil, Mexico and Russia. The USA alone has about 50 per cent of the world production. In India, it is grown in an area of 7.67 million hectares with production and productivity of 7.83 million tones and 1039 kh/ha, respectively.

Production of soybean in India is restricted mainly to Madhya Pradesh, Uttar Pradesh, Maharashtra and Gujarat. It is also grown on a small acreage in Himachal Pradesh, Punjab and Delhi. It is mainly cultivated in the districts of Pnchmahal,Dahod and Baroda. In Gujarat, it was grown in an area of 0.47 lakh hectares with the productivity of 779 kg/ha (2012-13).

Economic importance

Soybean seed contains about 18-22 % oil and 40-42 % high quality protein (as against 7.0 % in rice, 12 % in wheat, 10 % in maize, 20-25 % in other), which is rich in the valuable amino acid - Lysine (5%). In addition, it contains a good amount of minerals, salts and vitamins (Thiamine and Riboflavin) and its sprouting grains contain a considerable amount of Vitamin C. Bread, Chapati, Milk, Pastries, Sweets etc. can be prepared with soybean. Wheat flour fortified with soybean flour makes good quality and more nutritious "Chapati". Soybean oil is used for manufacturing Vanaspathi Ghee and several other industrial products such as soymilk, soya flour, cake, biscuits, varnish and paint and different antibiotics. It is used for making high protein food for children.

Soybean builds up the soil fertility by fixing large amount of atmospheric nitrogen through the root nodules. It can be used as fodder and its forage and cake are excellent nutritive feeds for livestock and poultry. It also enriches soil by fixing atmospheric N. Approximately 85 % of soybean produced is utilized for oil extraction,10 % for seed and 5 % for food purpose.

Soybean being a richest, cheapest and easiest source of best quality protein and fats and having a vast multiplicity of uses as food and industrial products and hence it is called as wonder crop.

Climatic requirement

Soybean grows well in warm and moist climate. A temperature of 30 º C appears to be the optimum. The minimum temperature for effective growth is about 10 ºC. A lower temperature tends to delay the flowering. Day length is the key factor for this crop as they are short day plant and are sensitive to photoperiods. The day length less than 14 hours is favourable for early flowering and maturity. Rainfall at maturity deteriorates grain quality.

Soil

Soybean can be grown on all type of soils having good drainage capacity. However, it grows well in well-drained loams or medium deep black soils. Saline/acidic or water logged soils are not suitable for this crop as it is sensitive to water logging.

Field preparation

Land should be well levelled and free from crop stubbles. In general, the preparation of the land for soybean should be the same as it is for groundnut. One or two deep ploughing with moldboard plough followed by two harrowing and planking should be carried out.

Seeds and sowing

Seeds should be treated with fungicide like Thiram or Captan @ 2-3 g/kg of seeds, which reduce the seedling rot and thereby seed rate. For efficient biological fixation of atmospheric nitrogen, it is essential that soybean seeds should be inoculated with suitable strain of *Rhizobium japonicum* culture before sowing (Prepare a Gur solution by mixing about 116 g Gur in 930 ml of water and then boiled it for 10 to 15 minutes and cool it up to normal temperature and then add 250 g Rhizobium culture in this solution and mixed it thoroughly. It is enough for 25 kg soybean seeds). Moist the seed with water and mixed the above solution uniformly with 25 kg seed and then dry them under shade and use for sowing purpose.

Sowing time

Being a rainy season crop, sowing should be done with the onset of monsoon. If monsoon is delayed, sowing should be done up to the end of July.

Method of sowing

Sowing should be done with the help of seed drill or behind the plough. The depth of sowing should not be more than 3-4 cm under optimum moisture conditions. If seed is placed

deeper or there is crust formation just after sowing, the seed germination may be delayed and may result in a poor crop stand.

Seed rate: 60 kg/ha

Spacing: 45 cm x 5-8 cm

Manures and fertilizers

Manures

Well decomposed farmyard manure @ 10 t/ ha should be incorporated in the soil at the time of field preparation.

Fertilizers: 30 - 60 - 0 kg NPK/ha as basal application.If soil is deficient in sulphur, apply gypum @500 kg/ha before sowing.

Irrigation

This crop does not require any irrigation. However, if there is a long dry spell at the time of flowering and pod filling, irrigation should be given.

Interculturing and weeding

Two manual weeding and interculturing 20 and 40 days after sowing are sufficient for control of weeds. This is done with the help of khurpi, spade, hand hoe etc. Herbicide like pendimethalin 0.5 kg/ha as pre emergence should be applied.

Pre-emergence application of pendimethalin @ 0.75 kg/ ha + HW at 30 DAS or post emergence application of quizalofop @ 50 g/ ha (in 500 lit. water / ha) + HW at 30 DAS or interculturing and hand weeding at 20 & 40 days after sowing should be carried out for effective weed management in soybean.

Crops like cotton, pearl millet, maize and pigeonpea are grown as inter crop. In Saurashtra areas, following inter cropping patterns are followed.

1) Pigeon pea or spreading groundnut grown at 60 cm + one line of soybean.
2) Pigeon pea or spreading groundnut grown at 90 cm + two lines of soybean
3) Hybrid pearl millet or hybrid sorghum sown at 60 cm + one line of soybean
4) Hybrid pearl millet or hybrid sorghum grown at 90 cm + two lines of soybean
5) Cotton grown at 180 cm apart + two lines of soybean
6) Hybrid castor grown at 90 cm apart + one line of soybean

Plant protection

Pests: Leaf minor, Hairy cater pillar, Aphids, Whiteflies, Leaf roller

Diseases: Pod blight, Seedling rot, Leaf spots

Harvesting

At maturity, plants shade the leaves and leaves are turn into yellow colour. The harvesting period ranges from 90 to 120 days depending on the varieties. When all pods are

matured, plants are cut by the sickle and dried for two to three days under sunlight and threshing should be done by beating the pods with stick or by trampling under bullock feet. Delay in harvesting after maturity results in shattering of seeds from the pods. The grains should be fully dried in sun until moisture reaches 10 –12 %.

Yield : 800 kg/ha (as mixed crop), 1500 - 2000 kg /ha (as sole crop)

Varieties:

Variety	Maturity days	Area recommended for sowing
Gujarat Soybean 1	90	Area receiving low rainfall, 1590 kg/ha yield, released in 1983
Gujarat Soybean 2	120	2240 kg/ha yield, Released in 1983, Area receiving heavy rainfall
Gujarat Soybean 3	-	1350 kg/ha yield, released in 1999
Shilajeet	105	Bold seeds
Clark	90-95	Yellow and black haulm

Varieties viz., JS 335, NRC 37 and NRC 47 are also under cultivation.

Research Stations : ICAR- Directorate Soybean Research, Indore (MP)

Amreli and Devgadhbaria in Gujarat

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D FIBRE CROPS

16 C O T T O N

Botanical name :

Gossypium arboreum L. : It is a desi cotton/ Asian cotton (n=13).

Gossypium herbaceum L. : This species is known as desi cotton/ Asian cotton (n=13).

Gossypium hirsutum L. : It is known as American cotton (n=26)

Gossypium barbadense L. : This species is perennial type cotton. It is a Egyptian cotton (n=26)

Family : Malvaceae

Origin : India is believed to be the home of cotton because the art of making cloth from cotton was first developed in India.

Area and distribution

Cotton is one of the most important commercial crops playing key role in economic, political and social affairs of the world chiefly as fibre crop. Cotton is cultivated in about 60 countries of the world but 10 countries viz., Russia, USA, China, India, Brazil, Pakistan, Turkey, Egypt, Mexico and Sudan account for about 85 % of the total production. It is cultivated in an area of about 32.9 million hectares with a total production of 41.1 million tones of seed cotton.

In India, cotton is cultivated under rainfed (65%) as well as irrigated conditions in the states of Maharashtra, Gujarat, Karnataka, Madya Pradesh, Punjab, Rajasthan, Haryana, Tamil Nadu and Uttar Pradesh. Gujarat is the largest producer of cotton in India followed by Punjab and Maharashtra.

The increase in total hectares of cotton planting in India is a reflection of acceptance of Bt cotton (9.4 million hectares) hybrids by cotton farmers throughout country and second in total seed cotton production.

Introduction of Bt cotton took place in 2002. *Gossypium hirsutum* L. represents more than 90 % of the hybrid cotton production in India and all the current Bt cotton hybrids are *Gossypium hirsutum* L.

Bt is a short form of ubiquitous soil bacterium *Bacillus thuringiensis* which is an aerobic bacterium characterised by gram positive and spore forming that forms parasporal crystals during stationary phase of its growth cycle.This bacteria was first discovered by bacteriologists in 1901 and subsequently in 1915 a German scientist isolsted the crystal toxin in Thuringen region of Germany.The synthesized crystalline proteins called “endotoxins” are highly toxic to certain insects. They kill the insect by acting on the epithelium tissues of

midgut of caterpillars.The worm feeding on the leaves of a Bt cotton plants becomes lethargic and sleepy,thereby causing less damage to the plant. Bt gene was isolated and transferred from a bacterium *Bacillus thuringiensis* to American cotton.

In Gujarat, cotton is cultivated in about 27.61 lakh hectares with an annual production of about 97.80 lakh bales of cotton (lint) (1bale = 170 kg lint) (2015-16).In Gujarat, it is widely cultivated in almost all districts except part of Dangs and Valsad districts. Bt.cotton is cultivated in more than 80 % of total area sown in Gujarat.Remaining about 20 % area is under Desi cotton.

Economic importance

Cotton is one of the most important fiber crops playing a key role in the history of mankind and civilization. Due to its importance in agricultural as well as industrial economy, it is also called as "white gold". Cotton is grown chiefly for its fibers, which are used in manufacturing of cloth for the mankind. It is also used for several other purposes like making threads, for mixing in other fibers and for extraction of oil from cottonseed. The oil content in the cottonseed ranges from 15-25 % depending on the varieties. Cotton seed cake after extraction of oil is a good organic manure and contains about 6 % N, 3 % P_2O_5 and 2 % K_2O. Cottonseed and cotton meal are good concentrated feed for cattle. It is also considered as a “cash” crop since past.

By-products:

Cottonseed constitutes about 65 % of the kapas by weight and contains about 19-20 % oil, while the oil content in kernels varies from 31 –34 % depending upon the species. Cottonseed oil is rich in essential fatty acid such as myristic, palmitoleic, steric, oleic and linoleic. Among this linoleic acid, most important fatty acid is present to the extent of 51 %. The deficiency of this fatty acid lead to the narrowing of the arteries causing reduced blood supply to the heart. Presently, refined cottonseed oil is widely used for edible purposes as well as hydrogenated oils. The coefficient of digestibility of the oil is 97 % and is nutritive value is about 9 K calories per gram. The keeping quality of the oil is comparable to those of groundnut and safflower oils.

The cottonseed meal is the production after extraction of oil. It is mainly a protein fraction of the seed and has around 50 % protein content. The quality of any protein is determined by amino acid composition. Cottonseed protein contains about 70 % of the essential amino acids, evincing its nutritive value. This protein is however deficit in methionine, tryptophan and lysine. CIRCOT, Matunga (Mumbai - Cotton Technological Research Labouratory) has successfully developed quality parameters such as fibre length, fibre strength, number of

counts, number of hank, and ginning % at laboratory scale as well as method for the protein enrichment of cottonseed meal cake.

Cotton linters are those short fibres, which are left on the seed after the removal of long fibres for textile purpose. As the cotton linters are the main source of the purest cellulose. They constitute a very important industrial row material for various cellulose based chemical industries.

Cottonseed hull is another by-product of cotton, which is very poorly exploited commercially. Hull is the seed coat, which constitute about 37 % of the weight of the cottonseed. Hulls contain about 35-47% of alpha cellulose, 19-27 % pentosans, 15-20 % lignin and 5 % ash, protein and fat etc. Presently hulls are used as roughage in live stock rations but this meal can be profitably exploited for the production of a versatile chemical furfural, activated charcoal, particleboards etc. CIRCOT developed a technique for production of furfural from cottonseed hulls. It has also developed techniques for use of hulls in production of particleboards. The average yield of furfural from the cottonseed hull is about 12 %. Cotton hulls also can be used to grow edible mushroom crop.

Presently most of cotton stalk available in the country are burnt off after the harvest of the crop. Cotton plant stalk contains 79 % holocellulose, 27 % lignin and 7 % ash. In comparison with other crop residues, cotton stalks is closer to hard wood in respect of fibrous structure evincing good potential for the manufacture of particle boards, pulp and paper, hard boards, corrugated boards and boxes, microrystalline cellulose, cellulose derivatives as a cellulose substance for growing mushroom etc. Two types of pulps, Soda and Kraft can be prepared from cotton plant stalks.

Climatic conditions

Cotton is warm season crop. It requires a mean annual temperature of over 16 ˚C and the annual rainfall of at least 1200 mm distributed throughout the growing season. A daily minimum temperature of 16 ˚C is required for germination and 21 to 27 ˚C for proper vegetative growth. It can tolerate temperatures as high as 43 ˚C but does not do well if the temperature falls below 21 ˚C. During fruiting phase, the day temperature ranging from 27 to 32 ˚C and cool nights are needed.

If heavy showers of rains occurred or heavy irrigation is applied during the fruiting period resulted in shedding of the flowers and young balls. Abundant sunshine during the period of ball formation and harvesting is essential to obtained good quality produce. Cotton plants cannot withstand against frost and hence its cultivation is restricted to an altitude of 1000 meters only.

Soil requirements

Cotton can be successfully grown on black to medium black soils of middle and North Gujarat regions preferably black cotton soils of "Kanam" tract of Bharuch district. Cotton needs a fertile soil with good moisture holding capacity. Good drainage and aeration are also essential, as the crop not withstand against excessive moisture and water logging conditions. It is grown on all types of soils, such as sandy loam, loam and clay loam soils.

Field preparation

Cotton being a deep-rooted crop requires well-prepared seedbed. The field after the harvest of the preceeding crop should be ploughed 15-20 cm deep with mould board plough. Black soils require frequent harrowing as these soils are cracked when dried. While other soils are prepared by giving one ploughing followed by one harrowing.

Time of sowing

Where irrigation facilities exist, advance planting of cotton should be done between second fortnight of May and first week of June by giving one pre-sowing irrigation. In rainfed condition,cotton should be sown with onset of monsoon.

Method of sowing

Dibbling in case of Bt.Cotton/ Desi cotton (Irrigated)

With the help of seed drill in rainfed condition

Spacing

Spacing depends on soil type, cotton varieties and irrigated or unirrigated condition.

Bt cotton **:** 120 cm x 45 cm /120 cm x 60 cm

Desi Cotton **:** 120 cm x 30 cm / 90 cm x 15 cm / 30 cm x 15 cm

Seed rate

Bt cotton **:** 2.0 to 2.5 kg/ha

Desi cotton **:** 8.0 to 10.0 kg/ha (Irrigated)

: 10.0 to 15.0 kg/ha (Uniirigated)

Seed treatment

Acid delinting of cottonseed : Mix 1 kg of commercial grade sulphuric acid (H_2SO_4) with 10 kg desi cottonseed in earthen /plastic container by stirring it vigorously for 2-3 minutes with thick wooden or glass rod. As soon as the fuzz gets dissolved, add 10 litres of water, stir well and drain out water through the perforated plastic basket. Repeat these washings three times to make the seed free from acid residue. Dip the washed seed for about 1 minute in sodium bicarbonate solution (50 g Sodium bicarbonate in 20 litres of water) to neutralize the acid residue on the cottonseed. Give 1 more washing with water and remove light damaged

and rotten in viable seeds floating on the surface. Dry the healthy fuzz free seed in the shade by spreading a thin layer. In case of undelinted cotton seed is used for sowing, rub it with earth, cow dung or ash to remove its fuzz and ensure its uniform distribution. Treat the seed with recommended fungicides like Thiram @ 3 g/kg of seeds before sowing.

Treated cottonseed of Bt.varieties are available in market, hence, they have no requirement of seed treatment.

Manures : Well decomposed FYM @ 10 t / ha

Fertilizers :

Bt cotton **:** 240 kg N/ha in 4 equal splits as a basal, at 30, 60 and 90 days (Middle Guj.)

: 240 kg N/ha in 5 equal splits at monthly interval (South Guj.)

: 240 kg N/ha in 5 equal splits at 30, 60,75,90 and 105 days (North Guj.)

(**Note : (1)** Application of 40 kg P_2O_5 / ha in phosphorus deficient soil

(2) Application of 120 kg K_2O / ha **or** 3 sprays of 3% KNO_3 at square formation, flowering and boll development stage in potash deficient soil.)

Desi cotton **:** Rainfed- 20 kg N/ha as basal and 20 kg N/ha as top dressing at 30-40 DAS

Irrigated-75 kg N/ha; Basal:37.5 kg N and two equal split of N at 30 and 60days

Gap filling and thinning

Gap filling is done immediately after germinating of seeds. Gap filling should be done with water soaked seeds for quick germination and dibble the seeds at gaps. Thinning is carried out by uprooting the excess plants, which are found weak and disease infested or damaged.

Irrigation

After last effective rainfall, in black soils having good moisture retentive capacity, irrigations should be given at 20-25 days interval. Similarly, in sandy soils, irrigations should be given at 10-12 days interval.

If irrigation is given during square (flower bud) formation and heavy flowering stage, the excessive shedding of flower buds and young bolls may occur resulted into low yield. To avoid this loss, irrigation should not be given during these growth stages.

If crop is irrigated by alternate furrow method, it saves about 25-30 % irrigation water as per soil type.

The farmers of south Gujarat growing irrigated hybrid cotton are advised to adopt drip technology under constraints of irrigation water to bring about 0.74 ha additional area under irrigation. The system should be operated at a distance of 1.2 m with dripper (4 lph) spaced at 0.45 m and operated for 60 to 70 minutes on alternate day.

Drip irrigation system should be followed in cotton for increasing WUE in any Agro-climatic zones.

Intercultivation and weeding

Cotton is highly vulnerable to weed competition especially in the initial stage of growth (90 days of its growth). Hence, control of weeds either by manual or by herbicides is essential to get high yields. Dry hoeing with hand hoe or spade 5-6 weeks after sowing or before first irrigation is very effective in controlling weeds. It should be repeated afterwards if necessary. Interculturing in cotton crop is necessary to create mulch, aeration of the topsoil, and better intake of water and control of weeds.

Plant protection measures

Pests: Aphids, Jassids, Thrips, White flies, Red mites, Pink boll worm, Spotted boll worm, American boll warm, Army worm, Mealy bug

Bt. cotton offers a promising solution to the serious problems of Pink boll worm, Spotted boll worm and American boll warm (Boll worm complex).

Diseases: Root rot, *Fusarium* wilt, Anthracnose, Bacterial blight, Leaf spot, Boll rot, little leaf

Harvesting

Cotton is harvested in three to four pickings by hand as the bolls mature. Picking should be done when bolls begin to fully burst and kapas begins to hang down. The kapas thus picked should be spread in the sun to dry for two - four hours on a clean surface. Soon after the last picking, pull out the cotton sticks along with the roots from the field and bury the remaining plant debris with a soil turning plough as a sanitary measures against pests and diseases.

Mixed cropping and crop rotation

A common practice in cotton cultivation is mixed cropping with maize, sorghum, sesamum, pulses or vegetables as practiced in many parts of central India. Inter cropping with ragi, other millets or groundnut is also quite common in parts of Tamil Nadu, Karnataka and Andhra Pradesh.

Inter cropping and mixed cropping under rainfed conditions serve both as an insurance against crop failure and as prevention against soil erosion.

The commonest crop rotations for cotton in the irrigated areas of Punjab, Haryana, northern Rajasthan and Uttar Pradesh are cotton – wheat, cotton – sorghum and cotton – wheat – toria. The growing of berseem and cluster bean has been found to have beneficial effect on the succeeding cotton crop. In central and western India, cotton – sorghum, cotton – pearl millet, cotton – wheat, cotton – gram and cotton – sesamum are the useful rotations followed. Cotton

following groundnut has been found to give 15-20 % higher yield than following wheat or sorghum. The raising of cotton crop after a legume in a rotation and preceded by a grain crop has been found to give a better yield.

Yield

Bt : 2500 kg/ha seed cotton

Deshi :1200 to 1500 kg/ha seed cotton, 233 kg lint/ha

Varieties
Bt cotton: G. cot. Hy. 6(BG II) (2012), G. cot. Hy. 8(BG II) (2012), G. cot. Hy. 10 (BG II) (2016), G. cot. Hy. 12(BG II) (2016) **:** All these varieties released by NAU GTHH 49 (BG II) (2014) : Released by SDAU
Desi cotton : V 797,G.Cot 13, G.cot 21, Anand Desi Cotton 1

Research Stations

Central : CICR, Nagpur, AICCIP (1966), CIRCOT (Central Institute for Research in Cotton Technology, Matunga (Mumbai)

Main: Main Cotton Research Station, Surat

Regional: Bharuch, Anand, Thasra, Talod, Amreli, Viramgam, Junagadh

Sub: Navsari, Hansot, Achhalia, Devgadhbaria, Khedbrahma, Bhachau, Khapat, Dhandhuka.

Gujarat Cotton Hybrid 4 was released in the year 1971 as first commercial hybrid. Gujarat cotton 101 (1977) was the first budded cotton in the world as perennial variety.

Important hints for irrigated cotton

- Land should be prepared suitable to irrigation.
- Appropriate variety should be selected. If land is irrigated partially, early variety of Desi type should be selected and where irrigation facilities are fully available, Bt. varieties should be selected.
- Avoid excess or stress condition. Irrigate the crop at proper time. Excess and improper time of irrigation damage the crop conditions.
- Cotton should be harvested up to the economic period, if the uneconomic period for harvesting is extended may cause for spread of insect and pest for next season.
- Grow multiple cropping patterns for more economic return.
- Avoid excess use of infrastructure facilities.
- Careful consideration of marketing.

Important hints for rainfed cultivation of cotton

- Adopt soil and water conservation techniques.
- Crop rotation should be followed.
- Preparatory tillage and planning should be considered.
- Selection of proper variety.
- Adopt recommended practices for different operations.
- Adopt mixed cropping to reduce hazards against low production.
- Careful consideration of marketing.

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E Forage Crops

Importance of forage

India is basically an agricultural country and about 70 per cent of its people live in villages. Their livelihood is dependent mainly on agriculture and animal husbandry. Feeds and fodders account for nearly 70 to 80% of the total cost of milk production on different farms. For full exploitation of the milk production potential of especially the crossbred and exotic breeds of cattle, it is imperative that nutritious lush green forage is made available at the rate of 35 to 40 kg per day per adult animal round the year. It is estimated that milk production can be increased to the extent of 300 % even in the indigenous breeds of cattle in India, if these could be adequately fed and managed. Therefore, every attempt should be made to grow high quality green forage legumes, cereals, grasses and trees to food milch animals in a proper manner.

Varying physical and topographical features and agro climate conditions of our country also pose problems of soil erosion, aridity, semi aridity, salinity, alkalinity and acidity combined with erratic monsoons. Intensive forage production in the marginal lands, grazing lands and in other areas that generally remain fallow can help us to overcome these problems and also improve the structure and fertility of the soil in these lands. The introduction of forage legumes in crop rotations can add greatly to soil fertility through fixation of freely available atmospheric nitrogen and thereby reduce expenditure on nitrogenous fertilizers for the succeeding crops. Hence, forage crops and trees need to be grown not only for higher milk production but also for maintaining the entire ecological balance and for properly harnessing the natural resources of our sub continent to increase the overall agricultural production to our advantage.

Fortunately, our country has varied climatic conditions and vast natural resources, placing us in a very advantageous position of growing a variety of forage crops to meet the requirement of different regions all the year round. Realizing the importance of forage and their impact on the overall economy in general and on the economics of milk production in particular, a good amount of research work has been conducted in our country. A number of varieties of cultivated forages have been developed which can give higher forage yields to encourage forage oriented cropping patterns on the farms for producing more milk at a lower cost. The efficiency of milk production is adversely affected by inadequate feeding practices, during the dry period and also in the late pregnancy of the milch animals as a result of forage shortage on he farms.

It has been possible to obtain economical and higher production of more than 2500 to 3000 kg in the case of purebred exotic cows, 1600 to 3000 kg in the case of crossbred and 1200 to 1600 kg in the case of improved indigenous cows and buffaloes under field conditions in our country by improving 35 to 40 kg of green, nutritious and palatable forage along with balanced cattle feed @ 38-40% of milk production per animal as against an average lactation yield of about 300 kg

18 F O D D E R S O R G H U M O R J O W A R

Botanical name: *Sorghum vulgare* [Pers]
Origin: East Central Africa, In India, it has been grown from pre-historic times
Family: Gramineae

Sorghum vulgare is one of the most important fodder crops of low rainfall areas of India. It can withstand heat and drought to a much greater extent than maize. Its other advantage is that it can give 2 to 3 ratoon crops and sometimes even four as in the case of M. P. Chari and Pioneer hybrid X-988. It can also tolerate water logging for short periods better than maize.

Area and distribution

The other countries where it is grown are Southern Europe, USSR, Australia, China, Pakistan and India.

In India, it is grown in Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka, Gujarat, Tamil Nadu, Rajasthan, Uttar Pradesh, Haryana and Punjab.

Climatic requirement

It is tropical crop ideally suited to moderate rainfall areas receiving 350 to 400 mm which bring the crop to flowering stage although it can tolerate a rainfall upto 600 mm. Mean temperature from 20 to 25 ˚C is favourable (congenial) for its growth. In winter, 15 ˚C and in summer about 35 ˚C temperatures are not seriously affected the growth of the crop. However, frost proved extremely harmful to its growth and increases the hazard of prussic acid poisoning due to its quicker release from the glucosidal toxicities The young plant contain a glucocide called dhurrin which break down into prussic or hydrocynic acid in the stomach of the animal. Young plants up to 30 days growth and new shoots near the soil surface are known to contain higher content of the acid. The ratoon crop is also toxic to the animals in the young stage. The crop should preferably be harvested after flowering but never before 50 days from sowing because concentration of hydrocynic acid is below the poisonous limit at this stage which is not harmful to the animal.

Young plants which have wilted in the field for want of water, cause instataneous death of animals due to very high content of the glucocide in the leaves.

The concentration of HCN (hydro cynic acid) is so high in one month of sorghum crop that a cow dies by consuming just 4 to 5 kg of such sorghum. The safe limit of HCN (Glucocide) is less than 20 g/100 g on dry matter basis.

Soil : Well-drained sandy loams, *Goradu* and medium black soils are preferable.

Field preparation

The soil should be prepared by two ploughings followed by harrowing and planking. The crop itself being shallow rooted does not require deep ploughing.

Sowing time

Kharif - June-July just after receiving first monsoon rain. In summer season, February-March is most suitable.

The farmers of Bhal and Coastal region are advised to sow sorghum variety SSG-59-3 upto 30th October to obtain higher green and dry fodder yields and higher net return under conserved moisture condition in *rabi* season.

Method of sowing

Drilling is the most common method. Seed can also be sown by iron funnel with a tube fixed behind a *Desi* plough to a depth not more than 3 to 4 cm. During the rainy season, seeds can be broadcasted at a little higher seed rate and mixed in soil with *Desi* ploughs or harrows.

Seed rate

60 kg for improved varieties

30 kg/ha for hybrids

Seed treatment

Seeds should be treated with 200 mess sulphur @ 4 to 5 g/kg of seeds for preventing measures against the grain smut disease. Andogonus Azotobacter culture @ 5 g or 5 ml is mixed with boiled gur when it is cooled down and then it is used for seed treatment. Keep double rate of culture when seeds are treated with sulphur.

Spacing : Drilling at 25 to 30 cm apart**.**

Manures and fertilizers

Apply well-decomposed FYM @10 t/ha and mixed thoroughly in the soil.

For single cut management system

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
50	40	0	
25	40	0	Basal application
25	0	0	30-35 DAS

For two cutting system

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Stage of application
75	40	0	
25	40	0	Basal application
25	0	0	30 DAS
25	0	0	Just after harvest of first crop

Irrigation

Kharif sorghum does not require irrigation but for summer sorghum, apply irrigations at an interval of 10 to 15 days. Single cut system crop requires 4 to 5 irrigations whereas in two cutting system, the crop requires 7 to 8 irrigations.

Interculturing and Weeding

One interculturing operation is required after 15 to 20 DAS. Hand weeding is done after 30 to 35 DAS.

Interecropping : Sowing of *kharif* forage sorghum with cowpea as an intercrop in 2:1 row ratio secure higher forage yield with good quality and higher return under rainfed condition.

Plant protection

Insects : Stem borer, Shoot fly

Disease : Grain smut

Harvesting :

Forage sorghum varieties are harvested at the time of 50% flowering stage, their forage is not harmful to the animals because at that stage (i.e. at 50 days after sowing) the concentration of HCN is below the poisonous limit, which is not harmful to the animal. At milking stage, HCN content is higher so, it is harmful to the small calf of cow and buffalo are not recommended to feed.

Maximum nutrients could be obtained by harvesting the crop at the time of flowering stage. The crude fiber content will be increased, while delaying the cutting will decrease the digestibility of nutrients and crude protein.

In two cutting system, first cutting should be done at 55-60 days of sowing and subsequent cuts would be harvested after 40- 45 days of the previous cut. As there is a possibility of adverse effect of fungicide/pesticide on animal, the spraying of the same is not advisable at least one month before harvest.

Yield : In single cut system, green forage yield 350-400 q/ha. In two cut system, green forage yield 650 q/ha. In multi cut system, green forage yield 800 to1000 q/ha.

Varieties

For single cut : S 1049, C 10 -2, GFS 3 (IA 5026), GFS 4,GFS 5, GAFS11, GAFS12

For multi cuts : M.P.Chari, SSG 59-3,Pioneer hybrid,GFSH 1(AS 16),Harasona, Safed moti, COFS 29

Research Stations

Main : Main Forage Research Station - Anand and Surat.

Sub : Sub research station – Dhari (Amareli),Navsari, Sardarkrushinagar

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19 Cowpea

Botanical Name: *Vigna sinensis* (Linn) Walp

Origin: Central Africa

Family: Leguminoseae (Fabaceae)

Cowpea is the most important leguminous fodder crop. It is second important crop after lucerne due to its quick growing habit, high yielding ability and high protein content. It is mainly cultivated in *Kharif* and summer seasons.

Cowpea is indigenous to Africa and India. It is grown in warm tropical and sub tropical Asia, Africa, South America, Australia and southern countries of Europe. In India, it is mainly grown in central and northern regions. Cowpea is best suited for moderately humid areas of the tropics and sub tropics. It is usually grown between 30^0 N and S and up to 1500 m elevation. The plants cannot withstands frosts, excessive heat and prolonged water logging. The optimum temperature for its growth is 27 ^{0}C and the minimum is 15 ^{0}C so it can be grown in the eastern and southern regions in the winter season also. The bacteria present on the cowpea roots add nitrogen in the soil resulted in increase in soil fertility. Cowpea crop is grown as a sole crop or mix crop along with cereals and grasses.

Improved Varieties

Sr. No.	Variety	Maturity (50% flowering days)	Recommended area	Special feature and GFY production
1	GFC 1	70	Entire country	A selection from local collection from Chharodi area from Gujarat released in 1980 for *Kharif* season. Plant height 125 cm, trailing habit, dark green pods seed of brown to buff colour 16-20 % protein, leafiness 42%, fairly resistant to diseases and yielding 250-300 q/ha green fodder.
2	GFC 2	65	Entire country	A selection from the local collection from Chharodi area of Gujarat, released in 1980 for summer season, plant height 140 cm with trailing growth habit, leafiness is 46% pods of dark green colour, brown seeds, protein content 14-19% and green fodder yield of 270-350 q/ha.
3	GFC 3	70	Entire country	A selection from the local collection from Chharodi area of Gujarat, released in 1980 for *Kharif* season. plant height 196 cm, tralling growth habit, 53% leafiness with dark green pods, light brown seeds, 17.5 to 19.5% protein content and green fodder yield of 270-330 q/ha.
4	GFC 4	70	Entire country	A selection from local collection from Chharodi area Gujarat, released in 1980 for summer season. Plant height 197 cm. trailing growth habits, 56% leafiness, pods and leaves dark green. Seeds of buff colour, protein content 17.5 to 19.5% resistant to disease and green fodder yield of 290-350 q/ha.
5	EC 4216	55-60	Entire country	Errect, early, bold-seed suitable for monsoon & summer sowing and green fodder yield is 280-300 q/ha.

Package of practices

1. **Soil:** Cowpea can grow in a wide range of soils from heavy to sandy loam with a pH range from 5.0 to 6.5. Saline, alkali or water logged soils should be avoided.
2. **Preparation of land:** Two times ploughing and harrowing are necessary to bring the land in proper conditions.
3. **Sowing:** For monsoon crop, the crop should be grown in the month of June-July with on set of rain. For summer cultivation, the sowing should be done in the month of February-March. The crop should be sown at 30 cm distant between two rows using a seed rate of 40 kg/ha.
4. **Manures and Fertilizers:** Farmyard may be applied at the rate of 10 t/ha at the time of land preparation. Apply of 20 kg nitrogen and 40 kg phosphorus fertilizer per hectare as a basal dose.
5. **Irrigation:** Generally, crop does not require irrigation during monsoon season. However, one life saving irrigation is given at the time of long spell of rains. In summer season, the crop is irrigated at an interval of 10 to 15 days.
6. **After care:** Two to three times interculturing if necessary and one hand weeding should be carried out.
7. **Plant protection**
   Pests: Leaf eating caterpillar, Aphids and Jassids
   Diseases: Cowpea mosaic
8. **Harvesting:** Generally, cowpea is harvested in 70 to 75 days. Crop should be harvested at the time of 50% flowering stage or the initiation of pod formation. Delayed harvesting will decrease crude protein and increase crude fiber content. So harvest the crop at proper time. For obtaining two cuts of cowpea, first cut is to be harvested at 50-55 days and second cut at 50% flowering or harvest at 40-45 days after first cut. In two cutting management, harvest first cut by keeping 15 cm. stem height from the ground level. Any insecticide should not be sprayed one month before the harvesting of green forage.
9. **Yield:** Green forage yield of 275 to 300 q/ha obtain in one cut. Cowpea variety GFC 3 had produced significantly higher GF (350 q/ha) and DM (59.0 q/ha) yield than EC 4216 in total of two cuts. It had also produced the highest CPY (10.37 q/ha) and CP content (17.0%).Cowpea varieties GFC 2 and GFC 4 were also at par with this variety.
10. **Mix cropping / inter cropping and crop rotation:** Cowpea could successfully be grown by mixing with cereal fodder crops like maize, sorghum and pearl millet and grasses like hybrid Napier & guinea grass. Generally, mix cropping gives more yields.In pasture land, the crop can be intercropped with grasses, cenchrus grass & sehima grass. This crop is also suitable for crop rotation due its short duration.

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20 N A P I E R H Y B R I D

Botanical name : *Pennisetum purpureum* Schumach

Origin : Napier or elephant grass is native of Rhodesia in south Africa. The name "Napier grass" is given in honour of Col. Napier, who first drew the attention of the Rhodesian Department of Agriculture in 1909 to the fodder value of this grass. It was introduced in India in 1920 from south Africa.

Family: Gramineae (Poaceae)

Napier grass is also called Elephant grass due to its tallness and vigorous vegetative growth. It is perennial grass, which provides nutritious and palatable green fodder year round. It contains about 8.2% protein, 5 to 7% crude protein, 34% crude fiber, and 10.5% ash with both calcium and phosphorus in proper balance. For hay making, this grass is too coarse, but it can be used for silage making.

Area and distribution

It is widely distributed in tropical and subtropical regions of Asia, Africa, southern Europe and America.

In India, it is grown mainly in Punjab, Haryana, Uttar Pradesh, Bihar, Madhya Pradesh, Orissa, Gujarat, West Bengal and Assam.

Climatic requirement

Warm and humid weather, as prevails in the monsoon season, is most congenial for the vigorous growth of this grass. Although, it grows best under moist conditions, it is remarkably drought resistant and once established, can tide over warm and dry summer period. The grass remains dormant during the winter season. The mean optimum temperature varies from 24 ˚C to 28 ˚C. Frost and severe cold conditions retard its growth.

Soil

Napier grass flourish well on well drained, sandy loam and medium soils. It can survive in waterlogged soils.

Field preparation

The field should be prepared well. After harvesting of previous *Kharif* crop, deep ploughing should be done by mould board plough followed either by tractor drawn cultivator or harrowing twice followed by planking.

Sowing time

Napier grass should be planted with pre-monsoon showers in the months of June-July. In summer season, February – April is most suitable.

Method of sowing

Hybrid Napier can be propagated by stem cutting and rooted slips, as the hybrid seeds are sterile.

Seed rate

Spacing	Requirement of three budded stem cutting or root slips/ha
60 cm x 60 cm	27,777
90 cm x 90 cm	12,345
100 cm x 100 cm	10,000
100 cm x 50 cm	20,000

Preparation of stem cutting

1) Three budded sets may be inserted into the soil in a slanting manner at an angle of 45^0 to the ground. Two buds should remain inside the soil and one above ground (exposing to the atmosphere).
2) Planting stem is cut like sugarcane. Furrows are opened with a small ridger or a *Desi* plough and three budded sets are placed end to end in these furrows. Planking is done to cover the sets and irrigation is applied, if moisture in the soil is insufficient for sprouting of the bud planting rooted slips.

Break up the old clumps and separate the tillers alongwith their roots. Each slip should have one or two tillers about 10 to 12 cm in height along with the roots and inserted into the soil by digging a hole with a weeding hook (khurpi). This is the best method particularly in the summer season when the stems in the first two methods are likely to dry up in the hot *Desi*ccating winds. Rooted slips should be preferred for planting in summer season under irrigation for easy establishment.

Crop mixture

For getting higher yield, planting distance of 100-150 cm x 50 cm should be kept, when it is grown as mixed crop with cowpea or guar in the *kharif* season and with lucerne in the winter season.

Sole crop should be planted at 1.0 x 1.0 m distance to facilitate the interculturing operations by bullock drawn implements, which helps to reduce the cost of weeding operation.

The stumps of hybrid Napier become old and the tillering capacity diminishes consequently, hence fresh planting is taken up after two years.

Intercropping:

Adopt the cropping system of hybrid Napier (APBN-1) with cowpea (EC-4216) as inter crop in *kharif* and Lucerne (GAUL-1) in *rabi* for obtaining higher net return (CBR-1: 2.05). It gives higher forage production round the year for two to three years cycle under irrigated condition.

Manures and fertilizers

Crop should be fertilized with 50 kg N/ha + 50 kg P_2O_5 / ha as basal and75 kg N/ha after each cut to obtain higher green forage, dry matter, crude protein yields and net return.

Irrigation

In *Kharif* season, if dry spell occur, irrigation should be given depending upon soil texture and atmospheric conditions prevails. The field should be kept well drained during the rainy season, as the crop cannot withstand wet conditions for more than a few days. In summer season, irrigations be given at 10 days interval.

Interculturing and weeding

In each season, interculturing should be done twice or thrice as and when found necessary. Weeding may be done as and when required.

Harvesting or cutting management

The first cut is generally taken after 2 months from planting and subsequent cuts can be taken at regular interval of 45 days for green forage yield. At this stage, the crop is nutritious, succulent and palatable and attains a height of about one and half metre. This crop should not

be cut before 35 days, because younger crop contains high amounts of oxalates, which is toxic (harmful) to the animals. Cutting should be done by leaving a stubble height of 25 to 30 cm from the ground level so as to avoid damage to the young growing buds near the base of the plant. If cutting is delayed, it becomes coarser and unpalatable.

The oxalate content in Napier grass varies from 3 to 6%. It depletes body calcium and damages the kidneys of the animals.

Therefore, feeding fodder by harvesting it at pre boot stage and mixing it with forage legumes and cereals minimizing the toxic effect.

Yield : First year **:** 1500- 2000 q/ha
Second year **:** 1500 q/ha
Third year **:** 1000 q/ha

Varieties

APBN 1, BNH 10 and CO 3

Research Stations

National: Indian Grassland and Forage Research Institute, Jhansi (UP)
State: Main Forage Research Station, Anand and **Sub:** Dhari (Amreli)

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22 B I D I T O B A C C O

Botanical name: *Nicotiana Tabacum L.*

Family: Solanaceae

Origin: south America

Tobacco is originated in South America. The Portuguese introduces it in India during 17th century. The Red Indian cultivated it when Christopher Columbus discovered it in America in 1492. He and his men landing in the little Island of Tobagas were greatly surprised to find the native smoking tobacco. In addition to smoking tobacco, the native ground the leaves into a fine powder or snuff and inhales it through a hollow cane tube called a Tobago. The name tobacco is derived from the word Tobago. The French Ambassador in Portugal Lean Nicota saw tobacco in Lisbon and he introduces this part in France. The scientific name Nicotiana and the word nicotine are derived from his name.

Tobacco is a herbaceous primarily grown foe its leaves. It belongs to solanaceae family. *Nicotiana rustica* sometimes found to behave like perennial. Tobacco plant generally forms a shallow branched root system. It has central taproot from which numerous short lateral root extend. The majority of the root system is confined to upper 60-90 cm of the soil. It has simple cylindrical stem. The height of the plant and length of the internodes vary in different types. Of the two species, *Nicitiana rustica* is shorter and more robust and densely

growing plant than *Nicitiana tabacum.* The size of the leaves may vary from 15 cm to 100 cm or even more in length. They may be narrow long and drown out like a whip, elliptical or broadly ovate with marked variation even in the same plant. The leaf angle varies from an upright to horizontal with dropping at the base, in the center of at any point of the leaf. The leaf base may be sessile or petiolate differing in the development of wings having a breadth of 5-6 cm. IN general the texture of leaves of *Nicotiana tabacum* is finer than that of *Nicotiana rustica*, which is more or less leathery and tough. The Nicotine content in leaves in *Nicotiana tabacum* ranges from 0.5 to 5.5 %, while in *Nicotiana rustica* it varies from 3.5 to 8.0 %. Tobacco has a terminal raceme panicle, which may be compact to very lax with a short or long peduncle. The inflorescence in main axis always flowers first and the side branches thereafter in order from top towards bottom. Flowers of tobacco plant are complete and perfect. The flowers are pink, yellow, purplish or white. The shape varies from funnel to flute. The development of green colour differs in its intensity both inside the corolla tube. The corolla may be wheel shaped with acute apices to pentagonal shape and obtuse tips. Clayx is usually tabular but in some types it is globular and inflated. The flowers bear 5

anthers, which are fused to corolla tube. The pistil is compound and matures into a capsule type fruit. The capsule varies in size, shape and nature of apex, blunt or conical. The shape may be elliptical, avoid or conical. The seeds are spherical or broadly elliptical with variation in degree of ridging on the seed coat. The colour varies from dark brown to light brown.

Area and distribution

The important tobacco growing countries in the world are Brazil,China, USA, France, Bulgaria, Canada, Rhodesia, Pakistan, Turkey and India.

India ranks third after China and USA in respect of tobacco production. In India, tobacco is cultivated in about 4.5 lakh hectares, which is about only 0.3 % of the total cropped area of the country. India produces about 6.4 lakh tonnes total production annually.

India grows different types of tobaccos viz., VFC, bidi, chewing, cigar, cigar wrapper, barley, cheroot and snuff tobaccos. India grows both *Nicotiana tabacum* (desi type) and *Nicotiana rustica* tobaccos of which *Nicotiana rustica* (vilayati or Kalkatti) requires cold climate and hence it is grown in *rabi* season only.

Tobacco is grown in almost all states in India but the principal tobacco growing states in the country are Andhra Pradesh, Gujarat, Karnataka, Tamil Nadu, Orissa, West Bengal, Bihar, Maharashtra and Uttar Pradesh. In other states, it is grown in very small area. More than 50 % of the total tobacco area and production in the country is confined to the states of Andhra Pradesh and Gujarat.

Among tobacco growing states, Gujarat ranks first with respect to the productivity and total production covering 24 % area and 40 % production of the total tobacco in the country, while Andhra Pradesh ranks first with respect to area. In Gujarat, different types of tobaccos grown are bidi, chewing (Lal and Kala chopadia), Hookah (Gadaku) and rustica. Before last decade, Virginia flue cured tobacco was also grown in Mehsana district but due to chloride problem, it is presently not cultivated in the district. Gujarat is the leading state in bidi tobacco cultivation and it covers about 80 % of the total area and production of bidi tobacco in India. Other states growing bidi tobacco are Karnataka and Maharashtra. It is also cultivated in small pocket of Kurnool district of Andhra Pradesh. In Gujarat, tobacco is grown in an area of about 1.10 lakh hectares with an annual production of about 1.80 lakh tonnes. Among different types of tobaccos grown in Gujarat, bidi tobacco contributes lion's share about 90 %. Rustica tobacco is grown in area of about 80,000 hectares. The cultivation of tobacco in Gujarat is largely concentrated in the districts of Kheda (Charotar area) and Vadodara, besides small area in Panchmahals, Ahmedabad and Mehsana and Banaskantha districts. Bidi tobacco cultivation is largely centered in Kheda, Vadodara and Panchmahals

districts, while hookah in Ahmedabad, chewing in Kheda and rustica in Kheda, Mehsana and Banaskantha (Dhanera) districts. Kheda district alone contributes sizeable area and production of bidi tobacco in Gujarat.

The types of tobacco cultivated in various states of India are as under

1. Assam: Wrapper, Hookah, Chewing and Cheroot
2. Andhra Pradesh: Cigarette (Virginia and Natu), Bidi, Cheroot and Barley
3. Gujarat: Bidi, Chewing, Rustica and Hookah
4. Karnataka: Virginia, Bidi and Barley
5. Bihar: Hookah and Chewing (Rustica), snuff
6. Tamil Nadu: Cigar, Chewing, snuff and Cheroot
7. West Bengal: Wrapper, Hookah, Cigar and Chewing (Motihari)
8. Orissa: Natu, Bidi, Hookah and Chewing
9. Uttar Pradesh: Virginia, Hookah and Chewing
10. Punjab: Chewing
11. Maharashtra: Chewing, Bidi

Classification

a) According to species

Classification of Indian tobacco was done by Howards in 1910, who described 20 types in *rustica* and 51 types in *tabacum* of which are described as petiolate and 64 are sessile. Later on Show and Kashiram (1931) added 19 types to those of Howards. Morphological characters were used as a basic for the classification of this spp. Only 2 species are cultivated extensively in India. The morphological characters of both the species are given below.

1) *Nicotiana tabacum* (Desi type): Usually the plants of this type are taller attaining the height of 150-250 cm. The leaves are large (long) but rather narrow. They may sessile or petiolate. Pedicle may or may not be. The colour of the flowers is reddish, pinkish and white. It is supposed to have desired as an amphidiploids of a cross between *Nicotiana sylvestris* and a member of the section tomentosae. It is extensively used for chewing and smoking purposes. It is also used in manufacturing of the cigarette, cigar, cheroot, bidi, snuff purposes. Nicotine 0.5 to 5.5 %.
2) *Nicotiana rustica* (Vilayati or Kalkatti): The plants of this species are stocky, more bushy in nature and shorter in height, usually not more than 90-102 cm in height. The leaves are large and broad and ovate in shape and always possess a petiole (small

roundish and wrinkled type). Always with pedicle. Flowers occur in cluster and are of dull greenish-yellow colour. It is suppose to have been derived as amphidiploids from a cross between *Nicotiana undulata* and *Nicotiana paniculata.* It is expensively used for hookah, chewing and snuff purposes. Its cultivation is limited to Gujarat, West Bengal, Bihar, Uttar Pradesh, Assam, and Punjab etc. Nicotine 3.5 to 7.5 %.

b) Commercial or according to utility

1) Cigarette or Virginia flue cured (VFC) (CFV and Natu tobaccos)
2) Bidi tobacco
3) Chewing tobacco
4) Cigar tobacco
5) Wrapper tobacco
6) Hookah tobacco
7) Snuff tobacco
8) Cheroot tobacco

c) According to curing of tobacco

1) Flue curing
2) Air curing or shade curing
3) Sun curing
4) Smoke or fire curing
5) Pit curing

d) According to aroma

1) Aromatic tobacco
2) Non-aromatic tobacco

Economic importance

Tobacco is one of the important cash crops in India though it is cultivated in an area of about 0.3 % of the total cropped area of the country as it earns sizeable amount of excise revenue (about Rs. 5000 crores). It is interesting to note that tobacco stands first among agricultural commodities and second only next to petro-products among all the commodities in Indian earning. Besides, being a labour intensive crop, it provides employment to a large number of peoples in its industries (about 56 lakh peoples) like cultivation, processing, curing, grading, manufacturing, cottage industries, marketing and rail and road transport. Tobacco is mainly grown for its leaves, which are used in smoking purpose like bidi, cigar, cheroot, cigarette, hookah, snuff or chewing. It is a rich man's solace and poor man's comforts. An industrial product of tobacco is nicotine sulphate is used as insecticides.

Debarked stems and stubbles are used for fuel purpose. Though tobacco has the significant important in Indian economy, it is considered as a health hazardous crop for human being (smoking or chewing of tobacco is injurious to health) and alternate uses of tobacco are being intensively investigated to make the tobacco use safe. In recent advances, manufacturing of edible tobacco leaf protein concentrate (LPC) is also possible from the leaves by growing dense crop. Tobacco oil can be used in cosmetics and varnishes industries. Perforated biddies are also developed. India is the third largest exporter of tobacco in the world next only to USA and Turkey. Nearly 80 % of the tobacco produced in the country is locally consumed and rest is exported. Tobacco seed contain 35-38 % nicotine, free oil. It is used in making soap and colours. Its cake is used as a cattle feed. Cake contain 3% N, 30-35% crude protein and 20-27 % carbohydrates.

Climatic requirement

Tobacco is a tropical crop in origin but it is raised in subtropical and temperate regions of the world. It is raised from 60º N latitude in Sweden to 40º S latitude in New Zealand, China, India and USA. Tobacco needs 50-100 cm rainfall, which should be well distributed through out the growing season. Areas having a rainfall more than 125 cm are not suitable for cultivation of this crop, whereas, a rainfall of less than 75 cm results in production of leathery leaves having very high nicotine content in them. The leaves remain smaller and possess very poor burning quality. The crop needs about 28 ºC as an optimum temperature for germination but it may germinate at a temperature ranging between 15 ˚C to 35 ˚C. The crop cannot withstand frost and starts withering or wilting at a temperature above 35 ˚C. Tobacco can successfully grown in areas where temperatures remain 21 to 31 ˚C (70 to 90 ºF) at least about 4 to 5 months period. But the areas where low temperature prevails during growing season are not suitable for tobacco cultivation. Water logging at any stage of growth is deadly harmful because the plants cannot withstand water logging. While hailstorm causes a serious injury to the leaves any time during growing period. Relative humidity is one of the deciding factors for yield quality and curing of leaves it is observed that relative humidity of 85-95 % is an optimum humidity for the crop because at this level of humidity the leaves are easily used and they do not become very brittle. Windstorm at any stage of growth after seedling establishment is very harmful because the leaves split and reduce the quality specially when the plants have large exposed leaf surface.

Soil

Tobacco in general needs open aerated well-drained light textured rich in P_2O_5, K_2O and Fe but poor in organic matter contents. Tobacco does best on well-drained, fertile sandy

loam type of soils. It can also be grown on soils having pH values ranging from 5.5 to 6.5. But the soils like black or heavy clay are not suitable for this crop because of poor drainage capacity. Tobacco cannot successfully be grown in waterlogged soil, as it is a wet sensitive crop. Sodic soils are not suitable for tobacco cultivation because plants absorbed lot of chloride ions which results in a poor burning quality of leaves and a mild acidic soil reaction is always better for production of superior quality leaves.

Field preparation

During summer, field should be prepared by giving one or two deep ploughings to a depth of about 25 cm by tractor drawn plough. Deep ploughing in summer helps to control nematodes and weeds due to natural soil solarization. Deep ploughing also increase the yield of tobacco about 10 % as compared to normal tillage operation. After onset of the monsoon, the tillage operation should be carried out by tractor drawn cultivator followed by harrowing and planking for sowing of green manure crop or to kill the weeds and conserve the soil moisture.

Green manuring

Preferably sannhemp crop is taken as a green manure crop, sannhemp seeds @ 100 kg seeds/ha should be sown either by broadcasting or with the help of seed drill in rows 15 cm apart with the onset of the monsoon or if monsoon is delayed, it should be sown by giving irrigation in second fortnight of June. Drill sowing facilitates interculturing operation for weed control.

The crop should be buried in the soil at least three weeks prior to transplanting of tobacco with mould board plough or disc harrow or it should be buried in the soil at about 45 days after sowing (before flowering). If there is no rain at the time of incorporating the sannhemp in the soil, irrigation should be given for enhancing the decomposition of green matter. If green manuring is not possible/feasible, apply 12.5 tonnes (25 cart load) well decomposed FYM/ha.

The field should be prepared after decomposition of green manure crop by giving cross cultivation of tractor drawn cultivator followed by one or two harrowings and planking to level the field for transplanting of seedlings.

Bidi tobacco nursery

Raising of healthy vigorous seedlings is an important phase of tobacco culture. Success in nursery raising demands (1) proper location of the nursery (2) proper preparation and manuring of the seed beds (3) adequate irrigation facilities and (4) timely control of insect-pest and diseases. These aspects of nursery raising are discussed below in brief.

In selecting the site of the nursery, consideration is to be given to surface and underground drainage and assured supply of irrigation water. The nursery site should be on a higher level than the surroundings and away from the tree shade. The nursery beds may be of any length but should not be more than 1.2 m width. Surface drainage is ordinarily provided by channels in between the seedbeds and these while draining away excess rain water also serve as pathways for inspection and weeding of the nursery. It is advantageous to have deep ploughing in summer and rabbing the nursery plot with about one foot layer of wheat straw, bajra husk,cotton stalks etc. during pre-nursery season or tarping should be done in the nursery area with clear plastic film for two months from 15th April. It will help in control of nematodes, weeds etc. For manuring of tobacco nursery, application of 180 kg N/ha is recommended. Out of which, 45 kg N from FYM or poultry manure, 90 kg N from castor cake both to be applied a week before the sowing and 45 kg N in form of ammonium sulphate or urea as top dressing in two installments. Two % (2%) solution of the above fertilizer (AS.) should be given and there after seedlings should be washed out with pure water to protect the seedlings from adverse effect (burning effect). Seeding in the nursery should be started in the first week of July and completed latest by 15th July so that transplantable seedlings become available during second fortnight of August. Five kg seeds/ha is optimum for sowing one-hectare nursery area. For control of damping-off disease, spraying of Bordeaux mixture (6:3:100) @ 3 litres/m^2 is carried out as and when required or one drenching of metalaxyl MZ (Ridomil MZ) 30 g in 200 l water/100 m^2 before sowing of seeds and 2-3 post emergence drenching of the same from 20-25 days of sowing were also found effective. Use of Bordeaux mixture has been found to be quite effective, economical and safe to control damping-off disease. For control of tobacco leaf eating cater pillar, spraying with the solution of Quinalphos 0.05 % (Ekalux 25 EC 20 ml in 10 l water) or Chlorpyriphos 0.04 % (Durban 20 EC 20 ml in 10 l water) is recommended. In heavy infection, fenvalerate 20 EC 5 ml in 10 l water should be sprayed. To control leaf spot disease, Bavistin 50 WP 5 g in 10 l water should be sprayed. White flies which are worked as vector for transmitting (spreading) leaf curl virus should be controlled by spraying systemic insecticides like Dimethoate (Rogor 30 EC) or Methayl S dematone (Metasystox 25 EC) 15 ml in 10 l water twice at 10 days interval and 2 sprays in field also at 10-12 days intervals. To control earthworm and rove beetle, aldrex 30 EC 20 ml in 10 l water should be applied 2-3 litres/m^2 area. The seedlings normally become ready for transplanting after 30 to 40 days of sowing.

Time of transplanting

Second fortnight of August is the optimum time of transplanting of tobacco seedling. However, it can be done latest by 3rd week of September. Transplanting should be done during drizzling rain and in late evening or late afternoon hours. However, in a cloudy day, it can be done at any time of a day. This type of weather conditions is very favourable for establishment of the seedlings.

Method of sowing (Transplanting)

The field is line marked with the help of iron or wooden marker at 90 cm apart. The furrows are opened with the help of plough as per the line marked in the field. There after cross marking at 75 cm distance is done at the right angle to the opened furrows.Seedlings are transplanted at cross mark at the hedge of the furrow to avoid seeding rot and uprooting of the seedlings due to heavy flow of rainwater. If there is no rain, the line-marked field is irrigated in furrows in the morning hours and cross marking is done for transplanting of the seedlings in the late evening time. Healthy disease free seedlings of 8-10 cm height should be used for transplanting. If rain is not occur after transplanting, light irrigation at 5-6 days may conveniently be given in furrows for good establishment of the seedlings.

Spacing :

Seedlings of hybrid tobacco and variety GABT 11 should be transplanted at 105 cm x 90 cm.

Seed rate : 5 kg/ha (50 gram for one are or guntha) for raising one hectare nursery.

Gap filling : Gap filling should be done after 10 days of transplanting.

Manures and fertilizers

180 kg N per hectare is recommended for the crop.

1. If green manuring is done or FYM applied 12.5 t/ha (25 C.L.)
   - 90 % of the recommended dose of N (160 kg N/ha) should be applied as basal in form of ammonium sulphate at the time of field preparation in fachara khed.
   - Remaining 10% N (20 kg N/ha) should be applied as top dressing 10-15 days after transplanting in form of ammonium sulphate or urea by ring method and mixed in the soil.
2. If green manuring is not done or not applied FYM
   a) 90 % of the recommended dose of N (160 kg N/ha) should be applied as basal dose in the following manner
      - 25 % N (40 kg N/ha) should be applied in form of castor cake or poultry manure. Use of poultry manure is beneficial for controlling the root knot nematodes.

- 75 % N (120 kg N/ha) should be applied in form of ammonium sulphate

b) Rest 10 % N (20 kg N/ha) should be applied as top dressing in form of ammonium sulphate or urea 10-15 days after transplanting by ring method and mixed in the soil.

NB. The efficiency of urea is 92 % in comparison of ammonium sulphate. If urea is applied as basal at the time of field preparation, there is a possibility of leaching down in the sub surface. In shortage of ammonium sulphate, urea can be used as substitute about 25 %, but frequent use of urea alone is not advisable as it deteriorate the quality of the produce.

Interculturing and Weeding

About 20 days after transplanting, when the plants get established their young rootlets require very fine and pulverized sub surface soil for their rapid growth and further expansion. Besides, inter-cultivation helps in mulching, removal of weeds, proper aeration etc. Cross interculturing should be done 4-5 times and hand weeding is done as and when required. For getting higher yield and economic return eight times interculturing at eight days interval should be done.

Topping and desuckering

Topping is done at flower bud initiation in individual plant and this operation may not occur at the same time. Hence, it should be carried out even at the time of desuckering operation. Topping is carried out by leaving 20-24 leaves(excluding sand leaves).

Removing the flower bud to switch over the plant from a seed producing (reproductive) to a leaf producing (vegetative) phase known as topping.To maximise leaf production and encourage leaf ripening, it is necessary to remove the flowers.Topping increases the size and weight of leaves, increasing the overall yield per hectare.

New shoots rapidly appear after topping.These are known as “suckers”.Suckers are controlled by manually breaking them off and through the application of “suckercides”. The process known as desuckering. Suckercides have a two – fold action of killing the sucker buds and inhibiting subsequent sucker development.

After the topping operation, suckers, which are emerged out from the leaf axils, are regularly removed at an interval of week. In later stage of the crop, suckers are also emerged out from the stem near the ground surface, which are also removed. Removal of suckers from leaf axils and ground surface near the stem is called desuckering operation. Generally desuckering operation is carried out about 5-6 times during the crop growth period. The main object of topping and desuckering operations is to divert energy the nutrients of the plant from flower head to leaves which affects the yield and quality of various types of tobaccos.

Topping and desuckering is necessary in bidi, chewing and rustica tobaccos for better quality (increase the thickness of the leaves, nicotine content etc.).

Irrigation

This crop does not require any irrigation, when there is well distribution and adequate rains are received. If the moisture stress conditions occur due to prolong dry spell, irrigation become necessary. Three to four irrigations should be given at an interval of 20 days. Irrigation should not be given at the time of incidence of orobanche during December. **Crop rotation**

Tobacco is generally not grown as mixed crop. In Bihar, chewing tobacco is inter cropped with onion, garlic or radish in rabi season and maize in summer season. It is a common practice with the tobacco farmers to raise tobacco as a mono crop year after year in the same field without following any crop rotation which leads to soil sickness, build up pest and disease problem and consequent reduction in tobacco yield. Therefore, it is advisable to grow tobacco in rotation. In Gujarat, the crop rotation is given below.

Bidi tobacco - Summer bajra - First year

Hybrid cotton - Fallow in summer - Second year

Bidi tobacco - Summer bajra - Third year

Plant protection

Pests

Rove beetle, Tobacco leaf eating cater pillar, Tobacco stem borer, Tobacco capsule borer, White fly

Diseases

Damping-off, Black shank, Leaf spot, Leaf curl, Mosaic, Root-knot, Anthracnose

Orobanche

The tobacco crop is very often infested by orobanche, a total root parasite. This weed is found to infest the field at the topping stage or at the later stage of crop growth. Orobanche

is found to be attached with the tobacco roots and they grew up through the soil round the tobacco plants. It is advisable to collect them by hand pulling and destroy them before seed formation. These parasitic weeds absorb all plant nutrients from tobacco plant. The hand pulled orobanche plants should not be fed to the animals as it again comes in the field through FYM.

Harvesting

The harvesting is done when spangles are developed on the leaves and normal green colour changes to yellowish green or slightly yellowish and leaves becomes thick, spotted and sticky to touch. If such leaves are pressed under thumb, a cracking sound is produced.

Method of harvesting

There are three methods of harvesting, 1) Leaf by leaf method, 2) Stalk cut method, 3) Priming (Gugharo method)

1) Leaf by leaf method

Leaf by leaf method is very popular among the farmers and it is considered to the best from quality viewpoint.

Bottom three to four leaves (sand leaves) mature first and also harvested first and kept separately which is known as galia.

In this method, the well developed spangles and matured leaves are hand picked and kept in inverse position in the field for 3 to 4 days for drying. The dried leaves are transported to farmyard where the lamina is stripped off; this portion is called bhuka and kept aside separately. The undried portion of lamina is kept for further drying in the farmyard. After complete drying, bits of lamina (dry pieces of leaves) and vein lets (small pieces of vein) are separated and kept separately, this portion is called geran. Finally after complete drying, the midribs are separated. The debarking is done on the green stem with sickle and bark is kept for drying, after drying, it is mixed with midribs, this is called rago or lakada portion.

Separate heaps of bhuka, geran, galia and rago or lakada portion is prepared. To bring uniformity, turning of the heaps is must. The produced is prepared in the four following manner and sold separately.

Name of produce	Particular	%
Bhuka	Only pure lamina	60
Geran	Small pieces of leaves and vein lets	10
Galia	Sand leaves	10
Rago or lakada protion	Midribs and bark	20

2) Stalk cut method

In stalk cut method, the whole mature plant is cut and dried in inverted manner in the field. After drying, the dried leaves are separated and all above four heaps are prepared separately as discussed above.

3) Priming (Gugharo)

In this method, the matured leaf is stripped off from bottom to top in between the thumb and fingers and the stripped leaves are dried in the field in such a way that the upper

side of the leaves should be towards ground side. The dried leaves are collected separately. The midribs are separately separated and dried. The geran is separated from the dried midribs, which includes small pieces of vein lets. The plant is cut and debarking is done. All above four heaps are prepared separately for marketing.

Flue curing (Virginia tobacco)

The flue-cured tobacco is raised with low nitrogen and harvested by priming method. The harvested leaves are strung on sticks, which are then stacked into a flue-curing barn. The barn is artificially heated. The green leaves should be loaded in the upper half of the barn and the lighter ones in the lower half, the curing process consists of 3 stages namely 1) yellowing 2) fixing colour and three drying. During yellowing, leaf is kept at a low temperature (32-35 C) and high humidity for about 30-40 hours till it attains a bright lemon yellow colour. After yellowing, the temperature is raised gradually and humidity of barn is lowered by operating the ventilation. Great care is required in raising the temperature during this stage. It is raised by not more than 1-2% every hour. With rapid rise in temperature when the leaf is still wet, results in a bluish-black discolouration called scalding. It takes about 16-24 hours. Drying is the last stage in flue curing process, which may last from 28-42 hours. The ventilators are closed and temperature is again gradually raised to 160 F to dry the veins and midribs of leaves. This completes the process. Now ventilators are opened to cool down the barn. The leaves are left in barn over night for absorbing moisture and to come to normal condition for handling and storage.

Leaf quality

The price of the entire produce is fixed on the basis of lamina quality which is governed by physical characteristics like leaf colour, luster, thickness of the leaf, spangling and smoking quality like nicotine, reducing sugar, aroma, strength, leaf burn, ash colour etc.

Varieties

Sr. No.	Types	Varieties
1	Bidi tobacco (Irrigated areas)	A 2, A 119, GT 5, GT 9, MRGTH 1, ABT 10 (Nematodes resistance) and GABT 11
2	Bidi tobacco (Unirrigated areas)	GT 4 and GT 7
3	Rustica tobacco (*Rabi*)	GC 1, GC 2, GC 3 and DCT 4

Yield : 1500-2000 kg/ha

Research Stations

- Central Tobacco Research Institute, Rajahmundry
- AICRP on Tobacco, Rajahmunadry (AP)
- Main - Bidi Tobacco Research Station, Anand
  - Rustica Tobacco Research Station, Ladol

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Rustica Tobacco

Botanical name : *Nicotiana rustica L.*

Family : Solanaceae

Origin : South America

Rustica tobacco is grown in Kheda and Anand district of middle Gujarat and Banaskhantha, Sabarkhantha, Mehsana and Gandhinagar district of north Gujarat in an area about 80,000 ha as a *rabi* crop under irrigated conditions.

Nursery

Soil

Upland loamy soil with proper drainage near irrigation source with optimum sunlight and away from shady trees.

Land preparation

Deep plough during summer and frequently cultivate the land during *kharif* season.

Manuring

145 kg N ha

Basal:

95 kg N ha of which 70 kg N from castor cake and 25 Kg N from either ammonium sulphate or urea.

Top dressing:

50 Kg N/ha as a top dressing from 0.5% solution of Ammonium sulphate or urea 15 days after germination of seeds.

Layout : Prepare the beds according to the slope of soil with 0.5 m wide drainage channel.

Sowing time : Second fortnight of September

Seed rate : 8 kg seed is required for raising one hectare nursery.

Sowing Method: Broadcasting

Irrigation : Water the seed beds with water cane immediately after sowing, thereafter once or twice in a day. Remove the cover gradually after germination.

Plant Protection:

Pest: Leaf eating Caterpiller, Stem borer, Whitefly **Disease:** Damping off

Field crop

Field preparation

After *kharif* crops like pearlmillet or paddy, apply irrigation and then at proper vapsa condition land should be prepared for the cultivation. If *kharif* crops are not taken, green

manure the field with sunnhemp @ 100 kg seeds per hectare in the last week of June and buried it in the soil after 40 days of sowing.

Nutrient management : 10 t FYM/ha + 200 kg N/ha

For Middle Gujarat:

Basal: 90% N as a basal (75 % N from Ammonium Sulphate and 25 % N from Urea)

Top dressing: 10% N/ha 10 to 15 days after transplanting

For North Gujarat:

Basal: 90 kg N/ha of which 50 kg N/ha through castor cake 40 kg N/ha in from of Urea or Ammonium Sulphate

Top dressing: Apply 20, 30, 30 and 30 kg N at 15, 30, 50 and 70 days after transplanting, respectively.

Transplanting:

The transplanting should be done in the last week of October to first week of November.

Spacing : 60 cm X 45 cm or 60 cm X 60 cm

Interculturing and weeding: As and when required

Irrigation:

For Middle Gujarat

Total nine irrigations out of these first three irrigations should be given up to 45 days at 15 days interval and remaining six irrigations should be given at 10 days interval.

For North Gujarat

Total six irrigations, the first irrigation should be given 25 days after transplanting and then after 18 to 20 days interval.

Topping : 15-20 leaves depending on varieties

Desuckering : Suckers are to be removed manually every week.

Plant protection **Disease:** Leaf curl

Crop rotation

Middle Gujarat: Pearl millet or paddy-*rustica* tobacco

North Gujarat : Cluster bean/sesamum/groundnut- *rustica* tobacco

Harvesting

Generally rustica tobacco matures after 125 to 135 days of planting. Culcutti tobaccos are harvested by two methods.

(1) Leaf by leaf method

(2) Whole plant or stalk cut method

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23 S U N N H E M P or B O M B A Y H E M P or B A N A R A S H E M P

Botanical name : Crotolaria juncea L.

Family : Leguminoceae

Origin : India and Burma

Area and distribution

In the world, it is grown in the countries of USSR, Romania, India, China, Hungary, Poland, turkey, brazil, Chili and Bangladesh.

In India, it is cultivated in the States of Uttar Pradesh, Madhya Pradesh, Maharashtra, Rajashthan and Orissa. Uttar Pradesh stands first followed by Madhya Pradesh in production of sunnhemp. In India, it is cultivatd in an area o about 1.4 lakh hectares with an annual production of about 50,000 tonnes of fibres.

Economic importance

Sunnhemp is grown for (1) green manuring (2) fibre (3) fodder and (4) seed purposes.

Sunnhemp is one of the importance fibre crops of India. It plays importance role in the National economy both as raw material for industries and also as a foreign exchange earner through export. White fibres are used for manufacture of tissue paper and paper for currency as it contain high percentage of cellulose and low amount of lignin. The farmers themselves make use of the fibre for making ropes. It is used for making cordage of all kinds, twines, nets, mattings etc. It is also usd for making rug, sack etc. It is grown for green manuring which adds about 40-60 kg N ha into the soil. It is also a source of cellulose for rayon and artificial silk. It is also considered as the king of green manuring crops.

Climatic requirement

It requires warm and humid climate for proper growth with 1000-2000 mm of rainfall.

Soil

Well fertile sandy loam soil is most suited for its cultivation. Water logged soil is not suitable for this crop.

Land preparation

One or two deep ploughing with mould board plough and 2 to 3 harrowings followed planking should be carried out.

Seed rate

For fibre fodder and green manuring purpose – 80 to 100 kg ha

For seed purpose – 25 to 40 kg / ha

Sowing time

June – July

Method of sowing

Line sowing by seed drill at 3 to 4 cm depth for seed crop.

Spacing : 30 x 7-10 cm for seed crop and broadcasting for green manuring purpose.

Fertilizers : Only 50 kg P_2O_5 / ha as basal

Interculturing and weeding

The line-sown crop should be intercultured and weeding should be carried out as and when required to keep the crop weed free. Interculturing helps in conservation of soil moisture also.

Harvesting

For fibre crop, the crop is harvested at the pod formation stage for good quality fibres, colour and luster. Too early or too late harvesting spoils the fibre quality. Harvesting of the fibre crop is done by cutting the whole plant close to the ground with the help of sickle. The leafy top portion of the plants may be chopped off and used either as fodder or may be plougher down in to the soil to add organic matter. After shedding of the dried leaves, the plants are tied into bundles of convenient size having 50 to 100 plants in each bundle. Steeping, retting and extracting is followed as per jute crop. For extracting fibres the bundles are tied on drying and submerged in water for 5-6 days for retting and then the fibres are peeled off.

Extraction

Fibre is extracted single plant wise by breaking the lower ends of the plant and then stripping upward from the bottom. After extraction, the peeled fibres should be washed thoroughly in clear water to remove the dirt and other adhering plant materials. After drying the fibres, it is graded and bundled into small “Moras” for marketing.

Yield : 8 to 10 q/ha.

Varieties : K 12, M 19, M 35, ST 35, Nalanda sanni

Steeping and retting

The bundles are brought to the nearest ponds, pools or streams and arranged side by side to form a platform in water for steeping. In some States, bundles are covered with hyacinth, grass etc. and the “Jak “ is weighed down 10-15 centimeters below the surface of water by stone blocks, concrete slabs or seasoned logs, Substances rich in tannin like freshly cut logs or clods should not be used as weighing materials because it will turn the colour of the fibres into dark. Care should also be taken to see that while weighing down the “Jak”, the bundles do not touch the bottom of the retting tank. Retting in slow running water is better than retting in stagnant water. This process is complete when the fibre is loose enough for

extraction and is complete separated frm the sticks. This can be determined by examining one or two plants from the bundles after two or three days of retting. The period of retting may very from 3 to 15 days depending upon the temperature of retting water and the month of harvesting. In September, retting takes place generally within three to seven days, while in December, this period may range from 12-15 days. The optimum temperature for retting is 21 to 27^{o} C.

Yield of green material (NPK addition in soil) and fibre

The yield of green material for green manuring crop is about 10 to 15 tons/ha with deposition of 60-70 kg N, 30-35 kg phosphorus and 30-35 kg potash per hectare. Sunnhemp contained 2-4 per cent fibre on the basis of the weight of green stem or 8 to 12 percent in terms of dry weight. The yield of fibre from a good crop of sunnhemp is about 8-10 quintals of fibres per hectare.

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Reference books

Sr. No.	Name of books	Author/s
1	Modern techniques of raising field crops	Chhidda Singh,Prem Singh and Rajbir Singh
2	Field crops production-Foodgrain crops Volume I	Dr. Rajendra Prasad
3	Field crops production-Commercial crops Volume II	Dr. Rajendra Prasad
4	Crops of India	N.R.Das
5	Agronomy of field crops	S.R.Reddy

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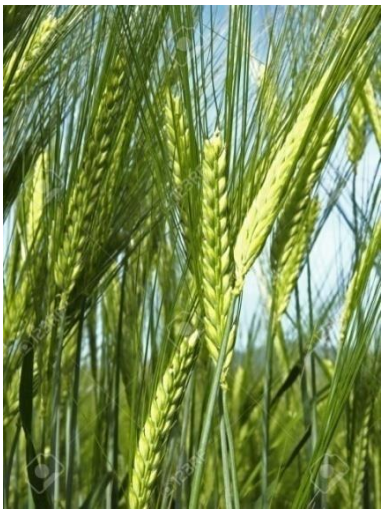
Cereals

The word ‘cereal’ is derived from ‘cereas’, the Roman Goddess of grain. A cereal crop is a grass grown for its edible grain which is rich in starch. Cereals are the most important food crops. Wheat and barley are the prominent cereals grown especially in *rabi* only. Cereals are the staple food in the diet of most population. The grains contain 58-72 % carbohydrate, 8-13 % protein, 2-5 % fat and 2-10 % indigestible fiber. They also contain about 310-350 Kcal/100 g of grain.

W H E A T

Botanical name:*Triticum aestivum* L., *Triticum duram* desf.
Family:Gramineae
Origin: South Western Asia



Wheat is locally known as *Gehun*/*Kanak.* In India, it is second important staple food crop after rice, which contributes nearly one-third of the total food grains production. The area under wheat is increasing since last three decades but its production has been increased by four-fold due to improved varieties, increase in irrigation and fertilizers use with modern production technologies.Throughoutthecountryonlyspring typewheat varieties aregrown,thoughtheseare raised inwinter.

Durum wheat is grown in central and south India under rain fed conditions with the production of 11-12 percent. It is used in s*uji, rawa (medo), ladu, semya, macaroni (sev)* and *bhakhari* making. Durum is the important species for rainfed condition. In Gujarat, cultivation of dry wheat is mainly concentrated in *Bhal* area comprising the parts of Ahmedabad, Bhavnagar, Kheda and Surendranagar districts and it is also grown in Vagra, Jambusar and Amod talukas of Bharuch district and in Ghed area of Porbandar district. The dry wheat cultivated in an area of about 0.95 lakh hectare with an annual production of 0.48 lakh tonnes. The land of *Bhal* area is leveled and low lying black and shallow soils. During monsoon season, the fields remain submerged with rainwater that caused salt accumulation in upper layer of soil and hence soils

become sticky. Under such circumstances, most of the fields remain fallow during *kharif* season. Frequent harrowing is carried out for removing weeds and conserving maximum moisture in the soil during fallow conditions of the land.

Classification

In the past there were 4 species, *viz*;*Triticum aestivum , T. durum , T. dicoccum and T. sphaerococcum* under cultivation in India. *T. sphaerococcum* has now practically gone out of cultivation because of its low productivity and high susceptibility to diseases.

(a) *Triticum aestivum*(Irrigated)

Also known as common bread or *chapati* wheat. It is the most important species, occupying more than 90 % of the total wheat area in the country. It is good for making *chapati* and bakery products. Mexican dwarf wheat developed by incorporating dwarfing gene Norin10wasintroducedinIndiabyDr. N.E.Borlaug.(GW496,GW503,GW366, GW173, GW 190 and Lok 1).

(b) *Triticum durum*(Unirrigated)

Known as macaroni or durum wheat mainly confined to cultivate in rainfed conditionsin central and southern India. Its cultivation was most common under rain fed conditions only,on account of high susceptibility to rusts**.** It is good for making *Suji, Rawa, ladu, Macroni (sev) and bhakhari*. In Gujarat, it is grown in *Bhal* region. The seeds are bold and light. This wheat is also known as *Bhalia* (GW 1 and A206).

(c)Triticumdicoccum

Also known as Emmer wheat which is grown in some pockets of Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu and Gujarat (Sabarkantha, Banaskantha, Mehsana, Ahmedabad and Kutch). In Gujarat, it is grown only in few hundred hectares on the sea shore belt of Saurashtra starting from Porbandar to Jamkhambhalia. It has a very high degree of heat tolerance and can be sown as late as December and January without much fear of heat damage during grain filling, even in the southern zone. It is good for South Indian dish "Uppama".

Geographical distribution:

The major wheat producing countries in the world are China, India, United States, Russia and France. In the world, wheat is cultivated in an area of about 239 million hectares with a total production of 425.5 million tonnes ofgrains.

Based on climatic conditions and disease prevalence, particularly rust, the country is broadly divided into 5 main wheat zones *viz*; north-western plains, north-eastern plains, central, peninsular, northern hill and a small southern hill region. In India, the major wheat growing states are Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, Rajasthan, Bihar, Maharashtra, and Gujaratduring the year 2015-16, it was cultivated in an area of 302.27 lakh hectares with a production of 935 lakh tonnes of grains with the average productivity of 3093kg/ha.

In Gujarat, during the year 2015-16, it was cultivated in an area of 8.51 lakh hectares with a production of 24.84 lakh tonnes of grains with the average productivity of 2919 kg/ha. Irrigated wheat is mostly grown in Mehsana, Banaskantha, Sabarkantha, Kheda and Saurashtra region, while unirrigated wheat is grown in *Bhal* region consisting of some parts of Ahmedabad, Bhavnagar and Surendranagar districts.

Economic importance

A turning point came in the history of wheat in 1965 with introduction of dwarf, photo insensitive, high yielding Mexican wheat breeding materials developed by Dr. N. E. Borlaug. In 1970, triple dwarf varieties were released in India. Wheat grain flour is used in form of *chapati, puri,* bread, cake, *halwa* etc. It provides 20 per cent of total calories for human race. Wheat grain contains 10-12 per cent protein, which is more than other cereals. Wheat provide characteristic substance gluten, which is very essential for bakers, because gluten provides the structural frame workforthe spongy, cellulartextureofbreadandotherbakedproducts.Floursofothercerealsare lacking gluten and hence, not good for bread making. Wheat straw is also a good source of feed as well as bedding material for livestock. Straw is also used in paper industries and for making temporary huts and roof. The husk and other portion of grain and straw are valuable feed for livestock. The ripe unthreshed earheads are used to make decorativeitems.

Soil requirements

Wheat does best on well-drained fertile, clay loam, loam to medium black soils. However, good crop can be raised in sandy loam soils and black soils also. Heavy soils with poor drainage are not suitable because wheat is sensitive to water logging. *Durum* wheat is considered more suitable in heavy and black soils, whereas *aestivum* wheat is grown in all types of soils. The *durum* types when grown in light soils tend to express high yellow berry problem, resulting in poor quality grains. Soil should be neutral in reaction

Climatic requirements

Wheat crop has wide adaptability. It can be grown not only in the tropical and sub-tropical zone but also in the temperate zone. Dry and cool weather is most suitable for this crop. The optimum temperature required for ideal germination of the wheat crop ranges from 20 to 25ºC. Rains received immediately after sowing, hamper germination and encourage seedling blight, while high humidity and low temperature is conducive for rustattack.

The high temperatures at both ends of the crop season determine the duration available for wheat cultivation, which ranges from100 days in down south to more than 145 days in north western plains and 180 days in the hills. Very hot temperature during the grain ripening period result in grain shriveling.

Cultural practices

(i) **Land Preparation:**The Wheat crop requires a well pulverized but compact seed bed for good uniform germination. In case of irrigated wheat, pre-sowing irrigation should be given after harvesting of the *kharif* crop and field should be prepared at *Vapsa* conditions by carrying out one deep ploughing with soil turning plough followed by two harrowings and planking is desirable. Stubbles, rootlets, weeds etc. are removed from the field. Recently zero-tillage and minimum tillage sowing practices using a specially designed zero-till seeding-cum-fertilizer drill have been recommended to save the time required to prepare proper seedbed under the rice-wheat croprotation.

Dry wheat requires friable seedbed for better germination and good growth of the crop. After complete drying of accumulated rainwater from the fields and when soil comes at *vapsa* conditions, the land is prepared by giving two to three harrowing. Harrowing

should be done in Swati Nakshtra or in second fortnight of October. This operation helps in removing weeds and conserving more moisture in the soil.

(ii) **Time of sowing and varieties:** Time of sowing is one of the important aspects for obtaining good yield of wheat. Normally wheat is sown when the average daily temperatures fall to around 22-23°C, which happens only in November in most wheat-growingareas.

Irrigated wheat:

Sr.No.	Time of sowing	Varieties recommended	Yearof release
1	Early sowing (1st week of Nov.)	J 1-7, Raj 1555, GW 89	1985
		GJW 463	2015-16
2	Timely sowing (10-15 Nov.)	Kalyansona	
		Lok 1	1978
		WH 147	1978
		Raj 1555	1985
		GW 496	1989
		GW 503	1989
		GW 190	1993
		GW 273	1997
		GW 322	2002
		GW 366	2006
		GDW 1255	2011
		GW 451	2015
3	Timely sown irrigated areas of Gujarat state and early sown irrigated areas of Saurashtra	GJW 463	2015
4	Late sowing (25 Nov. to 15 Dec.)	Lok 1	1979
		GW 40	1979
		GW 120	1985
		GW 173	1983
		GW 405	1985
		Sonalika	
		GW 11	2010

In middle Gujarat, wheat (GW 496) should be sown during November when mean air temperature approaches 24.5 ± 1.20 C with six irrigations i.e. at pre-sowing, crown root initiation, tillering, booting, flowering and milking stage.

Unirrigated wheat: Second fortnight of October to first fortnight of November is the optimum time of sowing which depend on moisture conserved in soil and soil temperature.

Sr.No.	Variety	Seed rate	Yield (q/ha)	Release year

		(kg/ha)		
1	A 206	50	11.00	1954
2	GW1	60	13.00	1978
3	GW-2	50	12.50	1980
4	GW1139 (irrigated duram)	150	44.00	1999
5	Raj1555 (irrigated duram)	150	30.00	1985
6	GDW 1255		47.61	2011
7	Gujarat Anand Durum Wheat 3		15.08 (under rainfed condition) 26.63 (under restricted irrigation condition)	2017

(iii) Method of sowing:

Irrigated wheat: Recently, for wheat sowing seed drill is used. Depth of sowing is a critical for dwarf wheat, because Coleoptile is short in length and hence, dwarf wheat should not be sown 4 to 5 cm deeper in the soil, otherwise emergence becomepoor.

Unirrigated wheat: By drill method, seeds should be drilled about 5 to7 cm deep in moist soil layer.

(iv) Spacing:

Irrigated wheat: Generally, sowing is done at 22.5 cm row spacing in sandy or *Goradu* soils. Wheat sown at 22.5 cm apart in cross manner also gives good germination, reduced weed growth and higher yield.

Unirrigated wheat: Seeds should be sown in rows 30 cm apart.

(v) Seedrate:

Irrigated wheat: Normally seed rate is depends on the size or weight of seeds. The size of seed is medium if test weight (1000 grain) is 38 to 44 g than 100 kg seed/ha is recommended. For bold seeded varieties if test weight is 45 g or more than 125 kg seed/ha is enough. For late-sown and mild saline soil condition, 25% higher seed rate i.e. 125-150 kg seed/ha isrecommended.

Unirrigated wheat:60 kg/ha

(vi) Seed treatment: Seeds should be treated with fungicides like captan or thiram @ 3.0 g per kg of seed for controlling soil borne diseases like root rot and seeding rot. In areas having light, sandy and *goradu* soils where termite is a serious problem the seeds should be treated with Bifenthril (200 ml) or Fipronil (600 ml) for 100 kg seeds in 5 lit of water) treatment should be given and treated seeds should be dried overnight period and used for sowing in next daymorning.

(vii) Manures and fertilizers:

Irrigated wheat: Well decomposed FYM @ 10 t /ha should be applied and incorporated in the soil at the time of field preparation.

N kg/ha	P_2O_5 kg/ha	Stage of application
60	60	Basal
60	0	20-25 DAS
120	60	

In sandy and well-drained soils, nitrogen can be applied in two splits, half (30 kg N) at first irrigation and second half at second irrigation.

In intensive cropping, taking more than one crop in the same field may result in deficiency of zinc. To overcome this deficiency, 25 kg $ZnSO_4$/ha should be applied at every three years interval.

In salt affected soils, gypsum @ 1.25 tonnes/ha should be applied at every two to three years interval to improve the soil structure.

In middle Gujarat, 120 kg N/ha (60 kg as basal and 60 kg at tillering stage) and 30 kg P_2O_5/ha (as basal) should be applied.

In north Gujarat, 30kg P_2O_5/ha along should be applied with PSB @ 30g /kg seed as a seed treatment + inoculation of 20kg VAM culture and also 20kg $ZnSO_4$/ha should be applied in soil, besides recommended dose of nitrogen.

Unirrigated wheat:20 + 15 + 0, NPK kg/ha

Total quantity of N and P should be applied as basal in the soil. N is not applied as top dressing for dry wheat. In Bhal area, it is recommended to apply gypsum as soil amendment @ 1.0 tonne/ha at about 10 cm deep in soil once in four years before onset of monsoon. F.Y.M. can also be used for thispurpose.

(viii) Irrigations:

Irrigated wheat: Irrigation should be given at the following critical growth stages. Additional irrigations are also given according to soil and climatic conditions. Generally 5-6 irrigations are applied to wheat crop. In North and Middle Gujarat, wheat crop requires 8irrigations.

The information on critical growth stages and their effect on yield are given below, if irrigation is not applied at the criticalstage.

Sr. No	Critical growth stage	DAS	Reduction in yield if irrigation is not given (%)
1	CRI	18-21	35
2	Tillering	35-40	20
3	Jointing	50-55	20
4	Boot stage	65	25
5	Milk stage	75-80	17
6	Dough stage	90-95	10

Under limited water supply conditions follow the irrigation schedule as given below:

1. If one irrigation is possible than it should be given at 21 DAS(CRI).
2. If two irrigations are possible, they should be given, first at 21 DAS (CRI) and second at 65-70 DAS (Floweringstage).
3. If three irrigations are possible, they should be given at CRI, Jointing and Floweringstages.
4. If four irrigations are possible, they should be given at CRI, Tillering, Flowering and Milkingstages.
5. If five irrigations are possible, they should be given at CRI, Tillering, Jointing or boot, Flowering and Milkingstages.

In middle Gujarat, in Narmada command area wheat (cv. GW-496) should be irrigated with canal water with 60 mm depth at sowing, CRI, tillering, flowering and grain filling stages. Irrigation with canal and tube well water should be applied alternatively or first 4 irrigations with canal water and one irrigation at grain filling stage with tube well water should beapplied.

Unirrigated wheat: Generally, in Bhal area, wheat is grown as unirrigated crop and not requires any irrigation. Ground water is harmful to the crop because it is saline. However, if rainwater is collected in farm pond, one irrigation should be given at maximum tillering stage i.e. about 30 to 35 days after sowing which give 30 to 40 per cent more yield.

(ix) Interculturing and weeding:

Irrigated: Weed reduces the yield considerable depending on their intensity. In wheat field, common weeds are *Chenopodium album* L. and *Cyperus rotundus* L. Wheat crop should be kept absolutely free from weeds at least up to 45 days of sowing. For that, one hand weeding should be carried out at 3 to 4 weeks after sowing. Due to hike in labour charges and unavailability of sufficient labour in time, use selective herbicide like Pendimethalin @ 0.5 to 1.0 kg/ha in 600 liter of water applied as pre-emergence. If it is not possible to apply weedicide at the time of sowing, 2,4-D sodium salt @ 960 g/ha in north Gujarat or 750 g/ha in middle Gujarat in 600 l of water should also be sprayed at about 30 to 35DAS.

In middle Gujarat, premix broad spectrum herbicide clodinafop propargyl (15%) + metsulfuron methyl (1% WP) 64 g/ha or sulfosulfuron (75%) + metsulfuron methyl (5%) WG 32 g/ha (mix in 500 litres of water) should be applied as post emergence application (25-30 DAS) or hand weeding at 20 and 40 days after sowing should be carried out for effective management of complex weed flora and higher net return.

Unirrigated: To keep the crop weed free, one or two interculturing should be done at 30 days interval after sowing. One or two hand weeding should be done as and when required. In Bhal zone, Glyphosate @ 0.4% + 1.5% Ammonium Sulphate should be sprayed for the effective control of 'camel thorn' locally called *Jawasia*. As this herbicide is nonselective in nature, it should be sprayed on the weed after harvest of the wheat crop.

(x) Diseases:

Irrigated wheat: Black rust or stem rust, Brown rust or leaf rust, Yellow rust or stripe rust, Loose smut, Flag smut, Karnal bunt, Powdery mildew, Ear Cockleetc.

Unirrigated wheat*: Rust*

(xi) **Pests:**

Irrigated wheat: Termites, Aphid and Jassid

Unirrigated wheat: Grass hopper, stem borer, ear head worm, termite etc.

(xii) **Harvesting:** The crop is harvested when grains become hard, straw become golden yellow, dry and brittle. The plants are harvested manually with the help of sickle early in the morning. Harvested plants are tied into bundles and then carry to threshing floor for heaping. The grain is generally threshed by trampling under the bullock feet on threshing floor or by wheat thresher. Clean grains should be dried for 7 to 8 days under open sunlight to reduce moisture content upto 10-12 per cent for safestorage.

Mix cropping in irrigated wheat

In North Gujarat, irrigated wheat and lucerne should be grown as mixed cropping by broadcasting the seed @ 120 and 12 kg/ha, respectively. Wheat and lucerne are to be harvested at the same time and recommended to give four irrigations to lucerne at 7, 22, 42 and 60 days after harvest of wheat crop. This mixed cropping practice increases the total yield of crops and net return as well as improves soil fertility and wheat fodder quality.

Research Station

Irrigated wheat:

Main :Vijapur (Mehsana) **Sub** : Junagadh and Bardoli

Unirrigated wheat*:*

Main: Arnej **Sub**:Dhandhuka

Yield : 2600 kg/ha (Irrigated), 1000 to 1500 kg/ha (Unirrigated)

BARLEY (JAV)

Botanical name: *Hordeum vulgare* L.
Family : Gramineae
Origin:Asia and Ethiopia

Geographical distribution

In world, Russia, Germany, France, Ukraine, Australia, Canada, Spain, Turkey, U.K. and U.S.A. are the major barley growing countries. This crop ranks fourth in world in both area and production of the cereal crops. The annual world harvest of barley is approximately 140 million tons from about 55 million hectares. It is one of the earliest domesticated food crops since the dawn of civilization.

In India, it is cultivated in 3.3 million hectares with 3.5 million tons of production per annum. The major barley growing states are Bihar, U.P., Punjab, Haryana, Rajasthan, Gujarat, Karnataka, Tamil Nadu, M.P., West Bengal, Himachal Pradesh and Jammu and Kashmir. Bihar is an important barley growing state, which covers over 0.3 million hectare, but the productivityis very low i.e. hardly 7 quintals/ha. The main reasons for such a low yield are that it is grown in marginal land which is unsuitable for cultivation of wheat and secondly, it is mostly grown as a rainfedcrop.

In Gujarat, it is grown in 65000 ha with production of 7000 tonnes per annum. Banaskantha, Sabarkantha, Mehsana, Dahod, Panchmahal and Ahmedabad are the major barley growing districts.

Economic importance

1. Barley is the major source of food for large number of people living in the cooler semi arid areas of the world, where wheat and other cereals are less welladopted.
2. The important uses of barley in India are as grain feed to livestock and poultry, as malt for manufacture of beer and other liquors like whisky, brandy etc.
3. As a food, barley flour is used in preparing '*Chapaties*'. Sometimes it is mixed with gram or wheat and then ground to flour for preparing better quality'*Chapaties*'.
4. Malt syrup is used in baking, in candies and in the textile industries. It is also added to medicines for its laxative/ purgativeeffect.
5. Barley flour can be substituted up to 50 % with wheat flour without detriment to the qualityof the bread.
6. The principal obstacle to the use of barley flour in bread is that it contains no gluten and that darkens theloaf.
7. Barley is cultivated for forage purpose and good quality hay is prepared frombarley.
8. By-products of brewing and distilling industry, known as 'brewewrs' and 'distillers grain'are useful as cattle feed.

9. Barley water is given to persons suffering from kidneydisorders.
10. Pearl barley is used for barley water which is diuretic and is given to persons suffering from kidneydisorders.

Soil requirements

It performs best on well drained, sandy loam to sandy soil. It can tolerate alkali and saline conditions compared to other *rabi* crops and it is grown extensively under such conditions in Rajasthan, Panjab, Haryana, Uttar Pradesh and Bihar.

Climatic requirements

Barley is a crop of temperate climate. In any given region, it matures 2-3 weeks earlier than that of wheat and other *rabi* cereals, indicating its lower requirement of heat to reach and thus it is also inherently equipped to escape drought. It grows best in areas where winter is cool and rainfall is either low or uncertain. Warm and moist area is not suitable. Frost at flowering and hail storm at grain development damage the crop. Rains at harvesting cause discoloration of grains which making them unfit for malting. The ideal condition for growing barley is moderately dry period forsowing.

Varieties: RD 2052, C 164, Kailash, Amber, BR 32, NP 113, Ratna, Jyoti, Kiran 9, Kiran 10, RS 6.

Cultural practices

(i) **Land preparation:**Land is prepared by 3-4 ploughing with desi plough or one ploughing with iron plough, followed by one harrowing and planking. At the last ploughing, proper insecticide should be applied to protect the crop against soil borneinsects.

(ii) **Time of sowing:** Middle of October to end ofNovember.

(iii) **Method of Sowing:** Drilling method is better thanbroadcasting.

(iv) **Spacing:** 22.5 cm in irrigated and 30 cm in unirrigatedcondition.

(v) **Seed rate:** Normal seed rate under irrigated condition is 75-80 kg/ha whereas 100 kg/ha for irrigated late sown and saline-alkalinesoils.

(vi) **Seed treatment:** Seed treatment with Vitavex, Benlate or Bavistin @ 2 g per kgseed before sowing for smut and Carboxin and Oxycarboxin for loose and yellow smut , respectively.

(vii) **Manures and fertilizers:**
Well decomposed FYM or compost @ 8-10 t/ha.
Basal application of N (40-60 kg/ha) and P_2O_5(20 kg/ha)

(viii) **Irrigations:** Barley is generally grown as a rainfed crop, but it requires 2-3 irrigations. First irrigation should be applied at active tillering stage and second at flowering stage. If there is a lack of moisture, one pre-sowing irrigation is necessary. Active tillering, flag leaf and milking stages are known to be the critical growth stages for irrigation. Out of these stages, active tillering stage is considered as the most criticalone.

(ix) **Interculturing and weeding:** As and when required, one or two operations are to be carriedout.

(x) **Diseases:** Loose smut, powdery mildew, root rot, stem rust, leafrust

(xi) **Pests*:*** Cut worm, termite,aphids

(xii) **Harvesting:** Barley is harvested when fully ripe. Light showers and heavy dew at this time are welcomed by farmers since they mellow the grains. Premature harvesting results in lower yield and poor quality malt. To prevent loss of grain by shattering, it is advisable to cut the crop in the early hours of morning. Threshing is done by trampling the dried produce under the bullock feet. The grain is separated and stored. In Maharashtra, Gujarat and Karnataka, harvesting starts by about the firstweek of February.

Research Station::National: Indian Institute of Wheat and Barley Research, Karnal,

State: Forage Research Station, Anand

Yield : The average yield of 2000-2500 kg/ha (Rainfed), where as that of irrigated crop is twice as much.

Pulses

The present production of pulses in the country hovers around 19 million tonnes, which falls short of the present domestic requirement of around 21 million tonnes. This shortfall in pulses is mainly due to near stagnation in production during the last decade (1999-2009) on account of poor spread of improved varieties and technologies, abrupt climatic changes, complex disease-pest syndrome, emergence of new biotypes and races of key pests and pathogens, and declining total factor productivity.

In order to narrow down the demand supply gap, the country resorts to import pulses to the tune of 2-3 million tonnes every year. In order to ensure self-sufficiency, the pulse requirement in the country is projected at 39 million tonnes by the year 2050 which necessitates an annual growth rate of 2.2%. This requires a paradigm shift in research, technology generation and dissemination, and commercialization along with capacity building in frontier areas of research.

CHICKPEA
(Gram - Bengal gram)

Botanical Name:*Cicer arietinum* L.
Family: Leguminoseae
Origin: Afghanistan and Persia

Classification of gram

The grams have been classified into two groups.

Character	*Deshi* or Brown gram	Kabuli or white gram
Botanical name	*Cicer arietinum*	*Cicer kabulium*
Color of the seed	Ranges from yellow to dark brown	Usually white
Seed size	Usually small	Bold and attractive
Adaptation	Most widely grown group	Specific adaptation
Plants	Small with good branching ability	Generally taller than *deshi* gram and plant less erect
Yield potential	High as compared to Kabuli	Low as compared to *deshi*
Varieties	Chaffa, Dahod Yellow, PG 5, Vijay (rainfed), ICCC4, ICCC10, GG 1, GG2 (rainfed for Bhal region), Pusa 209,Pusa 408, C235.	ICCC32, K4, K5, L144 and L550

Geographical distribution

The important gram growing countries are India, Pakistan, Ethiopia, Burma and Turkey. India ranks first in the world in respect of production as well as acreage followed by Pakistan. India alone has nearly about 75 per cent of the world acreage and production of gram. Gram occupies about 37 per cent of area under pulses and contributes about 50 per cent of the total pulse production of India. In India, gram occupied nearly about 8.251 million hectares of area with annual production of nearly about 7.332 million tonnes during 2014-15. The major gram producing areas are centered in the states of Madhya Pradesh, Rajasthan, Uttar Pradesh, Haryana, Maharashtra, Punjab, Himachal Pradesh and Bihar.

In Gujarat, gram was cultivated in about 1.61 lakh hectares area with total annual production of about 1.99 lakh tonnes and average productivity of 1330 kg/ha during 2014-15. Gram is grown in almost all the districts of Gujarat except Dangs. The cultivation of gram is predominantly centered in *Bhal* region consisting of Ahmedabad, Surendranagar, Bhavnagar, Kheda districts, *Ghed* region of Porbandar and in Godhra and Dahod districts.

Economic importance

Chickpea seeds contain on average 18-22% protein, 52-70% total carbohydrates, 4-10% fat, 6% crude fiber and 3% ash. Seeds are rich in mineral content as phosphorus, calcium, magnesium, iron and zinc. Its leaves contain malic and oxalic acid, which is very useful for stomach ailments. Chickpea is best blood purifier. It is used for human consumption as well as for feeding to animals. Chickpea is mostly consumed in the form of processed whole seed or dal or as dal flour (*Besan*). Stover of gram is an excellent fodder for cattle. Chickpea flour is used for preparation of number of sweets and recipes.

Soil requirements

Chickpea crop does best on medium black, loam and sandy loam well aerated soils. It can be successfully grown in paddy land if there is sufficient moisture available in the soil. Soils having excessive soluble salts and waterlogged soils are not suitable for gram cultivation. Gram being a deep-rooted crop, there should be sufficient moisture in lower layer of the soil.

Climatic requirements

Chickpea is a winter season crop requires a cool and dry climate. Frost received at the time of flowering results in the failure of the flower to develop seeds. Excessive rains soon after sowing or at flowering, pod formation or at maturity cause heavy yield loss. It is best suited to areas having moderate rainfall of 65 to 100 cm per annum. Late sown gram crop is adversely affected by summer weather, which causes early ripening and reduced yield.

Varieties

Shubhra(Kabuli type, Bold seed-35 g/100 seeds),Ujjawal, Chaffa, Dahod Yellow,ICCC 4, Gujarat Gram 1,Gujarat Gram 2 (rainfed for *Bhal* region),Gujarat Gram 4,Gujarat Junagadh Gram 3,Gujarat Junagadh Gram 5,Gujarat Junagadh Gram6

Cultural practices

(i) Land preparation : Chickpea needs cloddy and rough land for good aerationin root zones and does not need a fine seedbed. After harvesting of previous *kharif* crop, the field should be prepared in first fortnight of October by carrying two-three ploughing followed by one light harrowing and planking. For unirrigated crop, deep ploughingin

rainy season found to be advantageous because it helps in conservation of more moisture in the soil.

(ii)Time of sowing: Optimum time of sowing is second fortnight of October or first week of November. Early or late sowing results in low yields due to occurrence of wilt disease or pestattack.

For middle Gujarat, chickpea (Cv.GG 2) for green pods, crop should be sown from 4th week of September to 2nd week ofOctober.

(iii) Method of sowing: Chickpea should be drilled about 10 cm deep to obtained good yield when it is raised under conserved moisture. If it is taken as irrigated crop, it should be drilled about 5 cm deep. Seed rate:

(iv) Spacing: Chickpea variety Chaffa should be sown keeping the distance of30 cm x 10 cm and variety Dahod yellow 22.5 cm to 30 cm x 10 cm. Seeds should be drilled about 10 cm deep under unirrigated and 5 cm deep under irrigatedconditions.

(v) Seed rate: 60 to 70 kg/ha. The chickpea variety Gujarat Gram 2 (rainfed) has bold seed size and requires more seed rate i.e. 80-85kg/ha.

Delayed sowing require higher seed rate for optimal plant stand than the normal planted crop due to restrictedgrowth.

(vi)Seed treatment: The seeds should be treated with Thiram or Cabendanzim 2 to 3 g/kg of seed to control the seed borne and fungal diseases and also for bettergermination.

For nodulation and nitrogen fixation, the seed must be treated with specific *Rhizobium* culture before sowing. Rate of culture should be kept double when seeds are treated with any fungicide. One packet of culture (250 gm) is enough for treating 8-10 kg seeds.

(vii) Manures and fertilizers:

For irrigated crop (kg/ha)			For unirrigated crop (kg/ha)		
N	P_2O_5	K_2O	N	P_2O_5	K_2O
25	50	0	15	40	0

Entire quantity of fertilizers should be drilled 3 to 4 cm deep in furrows before sowing. Application of sulphur @ 20 kg/ha is found beneficial if the soils are deficient in sulphur.

When the soil is medium in available phosphorus, the crop may be fertilized with 37.5 kg of P_2O_5 per ha and adequately manured at the time of sowing

In middle Gujarat, gram (GG2) crop should be applied 75 per cent of recommended phosphorus fertilizer @ 30 kg/ha and phosphobectaria culture with adequate organic manure as a basal treatment in conjunction with irrigation at two stages (i.e. branching and pod formation) for getting higher yield as well as higher net profit.

In *Bhal* area, chickpea crop under limited irrigation facility should be applied *Rhizobium* as a seed treatment (30 g/kg seed) and 20 kg N + 20 kg S/ha as basal and remaining 20 kg N/ha at the time of first irrigation to obtain higher seed yield and net return.

(viii) Irrigations: Generally gram is cultivated under conserved moisture. It is also grown as irrigated crop in the areas where irrigation facilities are available. It requires 3irrigations

at critical growth stages, first at branching (30 DAS), second at flowering (55 to 60 DAS) and third at pod formation (60 to 65 DAS) stages.

If there is a facility to give only two irrigations, first irrigation should be given at flowering and second at pod formation stages.

In middle Gujarat, chickpea (GG 1) should be irrigated twice each of 50 mm depth; first at branching stage (30 DAS) and second at pod filling stage (70 DAS).

(ix) Interculturing and weeding : One or two interculturing and hand weeding are necessary to keep the crop weed free. Interculturing should be carried out during 4 to 6 weeks aftersowing.

In south Gujarat region, two hand weeding should be done at 20 and 40 days after sowing or weed is controlled by application of pendimethalin @ 1.0 kg/ha as pre-emergence application. In south Saurashtra region, interculturing and hand weeding should be carried out at 30-35 days.

(x) Diseases: Wilt andblight

(xi) Pests: Podborer

(xii)Harvesting: Crop becomes ready for harvest when leaves turn reddish brown in colour and start shedding. Plants are either pluck out by hand or cut with sickle. The plants allow drying under sunlight on threshing floor for about 5 to 6 days. Thereafter, threshing is done either by beating the plants with sticks or by trampling under the bullockfeet.

Nipping

It is the process of plucking the apical buds of the crop at about 30-40 days after sowing to control excessive vegetative growth. Nipping stops the apical growth and promotes the lateral branching thus, the plants become more vigorous and produce more flowers and pods thereby increase in yield.

Research Station

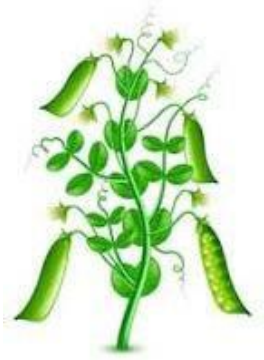
National: IIPR,Kanpur

Gujarat:: Main : Junagadh, **Sub** : Sardarkrushinagar, Vadodara, Dahod, Derol, Arnej

Yield ::Irrigated : 1500 to2000kg/ha **Un-irrigated :** 800 to 1000kg/ha

PEA

Botanical name: *Pisum sativum* L.
Family: Leguminoseae
Origin : South Europe and Western Asia



Pea is an important leguminous crop which is also known as *Matar* in India; the crop is generally cultivated for its green pods.It is sown after harvest of *kharif* crops. Common rotations are maize-pea, paddy-pea, cotton-pea, sorghum-pea and pearl millet-pea. It is grown mixed with gram, barley, wheat, mustard and oats.

There are two types of cultivated pea, garden pea and field pea.

Garden pea	Field pea
Pisum sativum var. *hortense*	*Pisum sativum* var. *arvense*
It is also known as table pea	Hardy plants, grown on a large scale without irrigation. They can also withstand frost.
Generally white flowered	Coloured flowers. Leaf axils are often pigmented
Seeds are yellowish, whitish or bluish green.	Seeds are grayish green/brown or grayish yellow.
Seeds are bold and wrinkled	Seeds are rounded and angular
Young, green seeds are used in vegetables and for canningpurposes	The ripe matured seeds are used as pulse (*dal*). They are also grown as forage or green manure crop or covercrop.

Geographical distribution

The crop is mainly cultivated in the countries of China, Russia, India, Ethiopia and USA. In India, it is mainly cultivated in Uttar Pradesh, Madhya Pradesh and Bihar. Uttar Pradesh state alone contributes about 75 % of the total production of pea of the country.In India, the major , it was cultivated in an area of 1.06 million hectares with a production of 1.01 million tonnes of grains with the average productivity of 955 kg/haduring the year2016-17.

Economic importance

Garden pea is harvested at immature condition for cooking to provide delicious dish or to be canned as frozen for subsequent uses. Field pea is grown as a forage crop for cattle or as a green manure crop or as a cover crop or for dry seeds. These mature seeds may be used as whole

or split into '*dal'* and for various preparations for human consumption. It is highly nutritive and contains high digestible protein, carbohydrates, minerals and vitamins. It contains 22.5 %protein, fat 1.8 % and carbohydrates 62.1 %. It also contains calcium, iron, riboflavin andthiamin.

Soil requirements

It can be grown on a variety of soils; however, deep loamy soils of Indo-Gangatic plains are the best. The crop can withstand mild alkaline conditions but doesn't thrive well on acidic soils.

Climatic requirements

The crop requires cool growing season and moderate temperatures. High temperatures are more injurious than frost. Frost can damage the plants during flowering stage.

Varieties:

Sr. No.	Variety	Yield (q/ha)	Area of adaptation	Remark
1	Rachna	20-25	All zones	White seeded, powdery mildew resistant
2	Aparna (HFP 4)	26	NWPZ	Dwarf, PM resistant
3	Adarsh	20-22	CZ	Tall, PM resistant
4	Vikash	22-25	CZ	Dwarf, PM resistant
5	Prakash	22-25	CZ & NHZ	Large seeds, PM resistant
6	Aman	22-25	NWPZ	PM resistant, tolerant to rust
7	IPF 4-9	18-20	UP state	PM resistant, tolerant to rust
8	GDFP 1	25-30	Gujarat	For green pods and dry seeds

Cultural practices:

(i) Land preparation: A well-drained loam soil having pH 6.5 is most suited. The crop is highly sensitive to water logging conditions. After harvesting of *kharif* crop, two ploughing followed by two harrowing and planking should be carried out to make a field friable andclean.

(ii) Time of sowing: With onset of winter in the month of November for most of the varieties.

Under extra early group variety DDR 23 should be sown from 20th November to 10th December on light textured soils of north Gujarat.

(iii) Method of Sowing: Drilling

(iv) Spacing:30cm x 10cm, 45 cm x 10cm

(v) Seed rate:50 to 95kg/ha.

(vi) Seed treatment: Seeds should be treated with Thiram @ 2 - 3 g /kg of seeds and proper strain of rhizobium culture should be inoculated before sowing thecrop.

(vii) Manure and fertilizers:8 to 10 t good quality FYM/ha, 20 - 25 kg nitrogen, 40-50 kg P_2O_5 and 50 kgK_2O/ha

(viii) Irrigation: First irrigation should be given soon after sowing, second at 7- 8 DAS and subsequent irrigations at 12 to 15 days interval. In all, 7 to 9 irrigations arerequired.

(ix) Interculturing and weeding: Carryout hand weeding twice at 20 and 40 DAS or under constraint of labours, apply pendimethalin 30 EC @ 1.0 kg/ha as preemergence.

(x) Diseases: Wilt, powdery mildew, blight,rust

(xi) Pests: Aphids, podborer

(xii) Harvesting: When pods become mature and turn into yellowish colour, crop should be harvested and transported into threshing yard for drying them under sunlight for few days. After complete drying, seeds are separated by beating withsticks.

Research Station

National: Indian Institute for Pulses research, Kanpur

Gujarat state: Main Pulses Research Station, SDAU, Sardarkrushinagar

Yield :

Field pea **:** 20 to 25 q/ha dryseeds

Gardenpea **:** 100 to125 q/ha greenpods

Oil seeds

India is among the largest vegetable oil economies in the world, next only to USA and China. And, in the agricultural economy of India, oilseeds are important, next only to foodgrains in terms of area, production and value. When the country's agricultural scenario was undergoing a rapid transformation leading to impressive performances on the food fronts in 60s and 70s, the oilseeds scenario, had presented a dismal contrast. India changed from net importer in 80s to a net exporter status during the early 90s. Again,it is back to net importerstatus.

The Indian Institute of Oilseeds Research (IIOR) formerly Directorate of Oilseeds Research was established on August 1, 1977 with the elevation of All India Coordinated Research Project on Oilseeds (AICORPO). It was operated with the Headquarters at Rajendranagar, Hyderabad with Project Director as its administrative head with the assistance of seven Project Coordinators for groundnut, rapeseed-mustard, sesame & niger, linseed, castor, safflower and sunflower. Subsequently, groundnut and rapeseed-mustard were delinked from the Directorate with the establishment of National Research Centre for each of these crops during 1979 and 1993 respectively. In April 2000, the AICRP on sesame, niger and linseed have been separated from the administrative control of IIOR. With the upgradation of DOR to IIOR, sesame, niger and linseed have been added with the existing mandate crops such as castor, safflower andsunflower.

RAPESEED and MUSTARD

Botanical name:*Brassica campestris (*Rapeseed)

*Brassica juncea (*Mustard)

Family: Cruciferae

Origin::Rapeseed : Eastern Afghanistan and adjoining parts of India and Pakistan

Mustard : China

Rapeseed crop is known by different names in different places e.g. *sarson, toria*or *lahi*, while mustard is known as *rai* or *raya* or *laha*.

Mustard is the most important member of the group, accounting for more than 70 % of the area under rape seed – mustard followed by toria, yellow sarson and brown sarson. Taramira is raised on very poor sandy soils with low rainfall. Mustard and sarson group of plants however are grown both on sandy and heavy soils under irrigated and rainfed conditions. These crops are commonly cultivated in areas of marginal and sub marginal productivity, either mixed or intercropped with wheat, barley, gram, pea, sugarcane, lentil etc. In areas of advanced Agronomy, they are chiefly grown as pure crops. In recent years though there has been an increase in area and production of rapeseed and mustard, the average productivity (800 kg/ha) of the country is quite low in comparison of the developed countries of thewest.

The cause for low production is diverse and often complex, but major ones have been non-availability of improved varieties of seeds, susceptibility to various insect pests, disease and frost. Coupled with these is unawareness on the part of farmers about the crop management practices. If efficient crop management practices are adopted at appropriate time, the production and productivity levels can easily be enhanced.

Rape and mustard belong to crucifereae and genus Brassica. Brassica includes the following important oilseed species.

Rapeseed (*Brassica campestris var. sarson and toria):*

It is herbaceous annual plant. The plant is shorter than mustard. Plant height ranges between 45 and 150 cm. The roots are more or less surface feeder and the root system has limited working depth with an extensive lateral spread. The stem is usually covered with waxy deposit. In rape, leaves are borne sessile and are glabrous and hairy. Fruit are thicker than those of mustard and are laterally compressed with a beak one-thirdto half their length. Seeds are either yellow or brown with a smooth seed coat. Rape is self-pollinated but cross-pollination also takes place to someextent.

Mustard *(Brassica juncea):*

It is known as *rai*, *raya* or *laha*. The plants are tall (90-200 cm) and much branched. The plants bear normally long and tapering roots. The leaves are not dilated at the base and clasping as in the case of rape but are stalked, broad and pinnatified. The fruits are slender and only2 to cm long, strongly ascending or erect with short and stout beaks. The colour of seed is brown or dark brown. Seed coat is rough, mustard is self-pollinated but cross-pollination also takes place someextent.

Flowers of both the species have 4 sepals and 4 petals of deep yellow to pale yellow colour. Each flower has 6 stamens, 4 with long and 2 with short filaments. The pistil is compound and ovary matures into a 2-celled fruit (a siliqua). It is made up of a 2 carpels, which are separated by a false septum thus providing 2 chambers.

Geographical distribution:

The important rapeseed and mustard growing countries of the world are India, Canada, China, Pakistan, Japan, Poland, Bangladesh and Sweden. India ranks first in respect of acreage accounting for 31.8 % of the world total and second in production next to Canada with a contribution of about 16 % of world total. Rapeseed and mustard occupied 35.4 lakh hectares with annual production of 16.18 lakh tonnes.

In India, its cultivation is mainly confined to Uttar Pradesh, Rajasthan, Madhya Pradesh, Haryana, Punjab, Orissa, Assam, Bihar, Gujarat and West Bengal. Among different states growing mustard and rapeseed, Uttar Pradesh alone produces about 60 % of total rapeseed and mustard production in India.

In Gujarat, it is cultivated in about 3.4 lakh hectares with a total annual production of about 3.5 lakh tonnes. It is cultivated in the districts of Mehsana, Banaskantha, Ahmedabad, Jamnagar, Sabarkantha, Rajkot, Kutch, Kheda, and Amreli but not grown in Valsad, Dangs, Surat, Surendranagar, Panchmahals, Bharuch, Vadodara, Bhavnagar,Junagadh.

Economic importance

Rapeseed and mustard are the major *rabi* oilseed crops of India. They occupy a prominent place being next in importance to groundnut both in area and production, meeting the fat requirement of about 50 % populations of Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh, Bihar, Orissa, West Bengal and Assam. India co 17 tes lion's share in production of rapeseed and mustards and stand first in the world.

Rapeseed contains about 42 % oil and mustard seed contains about 38-40 % oil. The seed and oil are used as condiments in the preparation of pickles and for flavouring curries and vegetables. The oil is utilized for human consumption throughout Northern India in cooking and frying purposes. It is also used in the preparation of hair oils and medicines. It is used in soap making in mixture with mineral oils for lubrication. Rapeseed oil used in the manufacture of greases. The oil cake is used as cattle feed and manure (5.2 N, 1.0 P_2O_5 and 1.4 K_2O). Due to glucosinolates, mustard cake is not suitable for human purpose as it is adversely affects protein. Green stems and leaves are a good source of green fodder for cattle. The leaves of young plants are used as green vegetables as they supply enough sulphur and mineral in the diet. In the tanning industry, mustard oil is used for softening leather.

Soil requirements:

Generally the rape and mustard thrives best in medium or heavy loam soils except taramira which is raised on lighter soils but heavy soils subjected to water logging should beavoided as the crop cannot tolerate such conditions. Very light soils usually cause a serious moisture stress and a poor crop growth is observed while Saline and alkaline soils are often not fit for the crop though it has good tolerance to suchconditions.

Climatic requirements

Rapeseed and mustard are crops of tropical as well as temperate zones and require somewhat cool and dry weather for satisfactory growth. The crop requires about 18-25 ^{0}C temperatures, low humidity, practically no rains at the time of flowering. Rainfall, high humidity and cloudy weather are not good for the crop during winter as it invites aphids and the crop gets spoiled completely.

However, under rainfed conditions, 1 or 2 pre-flowering rains help in boosting the grain yield. Excessive cold and frost are harmful to the crop.Toria is more liable to suffer from cold and frost and is, therefore, usually sown earlier and harvested before the onset of frost. They require a dry clean weather at the time of maturity. Rapeseed and mustard are long day in periodic response. These crops are not drought tolerant. They require on annual precipitation of 35 to 45 cm. The crop also does not tolerate water loggingconditions.

Varieties:

Mustard	**Rapeseed**	**Taramira (Racket salad)**
Patan-64	Patan 66	T 27
Varuna (T 59) Released in 1976 from CSAUAT, Kanpur	Gujarat Sarsav 1 (1992)	GSL 1
Kranti (GBPUAT, Pantnagar), 1983	Bhavani (Kanpur)	

Krishna (GBPUAT, Pantnagar), 1984	Panchali (Pantnagar)	
GM 1 (1989)	Sangam (Hisar)	
GM 2 (1995)	PusaKalyani	
Vaibhav, Vardan and Rohini (CSAUAT, Kanpur)		
Pusa Jai Kisan		
Pusa Bold		
GM 3 (2004)		
GDM 4 (2011)		

Cultural practices:

(i) Land preparation: The crop is required clean, well pulverize, fine, firm and moist seed bed. For achieving this type of tilth the field should be given pre-sowing irrigation, ifthere is less moisture in the field. Therefore, deep ploughing followed by two to three harrowing and planking operations are to be carried out. Care should be taken to see that weeds and stubbles are well removed from the field and the field and the soil contains adequate moisture to ensure good germination.

(ii) Time of sowing: Sowing of rapeseed and mustard should be done between 15 to 25 October or during Swati *nakshtra*, when temperature goes down during daytime. Late sown crop produce low yield due to shorter duration of re-productive phase, allowing less time for siliquae formation and development of pods, slow growth and severe attack of aphids andsawfly.

(iii) Method of Sowing: Drilling

(iv) Spacing: Sowing should be done at 45 cm apart in rows and plant-to-plant spacing should be maintained 20 cm by thinning of weak plants at 15 days aftergermination.

(v) Seed rate: 3.5 – 4.0kg/ha

(vi) Seed treatment: Seed should be soaked in water for 8-10 hours before sowing for easy and prompt germination. Thereafter, dried seeds are treated with Thiram or Captan @ 3 g/kg of seeds. Seeds should be also treated with 25 ppm ascorbic acid solution (for seed soaking treatment, take 40 mg ascorbic acid and dissolve in 1.6. liters of water and add this solution in 4 kg of seeds of mustard, Stir seeds for uniform soaking). Keep the seeds for 3 hours and then spread treated seeds in shade on paper/gunny beg and dry. Repeat this procedure for 2times.

(vii) Manures and fertilizers: Well decomposed FYM @10t/ha

N (kg/ha)	**P_2O_5 (kg/ha)**	**K_2O (kg/ha)**	**Remarks**
25	50	0	Basal
25	-	-	At 30 DAS
50	50	0	

For rainfed crop, it should be manured with 25 kg N and 25 kg P_2O_5/ha as basal. For southern part of Saurashtra, top dressing is done at 45 DAS.

Soils of north Gujarat are medium in phosphorus; apply 25 kg P_2O_5/ha for mustard crop. The crop yields are poor in sulphur deficient soils. To get significant increase in yield, 20 kg sulphur or 200 kg gypsum per hectare should be applied.

In south Gujarat Agro-climatic zone, mustard (GM 1) should be fertilized with 10 t FYM + 75 kg N/ha + 25 kg P_2O_5/ha. The half dose of N should be applied after one month ofsowing.

In middle Gujarat, the crop should be fertilized with 50 kg N/ha.

In north West agro climatic zone, 50 : 50 N, P_2O_5 and 20 kg S /ha should be applied through gypsum to mustard under rainfed condition in salt affected soil for obtaining higher yield and net return.

In north Gujarat agro climatic zone (AES 1) of light textured soil, mustard should be applied 75 % recommended dose of N (37.5 kg) and P_2O_5 (37.5 kg) each along with seed treatment of bio - fertilizers (*Azotobacter* + PSB 30 g per kg seed) for realizing higher yield and net return.

(viii) Irrigation: Under irrigated conditions crop require 3 irrigations. First irrigation should be given at 20 to 25 days of sowing or immediately after thinning. Second irrigation should be given at 45 days after sowing and third (last) irrigation should be at seed formation in pods according to the crop requirement. If cloudy weather prevails at the time of pod formation, irrigation should not be given because it increases aphid'sattack.

Excessive irrigation at later stages of crop growth reduces the yield by inducing secondary flowering and lodging in the crop.

In middle Gujarat Narmada command areas, mustard should be irrigated at node elongation, flowering and pod development stages with 5 cm depth.

In north Gujarat Agro-climatic Zone (AES-I), mustard (GM 3) should be irrigated through sprinkler at 1.0 IW/CPE for obtaining higher yield and net return over surface method of irrigation.

(ix) Interculturing and weeding : The crop should be kept weed free up to 30 days for maximum yield. Interculturing and hand weeding should be carried out as andwhen required.

The mustard growing farmers of North Gujarat agro climatic zone (AES 1) should apply glyphosate @ 0.25% on moist soil at 42-45 DAS (after second irrigation) using protector hood on nozzle to control *orobanche*.

(x) Diseases: Powdery mildew, white rust and Alternariablight

(xi) Pests: Mustard sawfly, Aphids and Paintedbug

(xii) Harvesting: As soon as the silique turns yellowish brown, harvest the cropor when 75 % silique turn yellowish and moisture content of the seed is around 40 %. At this stage, maximum seeds should be harvested preferable early in the morning. Seeds are separated and stored when moisture content of the seed must be less than 8%.

Research Station:

Main: Sardarkrushinagar

Yield ::Rape seed : 1500 to 1800 kg/ha ,**Mustard:** 2000 to 2200 kg/ha

LINSEED (Alsi or Flax)

Botanical name: *Linum usitatissimum* L.
Family: Linaceae
Origin : Mediterranean region (including Egypt, Algeria, Spain, Italy and Greece).

Linseed is more commonly known as flax in western countries. Two species are under cultivation having equal number of chromosomes (2n = 30). The small seeded type (shorter) is grown mainly for oil purpose and bold seeded type is mainly grown for fiber purpose.

Geographical distribution

Linseed is one of the most important crops of the world cultivated over 5.5 million hectares. The important linseed growing countries are India, Russia, Argentina, Canada and U.S.A. In 2015-16, India had an area of 2,63,860 ha under cultivation and 1,25,490 tonnes with the productivity of 477 kg/ha. In India, it is cultivated in the states of Madhya Pradesh, Uttar Pradesh, Maharashtra and Bihar. Madhya Pradesh occupies premier position in India both with respect to area and production of linseed. In Gujarat, the crop is not cultivated.

Economic importance

Linseed is an important oilseed and fiber crop. Its seed and fiber are used for manufacture of linen, canvas and in dispersible products for defense purpose. Seed contains oil which varies from 37 to 43 % in different varieties. About 20 % of oil is used in farmers home, while about80 % oil is used in industries in various forms. Oil is used for the preparation of paints, varnish, pad ink, printing ink, oilcloths, soap, linoleum and patent leather and waterproof fabrics. Woody matter and short fibers may be used as raw pulp for making paper of quality comparable with that of currency notes. The oil cake is used as cattle feed. It contains 36 % protein. It is also used as organic manure. It contains about 5 % nitrogen, 1.4 % P_2O_5 and 1.8 % K_2O.

Among the oilseed crops grown in *rabi*, linseed is next in importance to rapeseed and mustard in areas as well as in production. In technical oil production, it ranks first in the country. Every part of the linseed plant is utilized commercially either directly or after processing. On a small scale, seed is directly used for edible purposes.

Soil requirements

It thrives best on almost all types of soils, but do better on heavier soils having more water retention capacity. It grows best on well-drained loam to clayey loam soils rich in humus.

Climatic requirements

It is a cool season crop. High temperature above 32 ˚C accompanied with drought during flowering stage reduces yield, oil content of the seed and quality of the oil. Moderate temperature 21 - 26.5 ˚C is ideal. The crop is susceptible to frost. At the time of flowering, frost is very harmful to the crop. It is a long day in photoperiodic response. The crop is suitable to lowrainfall

tract. The crop requires well surface moisture since the crop has shallow root system. Generally the crop is raised under conserved moisture. It is also taken as irrigated crop in dry climate.

Varieties

Irrigated: Garima,Himalini, Jeevan

Rainfed: Sweta, Kiran,Shekhar

Cultural practices

(i) Land preparation: One ploughing through soil turning plough followed by two tothree harrowing should be carried out followed byplanking.

(ii) Time of sowing: First week of October to first week of November is appropriate time for sowing. Delay in sowing adversely affects plant growth and ultimately reduceyield.

(iii) Method of Sowing: Drilling

(iv) Spacing: 30 cm x 5 cm(Sowing depth:4-5 cm)

(v) Seed rate: 20 to 30 kg/ha

(vi) Seed treatment: Seed should be treated with Bavistin (@ 1.5 g/kg seed) or Thiram @ 3 g/kg seed) to protect the crop from seed-borne diseases and to some extent from soil-bome diseasesalso.

(vii) Manures and fertilizers:

Well decomposed FYM @ 8-10t/ha

N (kg/ha)	**P_2O_5 (kg/ha)**	**K_2O (kg/ha)**	**Remarks**
25	40	0	As basal
25	0	0	At first irrigation (30-40 DAS)
50	40	0	

(viii) Irrigation: Two irrigations are sufficient to obtained good yield. First irrigation should be given at 30 - 40 DAS and second irrigation should be applied beforeflowering.

(ix) Interculturing and weeding : Two hand weedings and interculturing should be carried out at 3 and 6 weeks after sowing. Linseed is frequently infested with cuscuta infestation which causes serious yield losses by parasitizing on plant from15 DAS after sowing. Crop rotation with non-host cereals is the ideal solution. Pendimethalin @ 1 kg/ha as pre-emergence application iseffective.

(x) Diseases: Rust, wilt and powderymildew

(xi) Pests: Leaf cater pillar, leafminor

(xii)Harvesting: Generally the crop matures in 125-135 days after sowing. When stem turn into yellowish and capsules and leaves began to dry, crop is to be harvested. After harvesting, bundled the plants and leave them on threshing floor for 4-5 days for drying under sun light. After complete drying, seeds are separated by beating the plants with sticks or by trampling under feet ofbullocks.

Research Station: AICRP on linseed**,** Akola (Maharashtra)

Yield : 1500-2000 kg/ha (seeds)

SUNFLOWER

Botanical name: *Helianthus annus* L.
Family: Compositae
Origin : USSR

In India it is popularly known as *Surajmukhi* is an annual erect and herbaceous plant growing to a height of 1.5 to 6.0 m. The taproot going up to 3 m depth with larger lateral spread of feeder roots. Stems are usually round early in the season, angular and woody later in the season, and normally unbranched. Leaves are rough on both surfaces and irregular toothed on the margins with hairs on both sides varying in size having acute or acuminate tip. Inflorescence is a typical of compositae/ Asteraceae family. It is protandrous (relating to an organism, especially a plant, in which the male (Anther) reproductive organs mature before the female (stigma) reproductive organs), male and female parts mature at different times. Sunflower is essentially a cross pollinated crop. Flower is yellow. Heads are 10-50 cm in diameter with 40-80 rays and brown or black discs. A single head produces about 350-2000 seeds. Seeds are generally lessthan 1.5 cm long pointed at base and round at end. Seed may be white, black or black with white stripes.

There are 264 species in Helianthus genus. All the varieties grown in Russia and in India are divided into three groups.

a. Large white seeded varieties possessing high oilcontent
b. Small black seeded varieties best for eatingpurpose.
c. Intermediate type with striped seeds good for both eating and oilpurposes.

Sunflower varieties are varying greatly in plant height, maturity, number, diameter and colour of heads, size, shape, colour, oil and husk content of seeds and suitability for different climates. Thus, the cultivars may be divided into following types.

1. **Giant types:** Plant are 180-420 cm tall, late maturing, heads 30-35 cm in diameter, seeds large white or gray, with lower seed content, variety MammothRussia
2. **Semi dwarf type:** Plants 130-180 cm tall, early maturing, heads 18-24 cm in diameter, seeds smaller, black gray, higher oil content, varieties Polestar andJupiter
3. **Dwarf type:** Plants 60-135 cm tall, early maturing, heads 12-17 cm in diameter, seedssmall, highest oil content, varieties Advance, Sunriseetc.

Geographical distribution

Sunflower is an important oil-producing crop in temperate countries where it is grown during spring season from April to September. The major sunflower producing countries in the

world is the Russia, USA, Argentina, Romania, Yugoslavia, Bulgaria, Hungary and Canada makes up most of the rest. Russia is producing about 66 % of the world's sunflower oil.

Sunflower is an oilseed crop introduced in India during 1969. In India, Haryana, Karnataka, Rajasthan, Maharashtra, Madhya Pradesh, Tamil Nadu, Uttar Pradesh, Punjab,Orissa, Jammu and Kashmir, West Bengal and Gujarat are the major producer states of sunflower. It is cultivated in an area of about 4.0 lakh hectares in thecountry.

In Gujarat, sunflower is cultivated mainly in the districts of Vadodara, Ahmedabad and Kheda.

Economic importance

1. Sunflower seed contains 45-50 % good quality oil (light yellow in colour), which possesses pleasant flavour, high keeping quality and can be used for a variety of cooking purpose like any other edibleoil.
2. Sunflower oil is a rich source (64 %) of linoleic acid, which helps in washing out cholesterol deposition in the coronary arteries of the heart and is good for heartpatients.
3. Oil is also used in manufacture of soaps andcosmetics.
4. The oil cake contains 40-44 % high quality protein. It is ideally suited for poultry and livestockrations.
5. It can also be used for manufacturing babyfoods.
6. The sunflower kernels can be eaten raw orroasted.
7. Young plants are used for fodder as well as for ornamentalpurpose.
8. Next to soybean, cotton, rapeseed and mustard, sunflower is the largest source of vegetable oil in theworld.
9. It holds a great promise because of its short duration, photo-insensitive, wide adaptability and droughttolerance.

Soil requirements

Sunflower can be grown on variety of soils (wide range) and tolerate some salinity. It thrives best on deep loam soils with good drainage and irrigation facilities. The optimum range of soil pH for this crop is 6.5 to 8.5. It can also thrive well on poor, rocky shallow soils where no other crop can be taken with advantage. Sunflower crop can be a good choice for increasing cropping intensity both under irrigated as well as rainfed conditions.

Climatic requirements

The crop is raised from 40º S to 55º N but greater production is between the latitudes 20º and 55º N and 20º and 40º S. The crop can be raised up to altitude of 2500 m. However, the highest oil/ha is obtained below 1500 m. For all practical purposes, it is a dry day neutral crop. The crop requires a cool climate during germination and seedling growth. Seedlings are tolerating frost moderately well until they reach the four to six leaf stage of development. It requires warm weather from the seedlings stage to flowering stage and warm and sunny days during flowering to maturity. High humidity accompanied with cloudy weather and rainfall at the time of flowering results in poor seed setting and high plant mortality. The amount of linoleic acid decreases with high temperatures atmaturity.

Sunflower is a photo insensitive crop and hence, it can be grown successfully in any season throughout India. It tolerates temperature range of 8-35 ºC without significant yield

reduction indicating that it is adapted to the regions with warm days and cold nights. However, it grows well within the temperature range of 20-25 ºC. It can be grown at any time during the year and can serve as an ideal catch crop during the period when land is otherwise left fallow.

Varieties

Sr.No.	Name of variety	Duration	Remarks
1	CO1	Short duration	TN
2	Morden	Short duration	70-75 days, Gujarat
3	EC 68413	Medium duration	90-95 days
4	EC 68414	Medium duration	90-95 days, Gujarat
5	EC 68415	Medium duration	90-95 days
6	APSH11	Hybrid	80-85 days, yields 25-30 q/ha. (AP)
7	KSFH1	Hybrid	Suitable for all areas, rust resistant
8	TNAU SUF7	Open pollinated variety	95 days, 40 % oil (1 tonne/ha)
9	Guj. Sunflower1	Medium duration	93 days, released in 1994, 870 kg/ha

Cultural practices

(i) Land preparation: The first shallow ploughing should be done by local plough followed by 2 to 3 harrowing according to the requirements. Field should be clod free and levelled. For summer cultivation, land should be prepared by giving pre-sowing irrigation. Sufficient moisture should be available in the land for uniform and good germination.

(ii) Time of sowing: First week ofNovember.

(iii) Method of Sowing: Drilling - seed should be drilled up to 5 to 7.5 cm deep according to the soil moisture available in the soil at the time of sowing (for summercultivation).

(iv) Spacing: 60 cm x 20cm

(v) Seed rate:10 to 12 kg/ha (sole crop) ,5 to 06 kg/ha (mixedcrop)

For fodder, 20-25 kg/ha (30 cm spacing, 40-40 NP kg/ha and harvesting at flowering stage)

(vi) Seed treatment: Seed should be treated with thiram or brassicol @ 2 to 3 g/kg ofseeds.

(vii) Manures and fertilizers: Sunflower is exhaustive crop and responds well to manure and fertilizers for its successful cultivation. Manures and fertilizers both play an important role in sunflower cultivation. Use of FYM helps in better conservation of moisture in the soil. A crop of sunflower yielding 14 - quintals/ha exhaust 175 kg N, 65 kg P_2O_5 and 225 kg K_2O from 1 haland.

Therefore, it is necessary to apply adequate quantities of manures and fertilizers in the field ofsunflower.

N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Remarks
30	60	0	At the time of sowing
30	0	0	30 to 40 DAS
60	60	0	

(viii) Irrigation: If dry spell occur and there is a moisture stress in the soil, irrigation should be given at flower head initiation stage, second at flower head development and third at grain filling stage. Irrigation restricts the development of root though plants grow tall and become susceptible tolodging.

(ix) Interculturing and weeding: The crop should be kept weed free up to 45 days after sowing to obtain higher yields. Mechanical methods of control such as 2 hand weeding and 2 interculturings with hand hoe at 20-25 days and second at 30-35 days after sowing were quiteeffective.

(x) Diseases: Alternaria leaf blight, rust, root and collar rot, downy mildew, head rotand necrosis

(xi) Pests: Parrot damage the crop to a greater extent at seed setting and seed maturity stage and hence protection against this bird is must (Bird watching ismust).

(xii) Harvesting: All heads may not be ready for harvesting at one time. Harvesting may therefore, be done in two or three installments to avoid shattering of the seeds. The heads mature when back of the flower disc turn yellowish brown. The heads are cut and should be dried well under sunlight. The seeds are separated easily by beating the center of the head with small stick. Store the produce (seeds) after complete drying bykeeping the moisture at 10%.

Research Station::National: IIOR, Hyderabad, **State**: Junagadh

Yield : 800 to 1200 kg/ha

Sugar Crops

Importance of sugar crops

- In addition to providing the source for the manufacture of sugar, sugar crops are used to produce alcohol and ethanol.
- In certain countries, sugar cane is eaten raw in minor quantities.
- It also is used in the preparation of juices and for animal feed.
- There are two major sugar crops: sugar beets and sugar cane. However, sugar and syrups are also produced from the sap of certain species of maple trees, from sweet sorghum when cultivated explicitly for making syrup and from sugar palm.
- Sugar beets that are cultivated solely as a fodder crop and are classified as vegetable crops
- Sugar cane is a perennial grass that is cultivated mainly in the tropics.
- Sugar beet is an annual crop that is propagated by the seeds of the flowers, cultivated in cooler climates than sugar cane
- Both sugar beets and sugar cane have high water content, accounting for about 75 percent of the total weight of the plants. The sugar content of sugar cane ranges from 10 to 15 percent of the total weight, while that of sugar beets is between 13 and 18 percent.

SUGARCANE

Botanical name: *Saccharum officinarum* L.
Family: Gramineae
Origin : India

Sugarcane is a tall perennial plant growing up to a height of 2-3 m. The plant is composed of 4 principal parts, the root system, the stalk, the leaves and the inflorescence.

Classification of sugarcane

Cultivated sugarcane is classified into the following species.

1) Saccharumofficinarum

These canes are juicy and thin having higher percentage of sucrose, resistant to smut, but susceptible to red rot and mosaic diseases. Cultivation is limited to tropical areas, having low percentage of fibre because of which they are more preferred for chewing purpose.

2) Saccharumspontaneum

It is a wide Asian species with very thin stalks and narrow leaves. It is used for breeding purpose and containing very low sucrose, high fiber and having early maturity.

3) Saccharumbarberi

Varieties belong to this type species are slender stemmed type that originated in Northeastern India. It is characterized by short and thin stalks, narrow leaves, low to medium sucrose (moderate), high fiber, very early maturity.

4) Saccharumsinense

This species of cultivated sugarcane is indigenous to northeastern India. This species is characterized by long and thin stalks, early maturity, broad leaves, and low to medium sucrose content. Internodes of this group are long and more or less zigzag and nodes are prominent and used for breeding purpose.

5) Saccharumrobustum

This species originated in New Guinea. It has some thicker stalks, larger leaves, low sucrose and low fiber.

Geographical distribution:

The important sugarcane growing countries in the world are India, Cuba, China, Brazil, Mexico, Pakistan, Philippines, Japan, Spain, East Africa, Peru and Argentina. However, India, Cuba, Indonesia, USA, Taiwan and Philippines are the major one. Sugarcane is cultivated over an area of 11.46 million hectares with a total production of 754.13 million tonnes ofcane.

India ranks first in respect of sugarcane production in the world. It is a main source of sugar in India and holds prominent position as a cash crop. It occupies about 1.8 % of the total cropped area in the country.

In India, area and production of sugarcane has been fluctuating from year to a year depending upon pricing policy and climatic conditions. It occupies about 3.5 million hectares area with a total production of sugarcane about 158 million tonnes. In India, the north India can belt containing Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, and Bihar etc. givesabout 64 % of the total cane production and accounts for about 76 % of the total acreage under the crop. Uttar Pradesh has the largest area under sugarcane and accounts for about 57 % of the area of this crop in the whole country, which contributes 47 % of the annual production in terms of raw sugar but the production per hectare, is the highest in Tamil Nadu followed by Maharashtra and Andhra Pradesh.

The contribution of Gujarat is poor so as far as area is concerned and it is only about 3 % (1.65 lakh hectares) of total area having the annual production of about 11.84 lakh tonnes. The average production of sugarcane in Gujarat is 71.71 tonnes which somewhat higher than the national average. The sugarcane crop is taken more or less in each district but 90 to 95 % cultivation is concentrated in Surat, Valsad, Junagadh, Rajkot, Amelia and Bhavnagar districts. First co-operative factory was established in 1955 at Bardoli with initial crushing capacity of 800 tonnes per day. At present, its crushing capacity is of 7000 tonnes per day, which is the highest in Asia. At present, 15 co-operative sugar factories are working in the state.

In the Gujarat State, the area under sugarcane is increased five times more, while productivity is increased about seven times more during last 23 years.

Economic importance:

Sugarcane is the main source of sugar in India. Sugar juice is used for making white sugar, brown sugar (*Khandsari*) and Jaggery (*Gur*). Sugarcane is one of the main cropsof

earning foreign exchange. The main byproducts of the sugarcane industry are bagasses and molasses.

Bagasse is mainly used as a fuel. It is also used for the production of compressed fiberboard, paper, plastic etc.

Molasses is used in distilleries for manufacture of ethyl alcohol, butyl alcohol, citric acid etc. Rum is the best potable spirit made from molasses. Molasses is also used as an additive to feeds for livestock. Green tops of sugarcane are a good source of fodder for cattle.

Press mud is used as manure in alkaline and saline soils. A sugar industry in India is next in importance only to the textile industries and provides gainful employment to a large number of people.

Soil requirements

Sugarcane can be grown on all types of soil ranging from medium sandy to clay loam or heavy black soils. It can also be raised successfully on lighter soils and heavy clays.

The soils should be well aerated and well drained. The water should not be remained standing for a longer period. Sugarcane crop absorbs nitrogen in nitrate form. Soils rich in P and Ca are good for better juice quality. Soils rich in iron are good for sugar recovery.

Sugarcane crop tolerate moderate acidity and alkalinity but prefers slight acidic soils, i.e. pH 6 to pH 7 is optimum. If the concentration of sodium salt and Mn is high, it has adverse effect on growth, yield and quality of sugarcane.

Climatic requirements

Sugarcane is a tropical plant. It grows well in that region where the climate is more or less tropical but it can grow in subtropical too as in north India. Under warm humid conditions, it can continue its growth unless terminated by flower. An average mean temperature of 28-37 ºC is best suited for its growth. Lower temperature reducestillering.

Temperature above 50 ˚C arrest its growth, those below 20 ˚C slow it down. Under bright sunlight conditions the stems are thicker but shorter and leaves are broader and greener, while under low temperature, the stem are slender and long with narrower and yellowish leaves. Day length also determine flowering in cane. Thus, climate plays a very important role in yield of sugarcane.

Varieties:

Variety	Year of release	Yield (t/ ha)	Sucrose % in juice
Early variety			
Co 775	-	81.38	17.80
Co 6806	1981-82	73.07	18.16
CoC 671	1984-85	120.40	18.40
Co 8338	1990-91	113.46	18.79
Co 87263	1997-98	112.17	19.04
Co N 95132	2001-02	109.32	19.98

Co N 03131	2004-05	145.74	18.55
Co N 05071	2007-08	146.67	18.30
CoN 9072 (GNS-9)	2015-16	129.05	
Mid late variety			
Co 419	-	71.21	17.61
Co 791	-	107.68	16.72
Co 955	-	101.87	15.95
Co 6304	1981-82	91.79	17.71
CoA 7602	1982-83	100.69	19.50
Co 7527	1986-87	146.00	17.40
Co 62175	1986-87	100.00	16.00
CoN 91132	1996-97	120.06	18.94
CoLk 8001	1996-97	127.51	19.58
CoN 85134	2000-01	122.85	17.72
CoN 05072	2007-08	155.18	17.86
CoN 05071 (GS 5)	2012-13	121.20	-
CoN 07072 (GNS 8)	2012-13	-	-
For Gujarat			
Co 03131(Guj. Sugarcane 4)	2005	-	-
CoN 05071 (Guj. Sugarcane 5)	2007	-	-
CoN 05072 (Guj. Sugarcane 6)	2007	-	-
Guj. Sugarcane 7	2011	-	-
Guj. Sugarcane 8)	2013	-	-
CoN 09072 (Guj. Sugarcane 9)	2016	-	-

Note: Early varieties mature in 10 to 12 months (maturity days 300 to 330), Mid-late varieties mature in 12 to 14 months (maturity days 360 to 400) and late varieties mature in 14 to 15 months.

Cultural practices

(i) Land preparation: Sugarcane requires a very thorough, clean preparation of land and that is to be done by deep tillage. At least one or two, 20 to 25 cm deep ploughing should be carried out with the help of tractor drawn or bullock drawn mould board plough. Harrowing and planking is followed to make the field friable, leveled, smooth and clodfree.

(ii) Time ofplanting:

1) Pre-seasonal planting (Sara planting), Seasonal planting (Spring planting) andAdsaliplanting

This planting is done in the month of October - November and duration is of 15 months.

2) Seasonal planting (Spring planting)

This planting is done in the month of January - February and duration is of 10-12 months.

3) Adsaliplanting

This planting is done in the month of June - July and duration is of 18 months. Adsali planting is not followed in Gujarat but this method is common in Maharashtra state.

In south Gujarat, planting is started from second fortnight of November and continue up to end of February. In Saurashtra region, December - January is optimum period forplanting

Selection of plantingmaterial

The key points for selection of good quality sugarcane setts are as under.

1) Portion of thecane

Healthy seed material, free from pest and diseases and having high viability is essential. The top half or one third portion of sugarcane is considered better than the middle or bottom canes which is selected for planting. The reasons for that are givenbelow.

It is rich in glucose and water, which help in quick and uniform germination. The glucose content of buds decreases towards the base of the stem, while the content of minerals in the apex increases.

The buds are fresh in upper portion as compared to lower portion of cane and younger buds are capable of quick germination. Lower portion of the cane contains more sucrose, if the sucrose content is more, it take more time for liberation of energy and hence buds takes more time for germination, while glucose gives more energy within short time so buds takes less time for germination.

2) Seed should be selected from disease freecrop.
3) Seed should be selected from 8 to 10 months well-managedcrop.
4) Do not use the sugarcane plant on which the eye buds and roots areemerged.

(iii) Method of planting:

Sugarcane planting is done by two methods.

1) **Dry method:** The sugarcane setts are placed in furrow in dry soil and setts are covered with 4-5 cm of soil and then irrigation isgiven.
2) **Wet method:** In this method, the pre-planting irrigation is given and then the sugarcane setts are placed in furrows and inserted into soil by pressing them under foot. Wet planting method is found more convenient in ourstate.

Planting techniques

1) End to endtechnique

Three budded setts are put in furrow in such a way that end of the other sett touch to the end of the formersetts.

2) Over lappingtechnique

Three budded setts are put in furrow in such a way that eye of the one sett touch to the eye of another set. This technique requires more seed rate.

3) SlantTechnique

Three budded setts are planted slanting with one bud in the soil and two buds above the ground. When the above the ground buds sprout up into shoots of 20-25 cm length the setts are horizontally pressed down inside and the leaves of the shoots covered with soil.

4) Transplantingtechnique

Seedbed of 8.0 m x 1.5 m is generally prepared to raise the seedling. Setts of nearly 25 quintals of healthy cane are sufficient for planting of one hectare of land. Enough quantity of organic manure should be properly applied in the seedbed. Two budded setts dipped in agallol solution before planting in to the field. The germination of bud is complete within a fortnight and seedling become ready for transplanting after one week of germination. The spouted setts are taken out from seedbed and are cut into pieces making one budded setts. The spouted setts are thus planted in the field. This method is adopted when there is a shortage of planting materials.Sometimes, one - budded setts are used in nursery for raising theseeding.

The new techniques are developed for raising the seeding in small plastic or leaf bowl by putting eye bud only. The eye bud is separated by special instrument (eye separator) from setts. These separated eye buds are used for raisingseedling

(iv) Spacing: In fertile soils, distance between two rows is 100 to 120 cm, while in light soils; distance between two rows is 90 cm.However, it is advisable to go for 120 cm spacing where intercultivation and earthing up operation are done by tractor drawn implements.If drip irrigation system is available, the cane crop should be planted in paired rowsystem.

In Saurashtra, variety C0671 should be planted in paired row system by keeping the distance between row of 25 cm and between pair 75cm.

In middle Gujarat, sugarcane Cv. Co 91132 should be planted at 45-90-45 cm in paired rows and intercropped with cabbage for getting higher cane yield (133.58 t/ha) and net realization of Rs.1,11,531/ha for more profitable sugarcane cultivation (CBR1:4.48).

(v) Seed rate: Normally 30000 to 35000 three eye budded setts or 50000 two eye budded setts are required for planting of one hectare area (5 to 6 tonnes according to the varieties).

(vi) Seed treatment: If sugarcane setts are infested by mealy bugs and scale insects, setts are dipped in the solution of 0.1 % melathion for five minutes before use. After giving the above treatment, the sets are dipped for 2 to 3 minutes in a solution of 6 % mercurial fungicide like agallol or cerasan @ 500 gm in 100 liter water. This treatment helps to prevent set borne diseases like smut and to improvegermination.

Hot water treatment: The sets are kept in hot water at 50^0 C temperature for two hours to control red-rot, grassy shoots and other virus diseases. Just before planting sets are dipped in *Azotobacter* inoculants solution which is prepared by mixing 5 kg *Azotobacter* inoculants in 100 liter water for 2 to 3 minutes. This treatment helps in good germination and save nitrogenous fertilizers.

Lime water treatment: Sets are soaked in lime water solution prepared by dissolving 500 g lime in 200 liter water for 24 hrs to improve germination. This treatment ensures better germination and also kills eggs of insects.

Hormones treatment: To obtain good germination and vigorous seedlings treat the setts with 10-ppm solution of Naphthalene Acetic Acid (NAA) or Indole Acetic Acid (IAA) or Gibberellic Acid (GA).

(vii) Manures and fertilizers: Apply well decomposed FYM @ 25 to 50 CL/ha in two equal splits, first half quantity at the time of preliminary tillage and second half quantity in furrow at the time ofplanting.

In south Gujarat areas where application of FYM is not possible, castor cake @ 625 kg/ha or pressmud @ 11 tonnes/ha should be applied.

N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	Remarks
37.5	100-125	100-125	At planting in furrows
75.0	0	0	One and half months after planting
50.0	0	0	Four months after planting
87.5	0	0	5 to 6 months after planting before earthing up
250	100-125	100-125	

In middle Gujarat conditions, to get higher yield and net profit, the crop should be fertilized with 250-125-125 kg NPK/ha and the setts should be treated with Azotobacter @ 2 kg/ha.

In middle Gujarat, sugarcane (Co-6304) should be fertilized with 150 kg N + 125 kg P_2O_5 + 125 kg K_2O/ha and sugarcane setts for planting should be used after the

treatment of *Acetobacter diazotrophicus* ACG-2 (containing 10^8 CFU/g carrier) @ 4 kg/ha to save 100 kg N/ha for higher cane yield (14%) and net return.

In Saurashtra region, Sardar super culture @ 2 kg/ha should be applied in soil before planting and the crop should be fertilized with recommended dose of fertilizers (250-125-125 kg NPK/ha). To save the 25 % N, 187.5-125-125 kg NPK/ha should be applied along with Sardar superculture.

In south Gujarat zone, application of vermicompost @ 5 t/ha for planted crop and 2.5 t/ha for ratoon crop either alone or in combination with 75 or 50 % recommended dose of N, P and K was not found advantageous.

(viii) Irrigations: In south Gujarat area where soils are heavy clay, where canal irrigation is available, 20 irrigations of 60 mm water depth or 16 irrigations of 80 mm depth are needed and irrigations should be applied in furrows. If irrigations of 100 mm water depth are given, number of irrigation is reducing to13.

The crop requires 1800 mm water during its life span. If irrigations are given in alternate furrows, it cane save 43 % irrigation water.

There are four critical growth stages in sugarcane crop for water requirement. They are as under.

1. Emergence stage (up to 60 days afterplanting)
2. Tillering stage (60 to 130days)
3. Maximum growth (130 to 250days)
4. Maturing period (250 to 360days).

Out of which, second and third are the most critical growth stages. If moisture stress occurs during these stages, yield may reduce to a greater extent. During ripening phase, soil moisture content should be allowed to decrease gradually so that growth of the cane is checked and sucrose content increase. For this, irrigation should be stopped 15 days beforeharvesting.

(ix) Interculturing and weeding : The first hoeing and weeding should be done 3-4 weeks after planting.After germination, depending on the field conditions and the frequency of irrigations,2 or 3 more hoeings and weedings may be required during first 3 months afterplanting.

The most critical period for the weed competition in sugarcane is up to 4 months after sowing beyond which the crop smothers the weed flora by itself.

Chemical weed control offers a good substitute of mechanical measures. Several herbicides have been tested for weed control in sugarcane.

1) Atrazine @ 1.5-2.0 a.i./ha as pre-emergence (3-8DAP)

2)Diuron @ 2.0 kg a.i./ha as pre-emergence (3-8DAP)

3) Metribuzine or 2-4-D sodium salt @ 2.0 kg a.i./ha and 1.5 kg a.i./ha in 600 litres of water should be sprayed uniformly on the soil surface before emergence of eye buds i.e.10 to 15 days after planting. In addition to this, hand weeding should be done to remove weeds within the lines of cane as and whenrequired.

For south Gujarat :

Weeding at 30, 60 & 90 days after planting or Apply weedicide

i) Atrazine @ 2.0 kg/ha(PE) + 2,4-D @ 1 kg/ha at 60 DAPor
ii) Metribuzin @ 1.0 kg/ha(PE)+ one Hand Weeding at 60 DAPor
iii) Pendimethalin @ 1.0 kg/ha(PE)+ one Hand Weeding at 60 DAPor
iv) Glyphosate 1 lit a.i./ha as blanket spray at 20 DAP + one Hand Weeding at 60DAP

Tying, wrapping and propping of sugarcane

These operations are done in sugarcane just to provide mechanical support to grown up cane plants to prevent lodging. By wrapping, the distribution of CO_2 becomes easy and proper to all the plants throughout the field. The green leaves on the plants are wrapped together by taking all canes of one bundle. After wrapping, the clumps in adjacent rows are tied together (crosswise).The operation of tying the leaves together using the bottom dry and green leaves is known as propping. When wrapping and tying is over in entire field these tied clumps are given further support to bamboopoles from outside (on 2 opposite sides) of their field. In areas where cane top growth is heavy and wind velocities are high, propping is necessary. Tying should be done in August when cane reaches about 2 m height. Green leaves should not be tied up together while tying up thecrop.

(x) Diseases: Red rot, wilt, whip smut, grassy shoots,mosaic

(xi) Pests: Top shoot borer, stalk borer of sugarcane, pyrilla, scale insect, mealy bug, and whitefly

(xii) Harvesting: When sugarcane crop is matured, harvesting should be done in time. If immature sugarcane is harvested or harvesting delayed after maturity, the sucrose content decreased to a certain extent. To judge the maturity of sugarcane crop, the following points should beconsidered.

1. Entire field (crop) becomes yellow inappearance.
2. Appearance of arrowing in arrow (tassel) emergingvarieties.
3. While knocking / tapering to sugarcane stalks, the metallic sound isproduced.
4. Swelling of eyebuds.
5. Easy breaking of sugarcane stalks from thenodes.
6. Brix Saccharometer reading shows figure 19 or above which indicate sugarcane maturity and it is likely to be ready forharvest.

Irrigation should be stopped 15 days before harvesting just to increase the sucrose content. Sugarcane stalks should be cut to the ground level with "Koyta" and dried leaves are stripped off from top most mature internodes.

Research Station:

Main Sugarcane Research Station : Kodinar (Junagadh)

Regional Research Station: Navsari, Thasra, Vyara.

Coimbatore : Sugarcane Breeding Institute is located at Coimbatore.

Lucknow: Indian Institute of Sugarcane Research established in 1952.

Yield : The average yield of sugarcane is 70 tonnes per hectare in Gujarat. About 70 to 85 tonnes in Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka.

The yield of Adsali crop (18 months) in Southern India is usually 120 to 140 tonnes/ha. The ratoon crop also gives the yield about 60 q/ha.

Ratooning of sugarcane

Ratooning of the cane is an age-old practice in all sugarcane growing countries.

About 35 to 40 % of total sugarcane cultivated area each year covered under ratoon crop in India and Gujarat. Normally, one or two ratoon is permissible in most of the states. However, in certain states, only one ratoon is recommended. The second or more subsequent ratoon is not advised because of the risk of pest anddiseases.

Following points/cares to be taken into consideration for obtaining maximum yields from ratoon crop.

- Improved varieties for ratoon crop. All the recommended varieties except Co-C 671 are suitable for ratoon crop.
- Selection of time for ratooning.

1. When main crop is harvested during November to February should be selected for ratooncrop.
2. But when main crop is harvested during April - May should not be selected for ratooning because ofless time available for better growth and development and ultimately yields are reduced. So it is not advantageous to take ratoon crop from late harvested main sugarcane crop.

Other cares

1. **Gap filling**- After preliminary field operation, the gap filling should be done by transplanting of one or three budded seedlings raised well in advance in nursery before first irrigation or with rooted slips from excess tillers of the same field or by using new sugarcanesetts.
2. **Top dressing** - the ratoon crop required more nitrogen than main crop because sugarcane crop stands on the same field for about 22 to 24 monthsaltogether.
3. Earthing up should be done to avoid lodging which occurs due to wind and heavyrainfall.
4. Main crop should be harvested as close to the ground level aspossible.
5. After harvesting of main crop, field should be cleaned by removing leaves and other small stalks pieces left on thefield.

Ratoon crop requires following fertilizers dose (kg/ha):

N	P_2O_5	K_2O	Remarks
300	100-125	100-125	
75	100-125	100-125	Should be drilled on both the sides of rows 8-10 cm deep at the time of first irrigation but after preliminary field operations
150	0	0	After two months
75	0	0	When crop reached at an age of 4-5 months

1. Irrigation - In deep and more moisture retentive soils, the first irrigation should be given at 25 to 30 days after harvesting of fresh crop/main crop/first crop. While in light types of soils, the first irrigation should be given 15 to 20 days after harvesting of maincrop.
2. In South Gujarat area, if ratoon crop is taken for the first time requires 14 irrigations.

3. While in middle Gujarat and Saurashtra region, normally irrigations are given more frequent 10 to 15 days interval according to the structure and depth of thesoils.
4. Two to three interculturing and two to three hand weeding are required for effective control of weeds. Light earthing up should be carried out 2 to 3 months (i.e. after second top dressing) and heavy earthing up is done with the help of ridger at the time of last topdressing.

Advantages of ratoon crop:

1. No need of land preparation and layout which reduce the cost of production.
2. Due to saving of time behind land preparation, ratoon crop get sufficient time for better growth anddevelopment.
3. It saves the cost of planting and seed materials.
4. The ratoon crop matures about one month earlier than freshcrop.
5. The recovery of sugar and Gur is obtained more, which reduced the cost of sugar production and increaseincome.
6. One or two ratooning reduces about 25 % cost ofcultivation.

SUGARBEET

Botanical name:*Beta vulgaris* L.
Family: Chanopodiaceae
Origin : Western Asia

Geographical distribution

In the world, European countries like France, Germany and USA, having temperate region are growing sugar beet. In India, states like Punjab, Haryana, Uttar Pradesh and Bihar have possibilities of cultivating sugarbeet.

Economic importance

Sugar beet is an important sugar crops grown in *rabi* season. It is a good source of sugar. It contains 15 to 18 per cent sugar, whereas, sugarcane contains 10 to 12 per cent sugar.Sugar beet contributes about 40-45 per cent of the total sugar production of theworld.

Uses :

1. Manufacturing ofsugar.
2. Top portion is used for cattle feed. In western countries, tops are turned into silage or dehydrated for feeding to cattlelater.
3. Tops are rich in nitrogen, so make good green manure, if ploughed in tosoil.
4. Sugar beet pulp obtained after extraction used as cattle feed. It is fed in various forms viz; fresh, processed, dried or assilage.
5. Sugar beet molasses also used as cattle feed either alone or in mixture with otherfeeds.

Soil requirements

It performs best on well drained, slightly alkaline, sandy loam, loam and black soils having pH value about 8.3. Heavy clay soils having poor drainage capacity are not suitable.

Climatic requirements

It requires cool climate. Temperature ranging from 18 to 22^0C is most suitable. Sugar beet can be grown best where winter season is mild and extends up to March-April.

Varieties: Erotype E, US 35, US 75, Ramonskaya 60, Maribo Auglo Poly, Maribo Resists Poly, Maribo Magna Poly, KWS-Cerco Poly, KWS Poly Bata, Meribo Contintenta Poly.

Cultural practices

(i) Landpreparation:

It requires a good, firm and well leveled seedbed. One or two ploughing should be done followed by harrowing and planking. Stubbles of preceding crop should be removed from the field.

(ii) Time of sowing:: Sowing can be done on ridge. Seeds are dibbled by hand onridges about 2-4 cm deep and at 20 cm distance between twoplants.

(iii) Method of sowing:: Sowing can be done on ridge. Seeds are dibbled by hand onridges about 2-4 cm deep and at 20 cm distance between twoplants.

Singling and thinning :

The multigerm seeds of sugarbeet give rise to cluster of seedlings, and hence it is necessary to remove all but one single robust seedling per seed pocket. Thinning should be done when plant reaches 4 leaf stage by keeping only one healthy plant at 20 cm spacing withinrow.

(iv) Spacing: Ridge to Ridge : 45 cm ; Plant to Plant : 20cm.

(v) Seed rate:3 kg/ha by dibbling method and 10 kg/ha by furrowsowing.

(vi) Seed treatment: Sugar beet seeds have hard seed coat. So, it should be soaked in water for 10 to 12 hours before sowing for easygermination.

(vii) Manures and fertilizers: Well decomposed FYM or compost @ 8-10 t/ha should be applied and incorporated in the soil at the time of landpreparation.

N(kg/ha)	P_2O_5(kg/ha)	K_2O(kg/ha)	Remarks
100	100	100	Basal
50	-	-	After thinning
50	-	-	Before end of January
200	100	100	Total

(viii) Irrigation: It requires 8-10 irrigations depending upon the type of soil and climate. It gives better response to lighter and frequent irrigations than heavier and less number of irrigations.

(ix) Interculturing and weeding:

Seedbed has poor tolerance to weed competition and hence crop should be kept weed free at least for first the first 2 months of its growth. The earthing up of the crop should be completed by December after the last top dressing of nitrogen.

(x) Diseases: Yellow virus, root rot, heart rot, leaf spot, crowers gall, charcoalrot

(xi) Pests: Cut worm, hairy caterpillar

(xii) Harvesting: Root development progresses steadily. Sugar content is about 12-14 % by middle of March. It increases to 15 to 18 % by middle of April. Rate of increase in sucrose is slow but remaining at high level up to middle of May. By middle of April, many of the lower leaves of the crop dried up. This is a fair sign of the ripening of the crop. Crop can be harvested from middle of March to end ofMay.

There should be sufficient moisture in the field to facilitate the operation of uprooting crop plants. A country plow run close to the row, lift the roots and made free of soils by shaking. Roots should be topped at the base of the lowestleaf.

Intercropping :Sugarbeet can be grown as an intercrop with October-November planted crop of sugarcane. At Lucknow, it is found that the total out turn of raw material was the highest where the two crops were intercropped. Data given below shows significance of inter crop.

Sugarcane alone: 61.1 tonnes/ ha

Sugarcane + Sugarbeet: 93. 2 tonnes/ ha (38.4 t/ha of sugarbeet and 54.8 t/ha of sugarcane).

Research Station: IISR, Lucknow

Yield : Average yield ranges between 50 to 60 tonnes of fresh roots/ha.

Medicinal and Aromatic Crops

- India is endowed with a rich wealth of medicinal plants. These plants have made a good contribution to the development of ancient Indian medicine.
- One of the earliest treatises on Indian medicine the Charak Samhita (1000 B.C), records the use of over 340 drugs of vegetable origin.
- Medicinal and aromatic plants are important for human health. These plants have been used from the prehistoric times to present day. These plants based medicines are consumed in all civilizations.
- It is believed that the herbal medicine can give good effect to body without causing side effects to
- human‘s life. Besides, the usage of medical plants has been increasing as an important role that can support the economic system.
- The medical and aromatic plants for health are used as herbal treatments and therapies that can be new habits for culture.
- With the high consumption of medical plants, it is possible that the over exploitation of such plants could be happen.

Some of the medicinal plants can be cultivated well in a research centre, agricultural site or even in a house. But for the wild medical plants, it needs to be more concerned to avoid the over cropped and keep the sustainability of the medical and aromatic plants.

Mint

Botanical name: *Mentha arvensis, Menth acitrita,Mentha longifolia*
Family: Lamiaceae
Origin : Europe and Asia

The plants belonging to the genus *Mentha* are aromatic herbs. Several species grow wild; some are cultivated. The chief constituents for which these plants are valued are Menthol and Peppermint oil.

Geographical distribution

Mint is believed to have originated in the Mediterranean basin and, from there, spread to the rest of the world by both natural and artificial means. Among the mints, Japanese mint is cultivated on a large scale in Brazil, Paraguay, China, Argentina, Japan, Thailand, Angola and

India. Peppermint is grown in the USA, Morocco, Argentina, Australia, France, USSR, Bulgaria, Czechoslovakia, Hungary, Italy, Switzerland and on a small scale in many Europe countries. USA is the major producer of peppermint and spearmint. The total area under mint cultivation, which is mostly confined to Uttar Pradesh and the Punjab is around 10,000 ha.

Mentha arvensis (English - Field Mint, Corn Mint; Indian name – Podina) is an erect branched herb up to about 60 cm high. Leaves up to 5 cm long; leafstalk small or none, margins toothed. Flowers small, lilac, in small bunches, borne on axils of leaves. This herb occurs in Kashmir at an altitude of about 1,500-3,000 m; it is also cultivated. Infusion of its leaves is usedin rheumatic pains andindigestion.

A Japanese variety of this plant (named *M. arvensis*) has been cultivated in Jammu and Kashmir. This yields oil; its trade name is Japanese Mint Oil or Japanese Peppermint Oil. It is used as a substitute for true Peppermint Oil (obtained from *M. Piperita*).

Mentha longifolia (English – Horsemint, Hindi – Jangli Podina, Punjabi – Koshu) is a larger herb and occurs in Kashmir and northern parts of Punjab and Uttar Pradesh. This plant is considered antiseptic, stimulant, and useful in digestive complaints and fever.

Economic importance

The dried leaves and flowering tops of the plant constitute the drug Peppermint. The drug is used in treatment of flatulence, vomiting, diarrhea and nausea. Bruised leaves are applied in headache and other pains.

The main use of this drug is for extraction of Peppermint Oil (which contains Menthol) and is largely used in medicine for stomach disorders, in ointments for headaches, rheumatic and other pains and in cough drops, inhalations, mouth washes, etc. The oil is also antiseptic.

Spent Grass:

The material left after distillation of oil is called spent grass. It can be used for mulching or as manure in Citronella fields. It can also be used for making paper and paperboards.

Chemical Composition and Uses:

(i) Japanese mint (*M.arvensis*)

Japanese mint is a primary source of menthol. The fresh leaves contain .4-6.0% oil. The main constituents of the oil are menthol (65-75%), menthone (7-10%) and menthyl acetate (12-15%) and terpenes (pipene, limonene and comphene).

(ii) Peppermint (*M.piperita*)

Peppermint is a hybrid mint, a cross between watermint and spearmint. The fresh herb contains essential oils ranging from 0.4 to 0.6%. The constituents of peppermint oil are almost similar to Japanese mint oil. However, the menthol content is lower in peppermint oil and varies between 35-50%. The other constituents are menthyl acetate (14-15%), menthone (9-25%) menthoufuran and terpenes like pinene and limonene.

(iii) Bergamot mint(*M.citrate*)

Linalool and linalyl acetate are the main constituents of Bergamot mint oil. The oil is used directly in perfumes. Cosmetic preparations like scents, soaps, after-shave lotions and colognes also contain this oil.

(iv) Spearmint (*M.spicata*)

The principal constituent of spearmint oil is carvone (57.71%) and the other minor constituents are phellandrene, limonene, L-pinene and cinelole. The oil is used mostly as a flavouring in toothpastes and as food flavouring in pickles and spices, chewing gum and confectionery, soaps and sauces.

Important constituents of oil:

Citronellal : 30 -35%
Geraniol : 12 -18%
Geranylacetate : 3 -8%

Soil requirements

Deep soils, loam to sandy loam well drained, well aerated and loose textured soil. Clay soils are not suitable. Well drained loamy soil high in organic matter content with pH 6.5 to 7.0 is suitable. Medium to fertile deep soil, rich in humus is ideal for the cultivation of mint. The soil should have a good water-holding capacity but water-logging should be avoided.

Climatic requirements

Sub-tropical areas receiving an annual rainfall of 100 - 150 cm are good. Temperate climatic condition, Tropical climate is not suitable, plentiful rainfall during growth and good sunshine during harvest is best suitable during crop growth. Japanese mint can be grown in all tropical and subtropical areas under irrigation. However, it does not tolerate damp winters which cause root-rot. A temperature of 20-25^{o} C promotes vegetative growth, but the essential oil and menthol are reported to increase at a higher temperature of 30^{o} C under Indian conditions. Peppermint and spearmint cannot be grown profitably in tropical and sun tropical areas, especially those areas with very high summer temperatures (41^{o} C) and the ideal yield is obtained only in humid and temperate conditions like in Kashmir and the hills of Uttar Pradesh and Himachal Pradesh. Open, sunny situations without excessive rains during the growing period are congenial for the good growth and development of the oil. Bergamot mint can be grown both in temperate as well as subtropical area. However, the yield is higher in temperateclimates.

In low temperature areas, the plants become dormant in November. In order to give a perennial crop (of 3 years only) in peppermint, recultivation is done either in autumn (November-December) or in spring (March-April). When peppermint is grown as a perennial crop, the first year crop is called 'Row mint', while the second and third year crop is called 'Meadow mint'. This practice is not followed in other mints which are to be planted everyyear.

Varieties:

A) Japanesemint

Himalaya: It is a selection released by the CIMAP Lucknow which contains 0.8 to 1.0% oil (FWB) with 81% menthol content and a low congealing point.

Kalka : It is a tall, vigorous variety evolved by the CIMAP Lucknow.

Shivalik: It was introduced from China and released by the CIMAP,Lucknow.

EC 41911: This is a progeny selection of an interspecific cross between *M. arvensis* & *M. piperita*.

B) Peppermint

Kukrail: This is a high yielding variety developed and released by the CIMAP Lucknow.

C) Spearmint

MSS 1: This is a selection from the spearmint cultivars introduced from USA. This variety was released by the CIMAP, Lucknow.

MESS 5: It is a selection from MSS 1 made at the CIMAP, Lucknow.

Punjab Spearmint 1: This variety is a clonal selection made at the CIMAP, Lucknow .

Arka and Neera are the recently released varieties from CIMAP, Lucknow.

Cultural practices

(i) Land preparation: Mints require thoroughly ploughed, harrowed, fine soil. All the stubble of weeds should be removed before the crop is planted. Manuring may be done at the time of land preparation by adding FYM @ 25 to 30 t/ha. Green manuring may also be done before the mint is planted. Sun-hemp (*Crotalaria juncea* L.) is an ideal green manure crop. Mints are planted on flat land or ridges. Hence, flat beds of convenient sizes or ridges are made according to the spacing recommended. Bring the soil to fine tilth by ploughing and 2 crossharrowings.

(ii) Time of sowing: Jan, Feb in Tarai areas or before the start of rainy season.In the plains, planting is done during the winter months, whereas in temperate climates, planting is done in autumn or spring from the last week of December to the first week of March or from the first week of January to the third week of February. Late planting always gives pooryields.

(iii) Method of sowing: It can be propagated through root suckers and terminal cuttings. Terminal cuttings are highly capable for rooting. The root suckers from the previous crop can be used forpropagation.

(iv) Spacing: Rooted stem cuttings should be spaced 30 cm apart in rows 60 cm apart. during June -July.

(v)Seed rate: Approximately 400 kg suckers/stolonsare required to plant one ha area. Suckers should be set in furrows. Plant the suckers end to end.Plants

Propagation

Mints are propagated through the creeping stolons or suckers. In the case of peppermint and bergamot mint, even runners are planted. Stolen are obtained from the previous year's planting. A hectare of well-established mint, on an average, provides enough planting material for ten hectares. The best time for obtaining stolons is during the months of December and Januaryp planting.

The stolons are cut into small pieces (7-10 cm) and planted in shallow furrows about 7-10 cm deep with a row-to-row distance of 45-60 cm, manually or mechanically. While planting on ridges, the stolons are planted half-way down on the inner sides of the ridges. The plot is irrigated immediately after planting.

(vi) **Manures and fertilizers:** Apply NPK 50:75:50 kg/ha as basal. At four months after planting, N 25 kg/ha is applied. FYM 10 t per hectare while preparing the land. Mint responds very well to a heavy application of nitrogenous fertilizers. The increase inherbage by the application of phosphorus is not as remarkable as in case of nitrogen. Generally, nitrogenous fertilizers @ 80-120 kg P and K at 50 kg P_2O_5 and 40 kg K_2O/ha is required for a good crop of mint. However, in *M. arvensia* an increase of up to 160 kg N/ha and, in *M. piperate*, 125 kg N/ha has given increased fresh herbage and essential oil-yield. An amount of 100-120 kg N/ha is recommended for producing the optimum herb and oil-yield in*M.*

citrata under Pantnagar conditions. A split application of 75 kg N/ha in combination with P at 60 kg P2O5/ ha is recommended under Kodaikanal conditions. Potassium application has no significant effect on herb and oil-yield. In *M. spicata*, the maximum herb-yield is obtained with the application of 100-120 kg N/ha. Nitrogen may be applied in three split doses at 1, ½-2 and 3 months after planting and the third dose after the first harvest of the crop. Boron deficiency reduces both the yield of green herb and the essential oil in peppermint. Increased yields of herb, menthol content and essential oil content in peppermint have been obtained by using a combination of boron and zinc fertilizers. Similarly, experiments conducted at the CIMAP, Lucknow, have shown that the application of 20 kg/ha of Sulphur had increased the herb and oil-yield in *M. spicata*. Among the different sources of S, calcium sulphate was best followed by ammonium sulphate and elemental sulphur.

(vii) Irrigation: Irrigation is given twice in a week. Mentha crop requires considerable moisture well distributed throughout the entire growing season. As roots do not penetrate deep in the soil, light and frequent irrigations are recommended. During summer irrigate the crop weekly.

(viii) Interculturing and weeding:

Uninterrupted weed growth causes about 60% reduction in herb and oil-yields. Hence, mints require weeding and hoeing at regular intervals in the early stages of crop growth. One hand-weeding is required after the first harvest. Combining organic mulch with a combination of 0.5 kg/ha of Oxyfluorfen herbicide and weeding or application of Pendimethalin herbicide @ 1 kg/ha and weeding are found to give excellent weed control throughout the crop growth.

(ix) Diseases: Verticillium wilt, mint rust, mintanthracnose

(x) Pests: Spider mites, flea beetles, root borers, cutworms and rootweevils

(xi) Harvesting: First cutting starts in about 5 months after planting and subsequently at 3 months interval. Under good management conditions, the crop will give economic yield for about fouryears.

Japanese mintis generally harvested after 100-120 days of planting, when the lower leaves start turning yellow. If the harvesting is delayed the leaves start falling, resulting in loss of oil. Further, harvesting should be done in bright sunny weather. Harvesting consists of cutting the green herb by means of a sickle 2-3 cm above the ground. A second harvest is obtained about 80 days after the first harvest and the third one after about 80 days from the second harvest. Whereas, in peppermint, spearmint and bergamot mints which are grown in temperate climates, the first crop is ready by the end of June and the second in September orOctober.

Packing of oil: Citronella oil must be packed in air tight containers of glass, tin or aluminum.

Distillation of oil :

Mint oil is obtained by distilling either the fresh or the dry herb. The distillation is done both in primitive and modern stills; in the former the principle of water and steam distillation is followed. While in the later steam generated in a separate boiler is employed. The stems are removed from the dried material prior to distillation, because they constitute 30 to 50% of the

material and contain only traces of the oil. The average yield of oil is 50-70 kg/ha. Although bergamot mint as well as Japanse mint give an average yield of 70-100 kg/ha, the yield of peppermint oil is lower
with an average of 50 kg/ha.

Storage of oil :

Containers are stored in a cool place away from light. Oil changes its colour from yellow to green if exposed to light. Mint oil is a light and golden-coloured, motile liquid and it should be completely free from moisture before storage. It is stored in large steel, galvanized steel or aluminium containers, filled up to the brim to protect against any air remaining inside and placed in a cool storage godown, away from light and humidity.

Research station:: National: CIMAP, Lucknow, **State:** Anand

Yield

Approximately 150 kg of oil per hectare during the first year and subsequently 200 - 250 kg per hectare can be obtained under good management. An average of about 24 - 30 t of herbage can be obtained from a hectare.

A good crop of Japanese mint can give as high a yield as 48 t/ha of fresh herb. However, the average yield of mints from three cuttings is 20-25 t/ha. The fresh herb contains 0.4% oil.

Lemon Grass (Malabar or Cochin grass)

Botanical name: Three types of lemon grasses *viz.* East Indian lemongrass (*Cymbopogon flexuosus),* West Indian lemon grass *(C. citrates),* and Jammu lemongrass *(C. pendulus)* are in cultivation in our country as the important sources of citrates. In North India, Jammu lemon grass (*C. pendulus*) is cultivated under irrigated condition as a source of citral.

Family: Poaceae

Origin : South Asia

Geographical distribution

C. flexuosus is grown commercially in Kerala and nearby adjacent state, its oil is popularly known as "Cochin oil" as it is shipped mainly through Cochin port. India is annually producing nearly 1000 MT per year while the world demand is much more. Annually, we are exporting lemon grass oil in a tube of about Rs.5 crores. Our country is facing a critical competition from Gautemala in the Internationalmarket.

Economic importance

The oil is distilled from leaves and flowering tops of lemon grass. The oil has stronglemon like odour, due to high percentage (over 75 %) of citral in theoil.

1. The chief constituent of the oil is the citral. It is the starting material for the preparation of important ionone *viz.* A - Ionone, used in flavors, cosmetics and perfume and P - Ionone- used in the manufacture of synthetic vitaminA.
2. The characteristic smell of oil makes its use in scenting soaps, detergents, insectrepellents.
3. The major use of oil as a source of citral which goes in perfumery, cosmetics,beverages.
4. Oil has bactericidal, insect repellent and medicinaluses.
5. The spent grass *is* a source of good cattle feed and can be converted into goodsilage.
6. Spent grasses are also useful for the manufacture of card boards and papers or asfuel.
7. Distillation waste of this crop is applied as organic mulch @3 t/ha and this is found effective in controlling weeds in thecrop.

Soil requirements

Regarding the soil, it can be grown from poor soils, in the hill slopes. Soil pH ranging from 4.5 to 7.5 is ideal. As it has good soil binding nature, they can be grown as vegetative cover over naked, eroded slopes. Lemongrass is widely adapted to a range of soils and performs well on sandy to clay loam soils with a pH range of 5.0 to 8.4 and good drainage. The lower the altitude and more alkaline the soil has, the higher is the citral content of the oil. The variety with high citrates is in demand. Drier and loamier soil yields a higher citral content. Lemongrass can

be an option for consideration in poor soils, alkaline soils, steep slopes, and degraded forests and rehabilitation of non-forest mining and industrial wastelands.

Climatic requirements

The plants are hardy and grow under a variety of conditions. The most ideal conditions are a warm and humid climate with, plenty of sunshine and rainfall of 250-280 cm per annum, uniformly distributed. Lemongrass prefers tropical or subtropical climates. It grows well at a temperature range of 10 to 33 °c, and it needs enough sunshine for the development of oil in the plant. The grass is sensitive to cold weather and cannot withstand frost.

Varieties

The Medicinal and Aromatic Plants Research Station, Odakkali (Kerala) and CIMAP, Lucknow have developed improved strains *viz.* OD 19 and SD 68 respectively as a result of breeding. The important features of these varieties are given below:

Name	Yield of herbage (t/ha/year)	Oil yield (kg/ha/year)	Oil recovery per cent ondry weight	Citral content (%)
OD 19 (Sugandhi)	50-55	80-85	1.2 to 1.5	80-85
SD 68	50-55	80-85	1.2 to 1.5	80-85

These two improved varieties are now recommended for wide cultivation. Recently the RRI, Jammu has developed hybrid strain CKP 25 by crossing *C. khasianus* and *C. pendulus* which is capable of yielding 50 % and 140 % more oil yield than RRL-16 and OD 19 respectively.

Other varieties: Pragati, Praman, Jama Rosa, RRL 16 , CKP 25, OD 408 and Kaveri

Cultural practices

(i) Landpreparation:

Nursery: The soil should be well pulverized for forming the seed bed and it should be a raised bed one. Leaf mould and farm yard manure are also added to the soil while forming the bed. 15-20 kg of seeds are required for raising seedlings for one hectare. Seeds are sown in lines drawn at 10 cm interval on the beds and -covered with cut grass materials when the seedlings are about 2 months old or, about 12 to 15 cm high, they are ready for transplanting.

Field preparations: The land is cleared of the underground vegetations and pits of 5 cm cube are made at a spacing of 15 x 19 cm. Splits from old clumps can also be used for propagations.

(ii) Time of sowing: The favorable time for planting of this crop is the onset of rains, in sub-tropical climates with assured irrigation. Planting can also be done in the month of Jan to March andJune-July.

(iii) Method of sowing:

- It can be propagated by seeds as well as vegetatively by slips. For better qualityand yield of oil it is recommended to be grown only by slips obtained by dividing well grown up clumps

- Planting is done in the last week of May or in the first week ofJune
- However, under irrigated conditions planting can be done during any part of theyear, except October-November months
- Before planting, the field is thoroughly prepared and laid out into 6 m x 6 m sizebeds. The soil is incorporated with full dose of phosphorus and potash
- Ridges are opened at 60 cm distance. Slips are prepared by clipping all the oldroots and removing the leaves completely for planting.
- They are then planted at about half way down the slopes of the ridges at a spacing of 60 cm x 60cm.

(iv) Spacing: A spacing of 50 x 50 cm isadopted.

(v) Seed rate: 2.5 kg/ha (For seedling preparation), about 55000slips/ha

(vi) Manures and fertilizers: Nitrogen is applied in six equal split doses, the first dose, being at the time of planting, another after one month and the remaining after every harvest. The Aromatic Plants Research Station, Odakkali (Kerala) recommended 100 kg of N/ha. Under North East conditions, application of 60 kg N, 50 kg P and 35 kg K is recommended perhectare.

(vii) Irrigation : The crop responds to irrigation especially during hot summer months. In northern India, 4-6 irrigations are given during summer months. After the establishment of plants, irrigation schedule is adjusted depending on water holding capacity of the soil and weatherconditions.

(viii) Interculturing and weeding : The field is kept weed free for the first 3-4 months after planting. Similarly weeding cum hoeing is done up to one month, after every harvest. Generally 2-3 weedings are necessary during a year. Among herbicides, Diuron @1.5kg /ha and Oxyfluorfan @0.5 kg/ha are effective.

(ix) Diseases: Red leaf spot, Leaf blight, Little leaf or grassyshoot

(x) Pests: Stem boring caterpillar,Nematodes

(xi) Harvesting: Lemon grass comes to harvest 90 days after planting and subsequently it is harvested at 50-55 days interval.. The grass is cut 10 cm above the ground level and 5-6 cuttings can be taken in a year subject to the climatic conditions. Depending upon the soil and climatic conditions, the crop can be retained in like field for 5 to 6years.

The grass is allowed to wilt for 24 hours before distillation as it reduces the moisture content by 30 %. The oil is obtained through steam distillation.

Research Station: Central Institute of Medicinal and Aromatic Plants, Lucknow

Yield : On an average 25 kg of oil can be obtained from first year per hectare plantation and about 80 to 100 kg of oil per year from 2nd to 6th year if wellmaintained.

ISABGOL

Botanical Name :*Plantago ovata Forsk*
Family: Plantaginaceae
Origin : Specially southern Europe, North Africa, and West Pakistan.

Geographical distribution

lsabgol is an important medicinal plant. India is the largest producer and exporter of this crop in the world. At present lsabgul crop has acquired the place of "dollar-earner of North Gujarat". It comprises about 800 species of which 10-14 are natives of India. Amongst them, 3 are important. They are *Plantago ovata*, *P. indica* and *P. psyllium*. It is mainly cultivated in Mehsana and Banaskantha districts of North Gujarat. To a limited extent this crop is also cultivated in the adjoining districts of Harayana andRajasthan.

In Gujarat, during 1915-16 the crop was cultivated in about 9100 hectares area with total annual production of about 10920 tonnes.

Economic importance

Husk (30 %) of the seed is the economic part, lali ,gola, oil(5 %). It has acquired the place of the ‘dollar earner’ crop of the Gujarat.

1. It is used to cure in genitor-urinarytracts.
2. The seeds and husks are used to cure in inflammation condition of themucus membranes of gastro-intestinaltracts.
3. In addition to medicinal uses, it is also used in dyeing,calicoprinting,in the ice-cream industry asastabilizer.
4. It is also used in confectionery and cosmeticindustries.
5. The seed without the husk is used as cattlefeed.

Soil requirements

The crop grown in marginal light, well-drained sandy-loam to loamy soils having pH between 7 and 8. To get more yields the soil should have NPK in enough amount.

Climatic requirements

It requires a cool climate and dry sunny weather during maturation, even a mild dew, cloudy weather or light or light showers cause seed shadding.

Temperature 20-25^{o}C is required for seed germination, whereas at time, maturing it requires 30-35^{o}C temperature.

Varieties: Gujarat lsabgul 1, Gujarat Isabgul 2, Gujarat Isabgul 3, Gujarat Isabgul 4, Trombay selections (1-10) and EC -124 345 are the recognizedvarieties.

Cultural practices

(i) Land preparation: Field must be free of weeds, clods and should have fine tilth for good germination. The number of ploughing, harrowing and hoeing depends upon the soil conditions, previous crop and degree of weed infestation. The field should be divided into suitable plots of convenient size, depending on the texture of the soil, the slope of the field and the source and quantum of irrigation water. For light soil with even contour, plot size of 8.0 m x 3.0 m will beconvenient.

(ii) Time of sowing: The seeds are sown from mid-November to mid-December. The seeds are small and light. Hence, before sowing, the seed is mixed with sufficient quantity of fine sand or sieved farmyard manure. Early sowing crop may be affected by downy mildew whereas, late sowing crop may be damaged by unseasonalrain.

The farmers of North Gujarat Agro-climatic Zone are recommended to grow the isabgol crop on 2^{nd} or 3^{rd} week of November.

(iii) Method of sowing: Broadcasting anddrilling

(iv) Spacing: 30 cm apart if sown in rows.

(v) Seed rate: 4kg/hectare

(vi) Seed treatment: For controlling downeymildew,seeds should be treated with metalexil35 SD@ 4g/kgseed

(vii) Manures and fertilizers: Isabgol makes a moderate demand for nutrients, usually 30 kg N and 15 kgP_2O_5/ha is given at planting and another 15 kg of N is applied with the third irrigation.

Apart from these fertilizers, it is advisable to apply 8-10 tonnes FYM or compost.

The farmers of North Gujarat Agro-climatic Zone are recommended to apply 150 % RDN (30 kg /ha) + 30 kg P_2O_5/ha as basal and remaining nitrogen (30 kg/ha) should be applied at 30 and 50 DAS in equal splits.

(viii) Irrigations: Light irrigation should be given just after sowing. Five to seven irrigations at an interval of two weeks from November to March are required under Indian conditions. Last irrigation should be given at the time when maximum number of spikes has reached the milkstage.

(ix) Interculturing and weeding : After 20-25 days of sowing, first weeding is done. Ordinarily only 2-3 weedings are required within 2 months of sowing. If the crop issown broadcast, hand weeding becomes very costlyoperation.

In north Gujarat agro climatic zone, in isabgol, two interculturings should be carried out followed by hand weedings at 25 and 40 DAS for obtaining higher yield and net return.

(x) Diseases: Downy mildew

(xi) Pests: Aphids

(xii) Harvesting: The plant bears the flowering spikes in about 60 days after sowing and matures in the next 2 months. The yellowing of the lower leaves is anindication of

maturity, that can be confirmed by pressing a spike between 2 fingers when the mature seeds come out. The crop is harvested to close to the ground in the early morning hours to avoid losses owing to seed shadding. The harvested material is stacked for 1 or 2 days, made to be trampled by bullocks, winnowed and separated seed is collected.

Crop rotation:

In Gujarat, pearlmillet in *kharif* and isabgol in *rabi* season are advocated as a suitable crop rotation. Groundnut-isabgol rotation gave higher economic return followed by soybean-isabgol and pigeonpea-isabgol rotations in Maharashtra.

Research Station: Directorate of Medicinal Aromatic Plants Research (ICAR-DMAPR), Boriavi

Yield : The average yield is 10 quintal/ha. A bold seeded crop fetches a better price.

CITRONELLA

Botanical Name :. *Cymbopogon winterianus*
Family: Gramineae
Origin : South East Asia

Geographical distribution

It is native to tropical areas of Asia. It is commercially grown in Indonesia, Java, Burma, India and Sri Lanka. This crop is a recent introduction into India and its cultivation is mainly done in the lower hills of Assam, in Karanataka and southern Gujarat, covers about 2,000 hectares ofarea.

Economic importance

Citronella oil is one of the essential oils obtained from the leaves and stems of different species of *Cymbopogon* (lemongrass). The main constituents of Citronella oil are Citronellol (65%), Citronellal (12-49%) and Geraniol (14-24%). The oil is used extensively in soap, candles, perfumes and other cosmetic properties. Citronella oil is perhaps most famed for its insect repellent properties. It has anti-bacterial, anti-microbial, anti-inflammatory, and anti-fungal features.Citronella oil is a raw material for isolation of above perfumery compounds.

Soilrequirements

Citronella can be cultivated in light loam soils, rich in organic matter and well-drained soils. It thrives best in humid tropical areas with moderately warm temperature and well distributedrainfall.

Climatic requirements

Humid climate with warm temperature with well distributed rainfall favours growth of Citronella.

Varieties: Bio 13, Manjusha, Mandakini.

Cultural practices:

(i) Land preparation: Plough 3-4 times. Land is laid out into ridges & furrows spaced at 60cm.

(ii) Time of sowing: June-July

(iii) Method of sowing: By planting each slip at recommendedspacing

(iv) Spacing: The planting distance of 60 cm x 90 cm can beadopted.

(v) Seed rate:28000 slips can be required for one ha ofplanting.

(vi) Manures and fertilizers: The crop requires FYM 10 t/ha and NPK at 25:40:40kg/ha as basal dose. 75 kg N/ha can be applied in 3 equal splits of 25 kg each at 3, 6 and 9 months afterplanting.

(vii) Irrigation: For healthy crop growth it should be irrigated frequently. This crop uses large amount of water. Irrigation interval of 15 days in winter and 10 days in summer is required for goodyield.

(viii) Interculturing and weeding : One to two weeding at the initial stages and earthing up after each harvest arerequired.

(ix) Diseases: Leafblight

(x) Pests: Red spider mite, whitefly

(xi) Harvesting: First harvest can be made in 4-6 months after planting then after 3-4 months.

Research Station: Central Institute of Medicinal and Aromatic Plants, Lucknow

Yield : The herbage yield is about 20 - 30 t/ha/year. Oil is extracted by water distillation. The oil content ranges from 0.2% to 0.3%.

Oil yield:

Firstyear : 50 - 100 kg/ha
Second year: 100 - 150 kg/ha
Fifthyear : 250 - 300kg/ha

Distillation: Oil can be obtained by steam distillation from dried grass for 12-24 hours. Average recovery of citronella oil is 1%. Yield is about 150-200 kg per hector. 16-20 tonnes of fresh herbage on distillation it gives 100-150 kg of oil. The Indian market rate of citronella oil is Rs. 250-300 per kg.

Forage Crops

Importance of forage crops

India is basically an agricultural country and about 70 per cent of its people live in villages. Their livelihood is dependent mainly on agriculture and animal husbandry. Though India has a huge livestock population of over 582 million, besides poultry, production of milk and other livestock products are the lowest compared to the production in theworld

There is a huge gap between demand and supply of all kinds of feeds and fodders. On the other hand, the average cultivated area devoted to fodder production is only 4.4 per cent of the total area. Similarly, the area under permanent pastures and cultivable wastelands is approximately 13 and 15 million hectares respectively. Likewise, the total area under forests is

crore hectares and that open to grazing is 2.1 crorehectares. All these resources are able to meet the forage requirements of the grazing animals only during the monsoon season. But for the remaining periods of the year, the animals have to be maintained on the cropresidues or straws of jowar, bajra, ragi, wheat, barley, sugarcane trash etc. either in the form of whole straw or *bhusa*, supplemented with some green fodder, or as solefeed.

OAT

Botanical Name: *Avena sativa L.*
Origin:Asia
Family: Poaceae (alt. Gramineae)

Geographical distribution

Oat is a crop of Mediterranean origin, the domestication dates back to ancient times. Oat seeds are reportedly found in 4000 year old remains in Egypt. The genus Avena comprises of about seventy species, a few are cultivated. *A. sativa* and *A. byzantina* are the main oats grown for fodder and grain. Oat is presently grown in temperate parts of the world including USA, Canada, Europe as spring-sown cultivars. In the tropical countries and higher altitude region it is grown as a winter annual. World oat production is generally concentrated between latitudes 35–65oN and 20–46o S. Oat is the most important cereal fodder crop grown in winter in north western, central India and is now extending to the eastern region. Oat ranks sixth in world cereal production following wheat, maize, rice, barley and sorghum. It is important winter forage in many parts of the world and is grown as multipurpose crop for grain, pasture, forage or as a rotation crop. Oat requires a long and cool season for its growth, therefore, it is successfully grown in the plains and hilly areas of the country. In India it is grown in Punjab, Haryana, Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh, Madhya Pradesh, Rajasthan, Maharashtra, West BengalandGujarat.Thetotalareacoveredunderoatcultivationinthecountryisabout500000

ha. The crop occupies maximum area in Uttar Pradesh (34%), followed by Punjab (20%), Bihar (16%), Haryana (9%) and Madhya Pradesh (6%).

Economic importance

It is most important cereal fodder crop grown in winter season. It is quick growing, palatable, succulent and nutritive crop and forms an excellent combination when fed along with other cold season legume/s to the animals. Oat is used as a green fodder, straw, hay or silage.Green fodder contains about 10-12% protein. Oats are consumed as human food and fodder for cattle. They have a high fat, protein and mineral content. It has excellent growth habit, quick recovery after cutting and good quality herbage. It is a palatable, succulent and nutritious crop. The protein quality of oat is excellent.

Soil requirements

Oat can be grown on all types of soils. It can tolerate slight acid or saline conditions, but cannot do well on alkaline and water logged ones. Sandy loam, medium black well-drained soils are most suited for this crop.

Climatic requirements

Cool and moist weather is most suited to the oats for better growth and development of the plants. Frost and severe cold conditions retards its growth, whereas, hot and dry weather conditions hasten its maturity resulting in poor and inferior quality of fodder.

Varieties: Kent 24, Kent 37, Palampur1, Afferlee, Green Mountain, IGFRI-S 3021, Jawahar Oat 03-91

Cultural practices

(i) Land preparation: Two to three ploughing followed by harrowing and planking are sufficient to get friable and well levelledseedbeds.

(ii) Time of sowing: For one or two cuts of forage - sowing should be done on 15thNovember**.**

For continuous green forage production - sowing should be done at every 15 days interval start from the month of October and continued up to the month of December or different varieties vary in maturity period may also be grown on separate field.

(iii) Method of Sowing: Broadcasted for fodder. If sown for grains, the sowing ofseed should preferably be done in line with seeddrill.

(iv) Spacing:25 to 30 cm between row torow

(v) Seed rate:100kg/ha

(vi) Seed treatment: Seeds should be treated with fungicides like captan or thiram @ 3.0 g per kg of seed for controlling soil bornediseases

(vii) Manures and fertilizers: Well decomposed FYM @ 10-15t/ha should be applied at the time of land preparation. The chemical fertilizer dose is asunder.

For one cut method

N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Remarks
40	30	0	As basal application
40	-	-	At 30 DAS
80	30	0	

For two cut method

N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Remarks
40	30	0	As basal application
20	-	-	At 30 DAS
60	-	-	After first cut
120	30	0	

Oat crop should not be fertilized with more fertilizer than the recommended dose. If nitrogen content in oat plants is more than 0.15 to 0.20%, such hay or fodder should not be fed to the animals. In heavy fertilized oats with nitrogenous fertilizers, lot of nitrates may accumulate in hay. If such hay is moistened for 8 to 10 days and then exposed to air, nitrates are reduced to nitrites. Such hay when fed to the animals converts the hemoglobin of the blood into methaemoglobin, which cannot act as an oxygen carrier. In serious cases, the animals may die. Generally, the green oats do not accumulate high enough nitrate levels as to be toxic to the animals by conversion to nitrates in the alimentary canal.

In middle Gujarat, oat (Kent) for seed purpose should be applied N @ 75 kg/ha (50 % N at the time of sowing and remaining 50 % N in two equal splits at 30 and 60 days after sowing in equal splits) for getting higher seed yield and net realization.

In north Gujarat Agro-climatic Zone, forage oat crop should be fertilized with140 kg N /ha with two splits *i.e.,* 50 % N as basal + 50 % N after first cut and 60 kg P_2O_5/ha as basal for obtaining higher green and dry fodder yield as well as netreturn.

(viii) Irrigations: Irrigation should be given to the oat crop when there is 50% available moisture in the soils and interval between two irrigations should be kept at 12 to 15 days. In one cut method, five to six irrigations are required, whereas, in two cut method, 2 more irrigations areneeded.

In middle Gujarat, oat (Kent) for seed purpose should be applied six irrigations (each of 50 mm) i.e. first five irrigations at 15-20 days interval and 6th irrigation at 13-15 days interval after fifth irrigation.

(ix) Interculturing and weeding : Normally, there is no need of interculturing or weeding operations in this crop as the crop is grown very thick and plants have tillering habit, the growth of weed plants may suppressed. However, one interculturing and weeding should be done at 3 to 4 weeks aftersowing.

(x) Diseases: Sclarotial wilt, Leaf blotch, crown rust and stemrust

(xi) Pests: Stem borer, aphids, cyst nematodes andtermites

(xii) Harvesting:

1) In a one cut management method, the harvesting should be done at 70-80 days after sowing (at 50%flowering).
2) In a two cut management method, the first cut should be taken at 50 days after sowing and second cut should be taken at 50%flowering.

If crop is not harvested at 50% flowering i.e. if harvesting is delayed, the crude protein content decreased, whereas, dry matter, fiber, neutral detergent fiber etc may increase which lower the fodderquality.

In middle Gujarat oats (JHO 822) if grown as dual purpose, the first cut should be harvested at 60 days after sowing for green forage and leave it for grain production to get quality forage with higher grain yield and netreturn.

Research Station:: National: IGFRI, Jhansi, **State:** Anand (Main), Dhari (Sub)

Yield :

1) One cut management method - 400 to 500 Quintal greenfodder/ha.
2) Two cut management method - 500 to 600 Quintal greenfodder/ha.

LUCERNE (ALFALFA)

Botanical name:*Medicago sativa* L.
Family: Fabaceae (alt. Leguminosae)
Origin:South West Asia

Lucerne is commonly called as *rijka* in northern India. It is a perennial plant and can supply green fodder continuously for 3–4 years from the same crop stand. The root system is deep and so can be easily grown in the areas where water is in short supply. Lucerne hashigh palatability for all kinds of livestock as it provides nutritious fodder and possesses about 16-25% crude protein and 20–30%fiber.

Geographical distribution

Lucerne or alfalfa is one of the oldest cultivated fodder crops. Roman writers described its value as feeds for horses and other animals as early as 490 BC. Alfalfa is derived primarily from *M. coerulea*, a diploid 2n=16 that grows wild in grasslands of south west Iran, Caucasan region and eastern Anatolia. Tetraploids are usually more vigorous than diploids. Lucerne is a native to south west Asia as indicated by occurrence of wild types in the Cancasus and in mountainous region of Afghanistan, Iran. The cultivated forms probably arose in western Persia and then spread to become widely cultivated throughout Asia, Europe and America and widely distributed in temperate regions. The genus contains large number of species. In India other than *M. sativa*, the entire groups of Medics are treated as wild types. The existing *M. sativa* is largely a tetraploid species (2n=4x=32). However, diploids and hexaploids are also found in nature. Due to its high protein and vitamin A content, it is included as a feed component for poultry and piggery. Lucerne provides green fodder for a longer period (November-June) in northern parts and throughout the year in other parts of the country where winters are not severe. In India, Lucerne occupies one million hectare area and provides 60 to 130 tonnes of green forage/ha. It is grown as a farm crop in Punjab (13,554 acres), western districts of UP, Maharashtra (18400 acres), Gujarat (19,900 acres), Tamil Nadu and WB. After sorghum and berseem, Lucerne is 3rd important forage crop in India. Alfalfa is a perennial species with indeterminate growth habit, profuse basally branched and erecttype.

It is mainly grown on a large area in USA, Canada, Argentina, Australia, New Zealand, France, Italy and USSR. The Lucerne crop in India is mostly grown as irrigated crop in the states of Punjab, Haryana, Uttar Pradesh, Gujarat, Maharashtra and Tamil Nadu.

Economic importance

Lucerne crop is one of the most important fodder crops of India called as "queen" among fodder of "green gold". Being a deep-rooted crop, Lucerne extracts water from the deeper zone of the soil. It can be grown both as annual as well as perennial crop. This crop may supply green fodder continuously for 3 to 4 years from the same field as perennial crop. It yields nutritive and palatable fodder, which contains about 15 to 20% crude protein with 72% digestibility (dry weight basis) and high amount of vitamins A, B, and D. Since, Lucerne is a rich feed; it should be used only in small quantities. When, it fed to animals in excess of green fodder Lucerne causes “bloat” in cattle. Therefore, start with a small quantity of green feed in the beginning and then gradually by increases the quantity. Feeding of Lucerne hay may replace use of grains and concentrates. Lucerne hay is particularly rich in protein, calcium and vitamins. Lucerne crop supplies green fodder for a longer period in comparison to Berseem. Lucerne being a leguminous crop, adds about 194 kg N/ha to thesoil.

Soil requirements

Lucerne prefers well-drained, fertile, sandy loam to medium black soils having pH value ranging from 7.5 to 8.0. It does not do well on very heavy and water logged soils. Acid soils affect root growth, so liming is required in such soils, while, it can tolerate saline soils.

Climatic requirements

Lucerne is very important leguminous fodder crop grown as an annual in hot humid region and as perennial in dry region. It is valuable forage crop of irrigated areas and it is persistent, productive as well as heat and drought resistant crop. Lucerne is well adapted to wide climatic variations. It thrives best under warm, dry and sunny conditions. If the high temperature is accompanied with high humidity, the crop suffers badly. Its plant can also withstand fairly low temperature.

Varieties:

Sr. No	Variety	Area of cultivation	Remarks
1	Sirsa 9 (T9)	Entire Gujarat	Long and narrow leaves
2	GAUL1 (Anand Lucerne 2)	Entire Gujarat	Pale yellow broader leaves, tall with fast growing habit, 20% higher yield than Sirsa – 9
3	GAUL 2 (SS 627)	North Gujarat	Tall plants with broader leaves, Moderately resistant against downy mildew, 710 to 728 q/ha green fodder yield
4	Anand Lucerne 3	Recommended for middle Gujarat	Perennial type variety.

Cultural practices

(i) **Land preparation:** After the harvest of *Kharif* crop, land should be prepared by one mould board ploughing followed by repeated "*Desi*” ploughings or one tractor ploughing followed by disc harrowing or by tractor cultivator. Stubbles of the previous crop should be removed and land should be levelled with the help of rake and madeinto

rectangular compartments for uniform irrigations and proper drainage. Land should be laid out into beds of the size 2.5 to 3.0 m in wide and 8.0 to 10.0 m in length according to the slope offield.

(ii) **Time of sowing:** 15th November (second week of November) is the most appropriate time of sowing. However, sowing can be done from 15th October to 15thNovember.

(iii) **Method of Sowing:** This crop should be sown by broadcasting or drilling method. Seed should be sown 1 to 1.5 cmdepth.

(iv) **Spacing:** Lucerne should be sown at 25 cm row spacing for easy interculturing operations. Perennial crop should be sown at 25 cm rowdistance.

(v) **Seed rate:** 1) For annual crop - 10 kgseeds/ha
2) For perennial crop - 15 kg seeds/ha

(vi) **Seed treatment:** Seed should be treated with ceresan or thiram and then it should be inoculated with suitable strain of *Rhizobium* culture (*Rhizobium meliloti*, 1.0 to 1.25 kg of culture/ha) before sowing for fast growth, easy germination and moreyields.

(vii) **Manures and fertilizers:** 15 to 20 t/ha well decomposed FYM should be mixed properly in the soil at the time of landpreparation.

N, kg/ha	P_2O_5,kg/ha	K_2O, kg/ha	Remarks
20	40	40	As basal application

In middle Gujarat soils with marginal Zn and deficient Fe status, lucerne (Anand 2) shuld be applied 25 kg $ZnSO_4$ and 50 kg $FeSO_4$ per ha every year besides application of 20:40:40 kg NPK/ha to obtain higher seed yield and net return.

(viii) **Irrigations:** The water requirement of lucerne is high. The hard seeds absorbed moisture very slowly and often fail to germinate uniformly. Thus, two light irrigations within a week after sowing are useful and subsequent irrigations up to February should be given at an interval of 10-12 days and in summer season, with an interval of 7 - 8 days. The water requirement of Lucerne is more and if the interval between two successive irrigations is prolonged, the green forage yield of lucerne will be decreased drastically.

(ix) **Interculturing and weeding:** Crop should be kept weed free by hand weeding operations. Weeding should be done after each cut. If the line sowing is done, the interculturing operations should be done either by hand or bullock drawn hoe. In case of infestation of dodder (*Cuscuta reflexa*Roxb.) parasite weed, dodder infested plants along with dodder should be uprooted and removed from the field and then burnt them. Application of pendimethalin @ 0.5 kg/ha in 500 l of water after 10 DAS effectively controls the dodder infestation in Lucerne crop. This method also checks other weeds and no residual effect of herbicide are obtained in greenfodder.

(x) **Diseases:** Downy mildew

(xi) **Pests:** Aphids,Jassids

(xii) **Harvesting:** The first cut should be taken at about 55 to 60 days (two months) after sowing. The subsequent forage cuts should be taken at an interval of 28-30days in

Rabi and 20 to 25 days during summer season. In all, five to seven cuttings are taken up to end of May. With irrigation facilities, two-three additional cuts are possible in drier area also. Harvesting of Lucerne is delayed, the crude protein content decreases, whereas, the crude fiber content increases. Light intensity is more important in dry matter accumulation than temperature, thus, cloudiness retards dry matter production. If Lucerne crop is sown at 15th October than totally 7 cuts are harvested up to the month of May. Cutting should be done by keeping 7.0 cm suitableheight.

Research Station:: National: Indian Grass land and Forage Research Institute, Jhansi

State::Maincentre:Anand **Sub centre:**Dhari

Yield : Green forage yields about 700-800 q/ha for seasonal crop and in case of perennial crop, 1000 to 1100 q/ha could be obtained.

Mixcropping:

In middle Gujarat, lucerne (GAUL 1) and *pandadiu* (Wild chicory local) should be grown as mix crops with 5 kg/ha seeds of each crop along with 30 kg N/ha as a basal and 15 kg N/ha after alternate cut to obtain higher green forage, dry matter, crude protein yield and net realization (A commonbasalapplicationof10tFYM/ha+50kgP_2O_5/hashouldalsobegiventothe crop).

Precautions:

Green forage of lucerne contains poisonous substances like Oestrogen, which is dangerous to cattle if fed pure Lucerne. To avoid this, green fodder should be fed by mixing it with cereals and pulse fodder crops at the proportion of 6:4.

B E R S E E M

Botanical Name:*Trifolium alexandrinum* L.
Family:Fabaceae (alt. Leguminosae)
Origin: Asia

Geographical distribution

Berseem or Egyptian clover is one of the most important winter forage legumes in India, Pakistan, Turkey, Egypt and Mediterranean region. A few of the 237 species of this large genus have actually been cultivated to date. Out of 3 subgenus, *Falcatula* is represented in Europe, *Lotoidea*in Europe, Mediterranean region, USSR, Greece, Spain, Romania,Central and Portugal and subgenus *Trifolium* in Europe, Portugal, Balkan Peninsula, Greece and Mediterranean region. The genus has wide range of variability for habit (i.e., annual, biennial and perennial), habitat (tropical, subtropical and temperate) and tolerance to biotic and abiotic stresses. The important perennial pasture clovers, *T. repens* (white clover), *T. hybridum* (alsike clover), *T. pratense* (red clover) and *T. ambiguum* (caucasian clover) are widely distributed in the temperate and sub-temperate regions of the world while the annual types such as *T. resupinatum* (Persian clover), *T. subterraneum* (sub-terranean clover) and *T. alexandrinum* (Egyptian clover or berseem) are commonly cultivated as winter annuals in the tropical and subtropical regions. In India berseem is the most important winter season legume cultivated in an area of around 2 million hectares. Most of the present day cultivars are derivative of ecotype Mescavi. These cultivars are multicut (4–8 cuts) in nature, providing fodder for a long duration(November to April), very high quantum of green fodder (85 t/ha) and better quality of fodder (20% crude protein), high digestibility (up to 65%) and palatability. The phenomenal success of Berseem in India is also due to its high nitrogen fixing ability resulting insubstantial improvement in soilfertility.

It is grown mainly in irrigated areas of Himachal Pradesh, Punjab, Haryana, Delhi, Rajasthan, Uttar Pradesh, Bihar and parts of Madhya Pradesh, Maharashtra, Assam, Orissa, West Bengal and Jammu & Kashmir.

Economic importance

Berseem also called Egyptian clover has been rightly called king of fodder crops due to the high yields of succulent, palatable and nutritious fodder that it provides over a long season from November to May in five to six cuts. Berseem is important winter forage. It has 20% crude protein and 70% dry matter digestibility. It appeared to behave as a most potent milk multiplier in the lactating buffaloes, Sahiwal cows and cross breed cattles as compared to other forage crops alone on in combination.

Excessive feeding of berseem in the young stage or when it is wet with dew in the morning causes bloat called timpanists. If animals are allowed to graze, the crop should first be sprayed with emulsion of linseed or mustard oil to prevent bloat. Berseem is considered as agood green manure crop and useful in reclaiming alkali-saline soils. It adds about 24 kg N/ha and improves physical condition of thesoil.

Soil requirements

Berseem can be grown on all types of soils except very light sandy soils. The crop grown best on well drained soils but does not do well on acid soils.

Climatic requirements

Berseem requires a dry and cool climate for its normal growth. It needs mild temperature for germination and establishment. The crop is not sown unless average daily temperature reaches 13-15 ºC. However, temperature more than this will hamper the germination. The crop growth is very fast at 18-21 ºC. Its growth is checked during (intensely) severed cold or frosty period. Frost period during winter makes the crop dormant and no regeneration is recorded. Similarly, when temperature goes around 32-35 ºC, re-growth after cutting (harvest) may not be possible. It can not withstand drought & frost. It can not be grown in deep and hemp and heavy rainfall areas. It can be grown successfully in areas where annual rainfall is up to 250 cm. Berseem cannot tolerate hotweather.

Varieties:Meskawi, IGFRIS 29-1, Chhindwara, BL1

Pusa Giant (1000 to 1500 q/ha green forage yield.)

Cultural practices:

(i) **Land preparation:**A fine well-pulverized and levelled seedbed is a must. To secure a good seedbed, one ploughing should be done with mould board plough followed by three to four harrowing and planking to break all soilclods.

(ii) **Time of sowing:**15th September to end ofNovember.

(iii) **Method of sowing:**There are two methods for sowing of berseem i.e., dry and wet bed. For satisfactory germination and good plant stand, wet method is better. Seed should be sown in beds of convenient size by broadcast method after flooding the beds with 5–6 cm deep water. Before sowing seeds, the water in the beds should be stirred thoroughly with the help of puddler or rake so as to break the clods and capillary to avoid leaching during successiveirrigations.

(iv) **Spacing:**20 to 30 cmspacing

(v) **Seed rate:**50 kg/ha (Bold seeded variety likePusaGaint)

25 to 30 kg/ha (Small seeded variety like Meskavi)

(vi) **Seed treatment:** For elimination of chicory weed (kasani), the seed should be poured in 1 per cent common salt. Floating chicory seed should be taken out and remaining seed of berseem should be sown. Before sowing seed should be treated with *Rhizobium*. For treating the seed, it should be first soaked into fresh water for about 8–12 hrs. For better sticking of culture with seed, the culture is prepared with jaggery. About 1.5 lit ofwater

is mixed with 150 g of jaggery and boiled. After cooling, 2.5 packet of berseem culture is mixed with it and then seed is well mixed and dried in a cool shadyplace.

(vii) Manures and fertilizers:20-25t FYM/ha should be applied at the time of land preparation.

N(kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Remarks
20	80	40	Basal application

(viii) Irrigation: The crop requires 16 to 18 irrigations. Irrigation should be provided immediately after seedlings emerge and subsequent two or three irrigations should be given at weekly intervals. Normally, the crop should be provided with irrigation after eachcutting.

(ix) Interculturing and weeding : Menace of weeds in berseem can be curbed effectively with the adoption of preventive methods. Deep summer ploughing with soil inversion plough after harvest of the crop is very effective way to reduce the weed count. Pre-emergence application of pendimethalin at 0.3 kg a.i/ ha + imazethapyr at 0.1 kg a.i/ ha (after the first and second cut) was found effective to control weeds in berseem. Pre-emergence application of oxyflourfen0.10 kg/hafollowed by post-emergenceapplication ofimazethapyr 0.10 kg/haimmediate after harvest of first cutis effective for controlling weeds. **(x) Diseases:**Root rot, berseemmosaic

(xi) Pests: Aphid, leaf minor, dusky bug, thrips, whitefly,cutworm

(xii) Harvesting: First cutting is generally taken after 60 to 70 days, second after35 to 40 days of first cutting, third and fourth after 30 days of last cutting and 5th and 6th after 20 days of last cutting. Subsequent harvest (cuttings) should be taken at 25-35 days interval depending upon the rate of growth and temperature. The cutting should be done at about 5-7 cm height for better and quickre-growth.

Research Station: Indian Grassland and Fodder Research Institute, Jhansi

Yield : The average yield of green forage varies from 800 to 1100 q/ha.

Spices

A spice is a seed, fruit, root, bark, or other plant substance primarily used for flavoring,coloring or preserving food. Spices are distinguished from herbs, which are the leaves, flowers or stems of plants used for flavoring or as a garnish. Indian food and taste are famous all over the world for delicious aroma, great taste, unique color and finger-licking flavor. All these together make a perfect blend and are found in Indian foods only. The secret of the delicious flavor of Indian food is its rich spices that are used for thousands of years and spreading all over the world. Indian and Egyptian spices are known as world's best spices in taste, their appealing aroma adds tang to foodstuff. The real amalgamation of spices was done in beginning of 14th century by Mughals.

CORIANDER

Botanical name: *Coriandrum sativum L.*
Family : Umbellifereae
Origin : Egypt

Geographical distribution

Coriander is cultivated in the countries of India, Russia, Balgaria, Hungary, Polland, Pakistan and Rumania.In India, it is cultivated in the states of Madhya Pradesh, Andhra Pradesh, Maharashtra, Tamil Nadu and Rajasthan.In Gujarat, it is cultivated in Mehsana and Banaskantha districts. Coriander is generally grown surrounding the big cities to meet the requirement of green leaves locally known as *kothmir.*

Economic importance

Coriander leaves and seeds both contain antioxidents. It is used as condiments. Both seeds and leaves are rich in vitamin A (Carotene). Coriander leaves used for making *chutney.* Seeds are important ingredient of the famous *Indian curry*. Besides, seeds have a number of medicinal uses. Coriander oil is used for flavouring liquors, coca preparation etc. It kills spider, mites and cotton aphids too. Coriander is exported to Sri Lanka, Malayasia, East Africa and USA. India produces 8000 tonnes of coriander seeds. Among these quantities, 90 per cent seeds are utilized in India and only 10 per cent seeds are exported to the above saidcountries.

Soil requirements

Well drained sandy loam to medium black soil is most suitable for cultivation of coriandercrop.

Climatic requirements

It requires cool and dry climate and hence it is grown in *rabi* season for seed purpose. However, it can be grown in any season for green leaf.

Varieties

Gujarat Coriander 1,Gujarat Coriander 2, COR 29, GDLC 1 (Gujarat Dantiwada Leafy Coriender 1), Gujarat Coriander 3

Cultural practices:

(i) Land preparation: After harvesting of *kharif* crop, one to two ploughings followed by harrowing are needed. The field should be cleaned by removing stubbles and debris of previouscrop.

(ii) Time of sowing: First fortnight ofNovember

(iii) Method of sowing: Drilling

(iv) Spacing:30cm x 15cm

(v)Seed rate:12-15kg/ha. Split the whole seeds into two halves. This helps in reducing seed rate as each half has germinating capacity. Besides this, splited halves germinatingfaster.

(vi) Seed treatment: Coriander seed are separated in two equal parts. Treat with fungicideslike ThiramOrCaptan @ 3gm/ Kg ofseed

(vii) Manures and fertilizers: Well decomposed FYM @ 10-15 t/ha should be applied at the time of preparationland.

Nitrogen (kg/ha**)**	**P_2O_5 (**kg/ha)	**Remarks**
10	10	Basal
10	00	At 6 weeks after sowing
20	10	

(viii) Irrigations: First irrigation should be applied just after sowing. Second irrigation at 7-8 days after sowing and subsequent irrigations should be given at 12 to 15 days interval.

(ix) Interculturing and weeding: Generally 2 to 3 interculturings are sufficient to control the weeds. If labour are scare apply pendimethalin @ 1 kg a.i./ha aspre-emergence.

(x) Diseases: Powderymildew

(xi) Pests: Aphids

(xii)Harvesting: This crop is ready for harvest after 110 to 120 days. At maturity, seeds show yellowish green colour and medium hard when pressed. After harvest, the crop is dried under partial shade for maintaining green colour and aroma of grain. When the plants are completely dried, the seeds are separated by biting with wooden sticks and then grading is done with the help of sieve or byvibrator.

Research Station: Jagudan

Yield :1500 to 1800 kg/ha

FENNEL

Botanical Name :.*Foeniculum vulgare* L.
Family:Apiaceae (Umbelliferae)
Origin : Mediterranean

Geographical distribution

India is the world's largest producer, consumer and exporter of the spices and among all spices fennel is one of the most important spices. Fennel is cultivated in Argentina, America, Germany, China, Indonesia, Russia, Japan and Pakistan. In India, the fennel cultivating states are Haryana, Punjab, Himachal Pradesh, Maharashtra and Uttar-Pradesh. In India fennel is mainly cultivated in Gujarat, Rajasthan, Uttar Pradesh, Karnataka, Andhra Pradesh, Punjab, Haryana and Madhya Pradesh. Gujarat ranks first in area and production contributing more than 90 per cent of total fennel production of the country. In India, fennel fruits are classified for trade purposes according to their place of origin. Some of the well known types are Bombay, Bihar and UP fennels. Seeds from Lucknow are considered to be best and are priced higher than those from other areas.

Economic importance

It is a highly aromatic and flavourful herb with culinary and medicinal uses. The bulb, foliage and seeds of the fennel plant are widely used in many of the culinary traditions of the world. Dried fennel seed is an aromatic, anise-flavoured spice, brown or greenin colour when fresh, slowly turning a dull grey as the seed ages. For cooking green seeds are the best. The bulb is a crisp, hardy root vegetable and may be eaten raw. Many cultures in the Indian subcontinent and the Middle East use fennel seeds in their cooking. Fennel is one of the most important spices in Kashmiri Pandit and Gujarati cooking menu. Fennel water has properties similar to those of anise and dill water: mixed with sodium bicarbonate and syrup, these waters constitute the domestic 'gripe water', used to correct flatulence of infants. Fennel tea, also employed as a carminative, is made by pouring boiling water on a teaspoonful of bruised fennel seeds. In the Indian Subcontinent, fennel seeds are eaten raw, sometimes with some sweetener to improve eyesight. Extracts of fennel seeds have been shown in animal studies to have a potential use in the treatment of glaucoma, as a diuretic and a potential drug for the treatment ofhypertension.

It is well known for its essential oil. The characteristic anise odour is due to its essential oil makes it an excellent flavouring agentin baked goods, meat and fish dishes,ice-cream and

alcoholic beverages. The major components of seed essential oil have been reported to be trans-anethole,fenchone, estragol (methyl chavicol), and α-phellandrene. Essential oil of fennel prevents development of chronic liver damage hence it is very useful for controlling disease of chest, spleen, kidney and aid to longevity. The seeds are used as a flavouring agentin many herbal medicines, and to help disperse flatulence. The seeds, and roots, also help to open obstructions of the liver,spleen & gall bladder, and to ease painful swellings, in addition to helping with yellow jaundice. The essential oil is also used for scenting soaps and flavouring materials for cakes, liquor, sauces, pastries, confectionary, bread roll and meat dishes. In India fennel seeds are also used for mastication and chewing alone or with beetle leaves.

Soil requirements

Sandy loam to medium black soils with good drainage is suitable for this crop.

Climatic requirements

It grows in temperate and sub tropical areas. Fennel requires cool and dry climate for its cultivation. Dry and moderately cool weather conditions during seed formation increase seed yield as well as quality of the produce. Except sandy soil, fennel can successfully be cultivated in all types of soils having sufficient amount of organic matter. Black cotton soil and loamy soil containing lime with proper drainage are better suited for its cultivation.

Varieties: Gujarat Fennel 11, Gujarat Fennel 12

Cultural practices

(i) Land preparation: The soil is brought to a fine tilth by one ploughing followed by 2 to 3 harrowing andplanking.

(ii) Time of sowing: First fortnight ofNovember.

(iii) Method of Sowing: Drilling

(iv) Spacing: 45-60 cm between the row and 10-15 cm withinrow.

(v) Seed rate:5kg/ha.

(vi) Seed treatment: Treat with fungicides like Thiram OR Captan @ 3gm/ kg ofseed

(vii) Manures and fertilizers: Fertilizer dose: 90 : 30 : 00 NPK Kg/ha.

Basal dose: 45 : 30 : 00 NPKKg/ha.

Top dressing:

a) 22.5 Kg N/ha after one month fromsowing.

b) 22.5 Kg N/ha after two month fromsowing.

In north Gujarat agro climatic zone, the crop should be applied RDF (90 + 30 kg NP/ha) to *rabi* fennel along with 200 kg FYM enriched with 3.0 kg Fe + 1.5 kg Zn/ha in furrow at the time of sowing in Fe and Zn deficient soil for obtaining higher yield and net return. The FYM (200 kg/ha) should be mixed with required quantities of Fe (15.7 kg $FeSO4.7H_2O$) and Zn (7.1 kg $ZnSO4.7H_2O$). The FYM is kept about 70 % moisture content for 40 days in a pit with weekly intermixing before itsapplication.

(viii) Irrigations: Irrigation at sowing time, second and third irrigations at 8 and 33 DAS and remaining 7 irrigations at 12 to 15 daysinterval.

(ix) Interculturing and weeding : Apply pendimethalin @ 1 kg/ha a.i. aspre-emergence.

In north Gujarat Agro-climatic Zone (AES IV), for *rabi*fennel two hand weedings + interculturing at 20 and 40 DAS should be carried out to control weeds for getting higher yield and net return.

(x) Diseases: Collar rot, Ramularia blight, Sugary Secretion,Phyllody

(xi) Pests:

Fennel aphid (*H. coriandrai*),gram pod borer, seed wasp

(xii) Harvesting: Generally Rabi crop is raised for market type produce. Hence, harvest the crop when 70 % umbels on plant are at physiologicalmaturity.

Research Station: Jagudan

Yield :1800 to 2000 kg/ha.

DILL SEED

Botanical name:*Anethum graveolenus* L.
Family : **Apiaceae (Umbelliferae)**
Origin :Mediterranean

Geographical distribution

Dill seed is cultivated in India, Pakistan, Turkey, Persia and Iran. In India, it is cultivated in the states of Madhya Pradesh, Uttar Pradesh, Rajashthan, Maharashtra, Punjab and Gujarat. In Gujarat, it is cultivated in the districts of Mahesana and some part of Banaskantha and Sabarkantha.

Economic importance

Dill seed has its great medicinal value. It helps well against gastritis, old constipation, worm and indigestion troubles. The oil of dill seed also has great medicinal value. The seed of dill seed is used in preparation of some vegetables during theircooking.

Soil requirements

Crop thrives best in well drained sandy and medium black soils reach in organic matter.

Climatic requirements

Crop prefers cool and dry climatic conditions. Cloudy weather harms the crop. Rains during maturity spoil the seeds as well as sometimes entire crop too. For good vegetative growth, warm and moist condition is preferable.

Varieties: Gujarat Dill seed 1, GAVDS 1 (Gujarat Anand Vegetable Dill Seed1),
Gujarat Dill seed3

Cultural practices:

(i) **Land preparation:** To make soil friable, 2 to 3 ploughing, followed by harrowing should be carried out. Thereafter, remove stubbles and debris of previous crop and level the field by clod crushing with the help of plank. Prepare bed size of 1.5-2.0 to 3.5-4.0 sq.m. according to irrigation sources and slope of theland.

(ii) **Time of sowing:** Second fortnight of October to first week of November with onset of winterseason.

(iii) **Method of sowing:** Broadcasted seed should be properly mixed with the soil with the help of rake. Seed should not be go deep more than 1.0 cm or should not be remained open in thebed.

(iv) **Spacing:** Sowing is done bybroadcasting.

(v) **Seed rate:** 2kg/ha

(vi) **Seed treatment:** Seed should be treated with Agrosan or Ceresan @ 2-3 g per kg of seeds. Seed should be mixed with materials like sieved castor cake or fine soil or powdery FYM etc. for uniform distribution of seeds in thefield.

(vii) **Manures and fertilizers:** Well decomposed FYM @ 8-10 t/ha should be incorporated into the soil at the time of land preparation if it is not applied to previous *Kharif*crop.

Nitrogen (kg/ha)	P_2O_5 (kg/ha)	Remarks
20	30	Basal
20	00	At 40 DAS
40	30	

In Bhal and Coastal Zone, dill seed (GD 2) should be fertilized with 20 kg N/ ha and 20 kg P_2O_5/ha as basal application. top dressing of 20 kg N /haafter the irrigation to secure higher yield and net return (CBR-1:5.7). While, under conserved moisture condition, only 40 kg N /ha should be applied as basal at the time ofsowing.

In North West Gujarat Agro-climatic Zone rainfed dill seed under saline sodic soil, 40:20 kg N:P_2O_5/ha and 10 kg S/ha through gypsum (62.5 kg) should be applied as basal for obtaining higher seed yield and net return.

In North West Gujarat Agro-climatic Zone growing dill seed under saline sodic soil are recommended to apply 5 t FYM/ha and 50 per cent of gypsum requirement (4 t/ha) of soil with 60 kg N + 30 kg P_2O_5 /ha for obtaining higher yield and net return.

(viii) **Irrigations:** For irrigated crop, apply 3 to 6 irrigations according to soil texture and climatic condition First irrigation should be given just after sowing, second at 7 to 9 days after sowing, and subsequent irrigations should be applied as and when required (10 to 12 days interval).

(ix) **Interculturing and weeding:**In North Gujarat Agro-climatic Zone, dill seedunder irrigated condition, two interculturings should be carried out followed by hand weeding at 25 and 40DAS.

(x) **Diseases:** Powdery mildew andwilt

(xi) **Pests:**Aphids

(xii) **Harvesting:** Harvesting should be done in the early morning in damp condition (night due). Harvested crop should be stacked in threshing yard for sun drying. Thereafter, seeds are separated by beating the plants withsticks.

Research Station: Jagudan

Yield : 800- 1000 kg/ha

AJWAIN

Botanical Name : *Carum captimum* L.
Family: Apiaceae (Umbelliferae)
Origin :Egypt

Geographical distribution

Cultivated countries are India, Pakistan, Turkey, Persia and Iran.In India, it is cultivated in Madhya Pradesh, Uttar Pradesh, Rajashthan, Maharashtra, Punjab and Gujarat.In Gujarat, it is cultivated in Mehsana and some part of Banaskantha and Sabarkandha districts.

Economic importance

Seeds contain health benefiting essential oils such as **thymol,** which gives aromatic fragrances to seeds. In addition, they also comprise in small amounts other phyto-chemicals such as *pinene, cymene, limonene and terpinene.* The seeds used generously as condiment in snacks, spicy biscuits, to flavor drinks, soups, sauces in India. Thymol, the essential oil obtained from ajwain has local anaesthetic, anti-bacterial and antifungal properties. Seed is used in preparation of some vegetables during theircooking.

Soil requirements

Loamy to black soils are suitable for this crop. Ploughing and 2-3 harrowings followed by planking for getting good tilth.Well drained medium black and sandy soils rich in organic matter.

Climatic requirements

Cool and dry climatic conditions. Cloudy weather harms the crop. Rains during maturity spoil the seeds as well as sometimes entire crop; too. For good vegetative growth, warm and moist condition ispreferable.

Varieties:GujaratAjwan 1 (matures in 160-165 days)Gujarat Dantiwada Ajwain2

Cultural practices

(i) **Land preparation:** 2 to 3 ploughings, followed by harrowing should be carried out. Remove stubbles and debris and level the field by clod crushing with planking. Prepare bed size of 1.5-2.0 *to* 3.5-4.0 sq.m. according to irrigation sources and slope of the land.

(ii) **Time of sowing:**2nd fortnight of October to first week ofNovember.

(iii) **Method of Sowing:** Broadcasted seed should be properly mixed with soil with help of rake. Seed should not be go deep more than 1.0 cm or should not be remaining open in thebed.

(iv) **Spacing:**Sowing is done bybroadcasting.

(v) **Seed rate:**2kg/ha

(vi) **Seed treatment:** Seed should be treated with Agrosan or Ceresan @ 2-3 g per kg of seeds. Seed should be mixed with fine soil or powdery materials like sieved castor cake or FYM etc. for uniform distribution of seeds in thefield.

(vii) **Manures and fertilizers:** Well decomposed FYM @ 10 t/ha should be incorporated into the soil at the time of land preparation, if it is not applied to previous *kharif*crop.

Nitrogen (kg/ha)	**P_2O_5 (kg/ha)**	**Remarks**
20	30	Basal
20	00	45 DAS
40	30	

Farmers of North Gujarat Agro-climatic zone IV growingajwain are recommended to fertilize the crop with 20 kg N + 20 kg P_2O_5 /ha for getting higher yield and net return.**(2015)**

(viii) **Irrigations:** Crop requires 8 to 10 irrigations depending on type of soil and climatic conditions. First irrigation, should be given just after sowing, second at 7 to 9days after sowing, and subsequent irrigations should be applied as and when required (10 to12 daysinterval).

Farmers of North Gujarat Agro-climatic zone IV growingajwain are recommended to irrigate the crop with six irrigations each of 50 mm depth at sowing,8-10, 47,85,114 and 135 DAS

(ix) **Interculturing and weeding :** Hand weeding should be done as and whenrequired.

The farmers of North Gujarat Agro-climatic Zone growing ajwain are recommended to carry out two interculturingfollowed by hand weeding at 25 and 40 DAS for obtaining higher seed yield and net return.

(x) **Diseases:**Powdery, mildew andWilt

(xi) **Pests:**Aphids

(xii) **Harvesting:** Harvesting should be done in the early morning in damp condition (night due). Harvested crop should be stacked in threshing yard for sun drying. Thereafter, seeds are separated by beating the plants withsticks.

Research Station: Jagudan

Yield :800-1000 kg/ha

FENUGREEK

Botanical Name :*Trilgonella foenum-graecum* L.
Family: Fabaceae
Origin : South-East Europe, Ethiopia and West Asia

Geographical distribution

Fenugreek is mainly cultivated in the Countries of India, Argentina, Egypt, Morocco, China, Japan and Pakistan.In India, it is grown in all states except Assam and West Bengal. It occupies about 50000 hectares area with an annual production of 25000 tonnes.

In Gujarat, it is cultivated in Saurashtra, north Gujarat (Mahesana - Unjha and Maktupur area) and middle Gujarat areas.

Economic importance

It is used as condiments, as leafy vegetables and used in pickles, salad, curry preparation and used for medicinal purposes. Plants are used medicinally in different countries and are a source of many potent and powerful drugs. This plant decrease body fats and effective on obesity. Fenugreek leaves and seeds are consumed in different countries around the world for different purposes such as medicinal uses (anti-diabetic, lowering blood sugar and cholesterol level, anti-cancer, anti-microbial, etc.), making food (stew with rice in Iran, flavor cheese in Switzerland, syrup and bitter run in Germany, mixed seed powder with flour for making flat bread in Egypt, curries, dyes, young seedlings eaten as a vegetable, etc.), roasted grain as coffee-substitute (in Africa), controlling insects in grain storages, perfume industries, and etc. Fenugreek can be a very useful legume crop for incorporation into short-term rotation and for hay and silage for livestock feed, for fixation of nitrogen in soil and its fertility. Fenugreek seeds have been known and valued as medicinal material from very early times. Its seeds are considered to be of commercial interest as a source of a steroid diosgenin, which is of importance to the pharmaceuticalindustry.

Soil requirements

It thrives best on well drained and fertile sandy, sandy loam and medium black soils. It is also grown on clay soils but deep black and water logged soils are not suitable.

Climatic requirements

Fenugreek is a *rabi* season crop requires cool and dry climate. It can tolerate moderately well to frost. Cloudy weather is not suited well for cultivation of this crop.

Varieties: Pusa Early Branching, Methi No.47, Gujarat Methi 2

Cultural practices

(i) **Land preparation:** After harvesting of *kharif,* crop one ploughing should be done, followed by harrowing twice and planking to make the landfriable.

(ii) **Time of sowing:**4th week of September to 2nd week ofOctober.

(iii) **Method of sowing:** Drilling or bybroadcasting

(iv) **Spacing:**30 x 10 cm for line sowncrop

(v) **Seed rate:**15 to 20kg/ha

(vi) **Seed treatment:** For better and quick germination, seeds are soaked in water up to 6 to 8 hrs and then used for sowing after drying. Seed treatment with bio-fertilizer foundbeneficial.

(vii) **Manures and fertilizers:** If *kharif* crop is not manured with FYM, apply 8-10 t FYM/ha at time of preparation of theland.

Fertilizers dose: 20 : 40 : 00 kg NPK/ha + 10 Kg S/ha should be applied at the time of land preparation.

(viii) **Irrigations:**First irrigation should be given soon after sowing and subsequent irrigations should be given at 10 to 12 interval as required by thecrop.

(ix) **Interculturing and weeding :** Generally 2 to 3 hand weedings with 1 or 2 interculturings are sufficient for keep the crop weed free. Apply pendimethalin @ 0.6 Kg/ha as pre-emergence if labours are scare andcostly.

(x) **Diseases:**Powderymildew

(xi) **Pests:** Aphids andJassids

(xii) **Harvesting:**When pods turn brown and leaves become dry, the crop should be harvested early in the morning to avoid shattering of seeds pods (bursting). If climate is totally dry, spray water over the crop on previous day eveninghours.

Research Station: Jagudan

Yield : 800 to 1000 kg/ha

CUMIN

Botanical Name: *Cuminum cyminum* L.
Family: Umbelliferace
Origin: Egypt

Geographical distribution

In world scenario, its cultivation is largely confined to the countries of Egypt, India, Iraq and China. In India, the principal cumin growing states are Gujarat, Rajasthan, Uttar Pradesh, and Punjab. It is almost grown in all states except Assam and West Bengal. In Gujarat, its cultivation is predominantly in the districts of Mahesana, Banaskantha and Ahmedabad. It has got well adaptability in Saurashtra region because of its low water requirement and dry climate during its life period. Cumin is cultivated in Gujarat in about 60 to 80 thousand hectares with an annual production of about 30 to 40 thousand tonnes of cumin seeds.

Economic importance

Spices play an important role in human dietary because of their agreeable flavour and aroma to food and add greatly to the pleasure of eating. Cumin locally known as *Jeeru* is one of the important spice crops. Cumin helps in earning foreign exchange. Cumin seeds contain volatile oil ranging from 2.5 to 4.0 per cent. Indian cumin seeds are found to contain about 3.5 per cent volatile oil by their weight. The chief constituent of the oils is cuminaldehyde (20-40 %) and is used in perfumery. Cumin oil has medicinal value and is also used in perfumery and for flavouring food and beverages. It is good medicine against digestive and intestinal upsets. As condiment, cumin is used in preparation of curries, bread, and pickles. Seeds are used in diarrhea. The aroma in seed is only due tocuminol.

Soil requirements

Sandy loam to medium black soils having good drainage capacity is suitable. The soil is prepared for sowing by one or two shallow tillage by harrow. Stubbles of previous crop are collected and removed. Clods are broken and field is well leveled with the help of the plank. Small beds having the appropriate size (generally 6×3 m^2) depending upon the slope of the soil areprepared.

Climatic requirements

It requires cool and dry climates. High humidity associated with cloudy weather is harmful and cause powdery mildew and blight diseases in cumin and yield isreduced.

Varieties: GC 1 & GC 2 (Resistant to blight and having good quality ash colour seeds)
GC 3 (Released for whole Gujarat, especially, for wilt affected areas of the state).
GC 4 (Released for wholeGujarat, high yielding variety, resistant towilt).

Cultural practices

(i) **Land preparation:** After harvesting of *kharif* crop 2 to 3 ploughings followed by harrowing just to make the upper surface clods smooth and friable. Thereafter, stubble and debris (plant residues) of the previous crop are collected and removed from the field and finally the land is levelled by planking. Bed size should be kept according to the source of irrigation, type of soil and slope of the filed. In sandy loam soil, bed should be prepared of 1.0.m wide and 5 to 10 cm long. In medium to heavy black soils, raised bed are prepared to avoid water accumulation in the rootzone.

(ii) **Time of sowing:**Sowing should be done in the second fortnight of October to first week of November. However, first week of November is optimum time for getting maximumbenefit.

(iii) **Method of sowing:** Cumin is sown by broadcasting or drilling. Broadcasted seeds are covered with the soil in the bed by rake and at this time care should be taken that seed should not be remained open and also do not go deep more than 1.0 cm in thesoil.

(iv) **Spacing:** For drilling 30 cm rowspacing.

In *Bhal* and Coastal Agro-climatic Zone, for cumin (GC 4) crop, broad bed of 90 cm and furrow of 30 cm width should be prepared and sowing should be done keeping seed rate @ 20 kg/ ha through broadcast.

(v) **Seed rate:**15-20 kgseeds/ha

(vi) **Seed treatment:** Seeds should be treated with Agrosan or Ceresan @ 3 g per kg of cumin seeds before sowing. For better germination, seeds should be soaked in water for 8hours.

(vii) **Manures and fertilizers:** Cumin being a short duration and shallow rooted crop, it is not necessary to apply FYM every year. However, in sandy soils having low fertility status, well decomposed FYM @ 10 t/ha should be applied. The chemical fertilizers dose is asunder.

Fertilizers dose 40 : 15 : 00 kg NPK/ha.
Basal 13.3 : 15 : 00 kg NPK/ha
Top dressing 13.3 kg N/ha after 8-10DAS
13.3 kg N/ha after 30DAS

In *Bhal* and Coastal agro-climatic zone-VIII, cumin (GC 4) should be sown on broad bed and furrow and 30 kg N + 30 kg P_2O_5 /ha as basal and 30 kg N/ha as top dressing should be applied at 30DAS.

(viii) **Irrigations:**Cumin crop requires 3 to 5 irrigations according to the soil and climatic conditions. Irrigation should be given on cloud free days. First light irrigation should be given just after sowing for uniform germination so that seed may not carry away with irrigation water and gathered at one place in the bed. Second irrigation should be given at 10 days after germination; while third irrigation at 30 to 35 days, fourth irrigation at flowering time i.e. 45 to 50 days and last irrigation should be given at 80 days of sowing. At the most, five irrigations are enough in cumincrop.

(ix) **Interculturing and weeding :**In north and south Gujarat, two hand weeding at 15 and 30 DAS, keep the crop weed free for about 45 days or apply oxadiargyl 75 g/ha (6 EC 25 ml/10 lit) as early post-emergence application at 7 DAS followed by hand weeding at 45 DAS for effective weed management(Junagadh-2015).

(x) **Diseases:** Blight, wilt and powderymildew

(xi) **Pests:** Cumin aphid, thrips, leaf eating cater piller, Gram Podborer

(xii) **Harvesting:**The crop is ready for harvest after 105 to 115 days. The plants are uprooted early in the morning when plants are damp with night dew to avoid shattering of seeds. Harvested plants are dried under sunlight for 2 to 3 days on threshing floor. Then threshing is done by beating the dried plants with sticks. For better prices, seeds should begraded.

(xiii) **Intercropping:** In North Gujarat Agroclimatic Zone-IV, ajwain should be grown as intercrop in cuminwith 4:1 raw arrangement taking a cut of ajwain at 45 days after sowing for getting higher yield and netreturn.

Research Station: Jagudan

Yield :800 to 1200 kg/ha

CHICORY

Botanical Name :.*Cicorium intybus* L.
Family: Asteraceae or Compositae
Origin : Europe and Asia

There are mainly three subspecies of *C. intybus.*

(a) *C. intybus* L. var. *foliosum* (Hegi) Bisch: It is known as salad chicory which includes three types of this plant: witloof, sugarloaf and radicchio chicory (redchicory).
(b) *C. intybus* L. var. *silvestre* Bisch: It is known as wild red variety have been used in New Zealand
(c) *C. intybus* L. var. *sativus* Bishoff : It is commonly known as Belgianendive

Geographical distribution

This crop is widely cultivated in a number of temperate regions around the world including South Africa but has its origins in Europe, Central Russia, Western Asia, and also found in Egypt and North America. The genus *Cichorium* consists of six species with major distribution are as in Europe and Asia. It is cultivated in countries such as the UK, Belgium, France,Netherland,Germany,SouthAfrica,USAandIndia.Itisalsoknownascommonchicory, blue sailor's succor and witloof. It is native to the temperate parts of the Old World and is found wild in India in the Punjab and Andhra Pradesh regions. It is also cultivated in Bihar, Gujarat, HimachalPradeshandTamilNadu.ChicoryhasbeensuccessfullycultivatedinIndiasince1918 atCoimbatoreandsubsequentlyNilgirisinTamilNaduandatBharuch,AmalsadandJamnagarin Gujarat. The crop is cultivated in few states, mainly Uttar Pradesh and Gujarat. These two account for 97 per cent of the total production of chicory in India. It is the climate (or soil) which favours chicory in these States. Initially, chicory seed was imported into India, but now it is successfullyproducedlocally.CommercialseedproductionisundertakeninJammuandKashmir, temperate areas of Himachal Pradesh and some hilly regions of Uttar Pradesh. The agroclimatic conditionsofthesedrytemperateareasareconducivetoqualityseedproduction.InIndia,thefirst crop of chicory was taken by Jamnagar's farmer shri Jethabhai Kesvala on demand of Brooke Bond Company in 1956.

Economic importance

As a medicinal plant, chicory is often recommended for jaundice and for spleen problems. The juice of the leaves and a tea made from the flowering plant promote the production of bile, the release of gall stone, and elimination of excessive internal mucous. They are also useful for

gastritis, lack of appetite, and digestive difficulties. A decoction of the rootstock is said to be beneficial to the glandular organs of the digestive system.

The aerial parts and leaves of this plant are used to prepare salads and soups. The aerial parts can be fried with egg and are eaten with seasoned olive oil. It is widely used for pasta sauce. Leaves are used as infusions for anemia and digestive disorders. Its flowers have cholagogic activity and are also used in washing the skin, cooling and conditioning. Seed extract of chicory showed the highest antioxidant capacity compared to extract from the leaves and roots. Root is used as infusion to clear the organism and to stimulate appetite. The roots of some types are used as a substitute for coffee. The root is also used as a gum.

After being introduced in India, the process of adding chicory to coffee took hold and an amount of between 20% to 45% chicory became common. Benefits of chicory for the coffee drinker were found to be plenty such as:

(a) Improving digestion – the inulin in chicory is a probiotic that eases many intestinal and digestive issues, such as heartburn or reflux andconstipation.

(b) Antioxidant properties – according to the 2011 study, 'Phytotherapy research', chicorycan help combat thrombosis and inflammation.

(c) Nourishment – the chicory root contains vitamins C, K, choline and beta caretone,allowing you to boost your intake of these nutrients with your morningcoffee.

Soil requirements:

Chicory prefers fertile, well-drained soils rich inorganic matter for best growth. Loam, silt loam and clay loam soils often out-yield the lighter textured sandy soils as the latter have lower water retention ability and the crop suffers moisture stress sooner. Heavy clay soils are unsuitable as difficulty is experienced in lifting and cleaning the roots and yields are lower.

Climatic requirements

Chicory is a cool season plant. It grows most rapidly when conditions are warm and the mean monthly temperature does not exceed 25 °C. It grows more slowly with a decrease in temperature and it is not damaged by moderate frost but severe frost kills the foliage. Long days and abundant sunlight promote rapid growth. When raised for roots, chicory requires a hot and humid climate and is mostly cultivated in southern regions; however, when raised for seeds, the crop is grown in regions with a dry temperate climate. Chicory is a hardy plant and can tolerate extreme temperatures during its vegetative and reproductive phases of growth.

Varieties: Lucknow Local, Radicchio

Cultural practices:

(i) Land preparation: The land should lie fallow for 2 to 4 months before planting by ploughing to a depth of about 22–86 cm and cultivate periodically with a tined or disc implement. Tillage should be done parallel to the contour banks in order to minimize water run-off and erosion. The seedbed should be well prepared, that is, friable yet compact enough so that the seed will be placed in close contact with moist soil particles and free offtrash and vegetation that would interfere with theseedling.

(ii) Time of sowing: The date of planting is one of the most important factors affecting the performanceofbothchicorystecklingsandseedcrops.Theseedforraisingstecklingsissownin JuneintemperatezonesofnorthernIndia.ThestecklingsarereadyinNovemberforstorage.After overwinteringfor3-4monthsat3-8°C,thestecklingsbecomefitforreplantinginMarch-Aprilfor

the seed crop. In southern states of India the seed (3 to 5 kg/ha) is sown in October to November and the crop is ready for coffee blending in March. If planted early, the plants begin to flower early and tuber formation is adversely affected. The seed is very small and hence is mixed with fine sand and drilled in lines of 30 cm apart. The optimum depth for better germination is 3 – 5 cm.

(iii) Method of sowing: Ensure that the land lies fallow for two to four months before planting. Make the seedbed sufficiently compact so that the seed is in close contact with moist soil particles. Remove vegetation that could interfere with the seedling. Seeded witloof may be planted three to four weeks before the last frost-free date for the growingarea.

(iv) Spacing: 30cm

(v) Seed rate: 4–5 kg/ha (seed size830,000/kg).

(vi) Manures and fertilizers:

Farm yard manure at the rate of 20-25 t/ha

For the steckling crop, application of nitrogen at levels of 60, 80 and 100 kg/ha at the time of seed sowing, after thinning (30 days after germination) and at the roo tformation stage respectively is recommended. For the seed crop, nitrogen doses of 80, 120 and 160kg/ha applied before transplanting, at the bolting stage and at the pre-flowering stage respectively give higher seed/root yields.

Chicory has a high requirement of potash for both root and seed crops. Since the soils are very poor in potash, an application of potash at 60 – 70 kg/ha for the root crop and 80 - 100kg/ha for the seed crop will yield better results.

(vii) Irrigations: After sowing, the whole area is irrigated upto 5cm below the ridge level. In unirrigated lands the plants are watered on alternate days for the first week. Once the plants are established, irrigation can be reduced. Water requirements depend on soil type and temperature. Moisture is the main environmental factor affecting production. The seedling is sensitive to moisture stress and hot desiccating wind can cause severe stand reductions when the moisture content of the top 15 cm of soil is low. Once the crop has developed a root of approximately pencil thickness, it is drought tolerant as it ceases growth during periods of moisture stress. Most of the foliage may die back under severely dry conditions, but the plant recommences growth and develops new foliage as soon as soil moisture becomesfavourable.

Water chicory regularly to maintain a uniform moist soil, applying 2,5 to 5 mm per week. Using organic mulch around the plant also helps to conserve soil moisture and reduce weed growth. Drought stress during growth will cause slow leaf development and bitter flavours to develop.

(ix) Interculturing and weeding: Closely spaced plants will help control weeds. Shallow inter-row cultivation using animal or tractor drawn cultivators coupled with hand-hoeing in the row are the usual methods of controlling weeds. Cultivate at shallow depth to avoid root damage and ensure uninterrupted plant growth. Weeds can also be controlledchemically

(x) Diseases: The main diseases of chicory are *Sclerotinia* rot, charcoal rot and leafspot

(xi) Pests: Aphids andnematodes

(xii) Harvesting: To obtain roots of a large size, the soil must be rich, light, and well manured. Thechicoryplantcontinuestoflower foralongtime.Thereforeitismostimportant todetermine

its appropriate harvesting stage and curing. Maturity is indicated by browning of the plant.When70 to 75 per cent capitula are mature on the older branches, the whole plant is pulled out or the crop is harvested with the help of sickles.

In the light soils the crop is generally ready for lifting 120 – 135 days after sowing, while it may take nearly a fortnight more in heavier soils. After the crop has attained maturity,it should be lifted as soon as possible. The roots are lifted with the help of a fork or spade. The tops of the plants are removed and the roots are washed and cut into small pieces of 1 cm thickness. It is important to slice the roots immediately after lifting, as they contain a high percentage of sugar which is apt to ferment and affect the flavor and taste of chicory.

Yield :

About 20 t wet roots/ha is considered a good yield. In the small southern Indian town of Coimbatore, under irrigated conditions, crop yields of about 37.5 t/ha have been reported. Exceptional yields of upto 50 t/ha can be expected on well-cultivated and manured land.

Processing: Soon after harvest, roots that are bitter and mucilaginous are washed and cut into slicesanddried.Therootsareeithersundriedorkilndried.Althoughsundriedrootshaveabetter appearance, kiln drying is more efficient and is preferred. The dried roots are graded into four sizes before roasting so that uniform roasting is ensured. Roasting is done for 30 minutes in hot rotatingironcylinders.Smallquantitiesofoil,butterorclarifiedbutter(0.9kgper50kgchicory) areaddedtotherootsduringroastingtoimprovetheflavorandcolourofchicory.Duringroasting, the sugars are caramelised, thereby increasing the histidine bases. These changes are responsible for the characteristic flavor of the roasted product. The roasted root pieces are handpicked to removeforeignmatterandthenpowdered.Thispowderisthefinalproductusedforblendingand flavouring coffee.(Table 1 &2)

Table 1: Requirements for roasted chicory powder

Sr. No.	Characteristic	Requirement (%)
1	Moisture	10.0
2	Total ash	3.5 - 8.0
3	Acid-insoluble ash	1.0
4	Water-soluble matter	6.0

Table 2: Requirements for soluble coffee–chicory powder

Sr. No.	Characteristic	Requirement (%)
1	Moisture	4.0
2	Total ash	7.0 - 10.0
3	Caffeine	1.4
4	Solubility in boiling water	Dissolves readily in 30 seconds with moderate stirring

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IMPORTANT REFERENCES

No.	Name of Book	Author(s)	Year of Publication
1	Modern Weed Management	O. P. Gupta	2018
2	Weed Science: Basics and Applications	T. K. Das	2013
3	Principles and practices of weed management	S.S. Rana & M.C. Rana	2011
4	Weed Management : Principles and Practices	O. P. Gupta	1993
5	Scientific Weed Management	O. P. Gupta	1984
6	Modern weed science	O.P. Gupta & P.S. Lamba	1983
7	Principles of weed science	V. S. Rao	1983
8	Aquatic weed control for efficient water use	O.P. Gupta	
9	Dictionary of weed science	L.L. Sonani	1992
10	Manual of weed control	N.C. Joshi	1984

IMPORTANT JOURNALS

No.	Name of Journal	Published by
1	Weed Science	Weed Sci. Society of America
2	Indian J. of Weed Science	Indian Soc. of Weed Science
3	Weed Abstract	CAB, UK
4	Weed Research	Weed Sci. Soc. of Japan
5	Herbicide Hand Book	Weed Sci. Society of America
6	Weed Technology	Weed Sci. Society of America
7	Weeds Today	Weed Sci. Society of America

CHAPTER-1

Introduction, definition, losses, utilization and characteristics of weeds

1. Introduction

The insect pests (including mites, ticks and spiders), plant pathogens (fungi, bacteria, viruses, nematodes, mycoplasma), weeds, vertebrate pests (birds, rats and rodents and a variety of ruminants) and snails and slugs are considered as five important categories of agricultural pests and have been existing in the natural environment in a dynamic, but fairly balanced state since time immemorial.

Though plants are man's most valuable assets for his survival, their indiscriminate growth all over the land and water-bodies, create troubles to carry out his activities. Out of 300,000 species of plants known in the world, hardly 3,000 are of economic value to us. When one grows any of these economic species of the plants, invariably, a variety of volunteer vegetation comes up simultaneously which is not only competitive and undesirable, but also hazardous for man and animal's health and hamper normal activities of man otherwise.

There are four natural hazards, *e.g*. weather, weeds, insect pests and plant diseases, which stand between humans and continuing food supply, These hazards sometimes work independently and many times hand in hand. Weeds, one of the most prominent hazards, have been recognized as a problem since the man started domesticating/cultivating plants and animals around 10,000 B.C. and the battle against weeds is a never ending one and often the costliest agronomic inputs for the success in crop production. Weeds are considered as a hidden enemy of mankind as of the total annual loss of agricultural produce from various pests in India, weeds roughly account for 45%, insects for 30%, diseases for 20% and other pests for 5%, however, their direct and indirect hazardous impact gone unnoticed till the harvest of the crop.

1.1 Weeds Defined

Weeds are defined in many ways, but most definitions emphasize behavior that affects humans. The most basic concept of weed science is embodied in the word ‗weed' itself. Each weed scientist has a clear understanding of the term, but there is no universal definition that is accepted by all scientists.

- Weeds are the plants, which grow where they are not wanted ‖ (Jethro Tull, 1731).
- In 1967 the Weed Science Society of America defined a weed as ―a plant growing where it is not desired ‖ (Buchholtz, 1967).
- In 1989 the Society's definition was changed to define a weed as ―any plant that is objectionable or interferes with the activities or welfare of man‖ (Humburg, 1989, p.267; Vencill, 2002, p. 462).
- The European Weed Research Society defined a weed as ―any plant or vegetation, excluding fungi, interfering with the objectives or requirements of people ‖ (EWRS,1986).
- The Oxford English Dictionary (Little et al., 1973) defines a weed as a ―herbaceous plant not valued for use or beauty, growing wild and rank, and regarded as cumbering the ground or hindering the growth of superior vegetation.

The human role is clear because it is we who determine use or beauty and which plants are to be regarded as superior. It is important that weed scientists and vegetation managers remember the importance of definitions as determinants of their views of plants and attitudes toward them. Harlan and de Wet (1965) assembled several definitions to show the diversity of definitions of the same or similar plants. The array of definitions emphasizes the care weed scientists and vegetation managers must take in equating how something is defined with a right or privilege to control.

1. Definitions from plant scientists

- A plant out of place or growing where it is not wanted‖ W.S. Blatchley 1912‘
- A plant that is growing where it is desired that something else shall grow‖ A.E. Georgia 1916
- The obnoxious plants are known as weeds‖ W.W. Robbins et al. 1942
- Those plants with harmful or objectionable habits or characteristics which grow where they are not wanted, usually in places where it is desired that something else should grow‖ W.C. Muenscher 1946
- Higher plants which are a nuisance‖ J.L. Harper 1960
- A plant growing where we do not want it‖ E.J. Salisbury 1961
- A plant growing where it is not desired; or a plant out of place‖ G.C. Klingman 1961

2. Definitions by enthusiastic amateurs

- A plant whose virtues have not yet been discovered‖ R.W. Emerson 1912
- Weeds have always been condemned without a fair trial‖ F.C. King 1951

3. Ecological definitions

- A plant which contests with man for the possession of the soil‖ W.S. Blatchley 1912
- Weeds are pioneers of secondary succession, of which the weedy arable field is a special case ‖ A.H. Bunting1960
- Opportunistic species that follow human disturbance of the habitat‖ T. Pritchard 1960
- A weed is —a plant that originated in a natural environment and, in response to imposed or natural environments, evolved, and continues to do so, as an interfering associate with our crops and activities.‖ Aldrich (1984) and Aldrich and Kremer (1997, p. 8).
- They did not deny the validity of others but introduced a desirable ecological base

2. Losses Caused By Weeds

(1) Weed Menace in Agriculture:

(A) Reduction in crop yields and production efficiency

The reduction in yields due to uncontrolled growth of weeds is 34.3% to 89.8%. As the farmer adopts some kind of weeding on their field, it still leaves us with a conservative estimate of at least 10% reduction in crop yields. It is estimated that in general weeds cause

5% loss in agricultural production in most of developed countries, 10% loss in less developed countries and 25% loss in least developed countries.

In weedy fields farm operations like application of fertilizer, insecticides and irrigation become cumbersome. When spiny weeds invade the crop field it makes the harvesting difficult. Some weeds like bindweed bind the crop plants together so well that their harvesting becomes troublesome. Growing within and outside the fields weeds frequently provide shelter to insect pests and disease organisms of crops and act as alternate host to these, both during the crop season and off season.

In India, yield losses due to weeds are more than those from pest and diseases. Yield losses due to weeds vary with the crops. Every crop is exposed to severe competition from weeds. Most of these weeds are self-sown and they provide competition caused by their faster rate of growth in the initial stages of crop growth. In some crops, the yields are reduced by more than 50% due to weed infestation. Weeds compete with crops for water soil, nutrients, light, and space, and thus reduce the crop yields. An estimate shows that weeds can deprive the crops 47% N, 42% P, 50% K, 39% Ca and 24% Mg of their nutrient uptake.

Weeds are also act as alternate hosts that harbor insects, pests and diseases and other micro-organisms.

Alternate hosts of some of the pest and diseases

Crop	Pest	Alternate host
Red gram	Gram caterpillar	*Amaranthus, Datura*
Castor	Hairy caterpillar	*Crotalaria sp*
Rice	Stem Borer	*Echinocholoa, Panicum*
Wheat	Black Rust	*Agropyron repens*
Pearl Millet	Ergot	*Cenchrus ciliaris*
Maize	Downy Mildew	*Sacharum spontaneum*

- Weeds not only reduce yield but also interfere with agricultural operations. Weeds make mechanical sowing a difficult process and render harvesting difficult, leading to increased expenditure on labour, equipment and chemicals for their removal.
- In aquatic environment, weeds block the flow of water in canals, water-transport system and drainage system, rendering navigation difficult. The dense growth of aquatic weeds pollutes water by deoxygenating it and killing the fishes.
- Weeds are also a nuisance and a fire hazard along railway lines, roads, right-of- ways, airports, forest and industrial sites.

(B) Erosion of crop Quality:

Weeds mar quality of farm produce in many ways. Contamination of food grain with weed seeds fetches low price. The weedy grains produce flour with bad odour. In warehouses the weed seeds and weed fragments continue respiration and thus cause the grain to heat and rot. In tea the presence of Loranthus leaves impair its quality. In cotton the dry weed fragments adhere to its lint and hinder its spinning process. In dry land agriculture weedy cause severe moisture stress and force the food grain to shrivel. The vegetation and fruits are discolored and deshaped in the presence of weeds. Contamination of weed seeds of Datura, Argemone, Brassica etc., is harmful to human health and weed seeds present in the produce cause odd odour sometimes.

(2) Weed Menace in Animal Husbandry:

Growing with the forage crops, weeds often help to fill the carts and silos but it is the milk and meat returns that their damage becomes apparent. Certain weeds cause sickness in farm animals while others may prove fatal due to high levels of specific alkaloids, tannins, oxalates, glucosides or nitrates. Johnson grass at its tillering stage and *Xanthium pungens* at its cotyledon stage are poisonous to animal due to their high prussic acid contents. *Tribulus terrestris* a weed of dry lands, induces in sheep extra sensitivity to light. Also, its thorny fruits cause sores in the hooves of animals.

The leaves of lantana induce acute photosensitivity and jaundice in animals due to their toxic Lantradene-A‘. Carrot grass cause contact dermatitis in livestock and it is reported to be poisonous to sheep. Leafy spurge (*Euphorbia esula*) cause scours and weakness in cattle and it is fatal to sheep. *Crotolaria* spp. is fatal to chick. Datura is another sickening weed for animals.

Under drought conditions weeds like Chenopodium and Amaranths develop nitrate levels as high as 1000 ppm or more which causes asphyxia in animals. Spines of *Tribulus territories* can puncture animals‘ skin. When ingested these can also injure the stomach.

(3) Weed Menace to Human Health:

Health comfort and work efficiency of men are adversely affected by weeds. Numerous people are plagued year after year with hay fever and asthma aggravated by pollens of Ambrosia. The airborne pollens and other biotic particles of several other weeds belonging to diverse families are known to cause rhinitis and conjunctivitis. Carrot grass is held responsible for different kinds of dermal allergies in humans. Weeds provide food, protection and habitat for the reproduction of vectors of fatal, human diseases. Aquatic weeds like water lettuce (*Pistia lanceolata*), salvinia (*Salvinia auriculata*) and alligator weed (*Alternanthera* spp.) shelter the alternate hosts and vectors of malaria, yellow fever, dengue fever and filariasis.

Wheat flour contaminated with the seeds of corncockel (*Agrostemma githago*) gives bread a bitter taste and irritates the gastric-tract of the consumer. Mexican poppy (*Agremone mexicana*) seeds crushed with mustard seeds have brought death and blindness to thousands of people in India. Milk from animals feeding upon this weed can cause glaucoma in humans.

(4) Weed Menace to Aquatic Ecosystems:

Not only on land, weeds are a nuisance also in and around water bodies. Aquatic weeds make the appearance of water bodies repulsive and decline their recreational values. In other water bodies they hinder navigation and fishing. Water-flow in irrigation canals and channels is slowed. The potable and drinking water-bodies are fouled by the presence of decomposing aquatic weeds.

Weed Menace To Industry And Public Utilities:

Weeds growing on industrial sites and air fields are potential source of fire hazards, besides being unseemly. They hide industrial pipelines and valve and contribute to deterioration of stores, equipment, and material. Weeds force the fence lines to corrode and obstruct road signs and curves on highways. The working road widths are reduced by weeds. Some weeds penetrate through even asphaltic surfaces which get weakened. Weeds growing around electric poles prevent their ready access to the work crew. Weeds also weaken the rail tracks and air-strips.

(6) Weed Menace To Forests And Pasture-Land:

In the forests and pasture-lands in India weeds are great impedance to regeneration of natural vegetation. In outer Himalayas, lantana (*Lantana camera*) has made large areas of forests and pastures useless. Now carrot grass (*Parthenium hysterophorus*) is entering these areas in a big way. In Maharashtra, many forest nurseries, and in Karnataka and Andhra Pradesh large forest areas have also come under the grip of this weed. With the world's wood needs increasing every year by 64 million cu m, there is need to manage the weeds in our forests to allow natural regeneration of the desired forest species and increase the productivity of the existing trees. Also, weed free buffer strips are essential in forests for preventing fire hazards.

(7) Weeds and Aesthetics:

In many advanced countries lowering of the aesthetic values is the primary objection to weeds. Their presence around living and working places makes the surroundings dull and insipid.

1.3 Beneficial Effects

In spite of all the difficulties caused by weeds, they can offer some beneficial properties, particularly when occurring at low densities. These aspects should be utilized in the farming system, although this may make organic management more complicated than chemical based systems. Some of the potential benefits of weeds are listed below:

- Helping to conserve soil moisture and prevent erosion. A ground cover of weeds will reduce the amount of bare soil exposed helping to conserve nutrients, particularly nitrogen which could otherwise be leached away, especially on light soils.
- Food and shelter can be provided for natural enemies of pests and even alternative food sources for crop pests. The actual presence of weed cover may be a factor in increasing effectiveness of biological control of pests and reducing pest damage.
- Weeds can also be valuable indicators of growing conditions in a field, for example of water levels, compaction and pH.
- Weeds can be an important source of food for wildlife, especially birds. Bird populations have been declining on farmland over the last few decades and leaving weeds as a resource has been shown to help revive bird populations.
- Several known weeds have been put to certain economic uses since ages. Of these, their medicinal use is perhaps the most ancient one in India. Typha and Saccharum spp. are used in cottage industry for making ropes and thatch boards.
- Cichorium intybus roots are used for adding flavour to coffee powder.

- Weeds like Chenopodium album, Amaranthus viridis, and Portulaca spp., form good leafy vegetables.
- Certain weeds have been used to donate specific genes to our crop plants, for instance, Saccharum spontaneum has been widely exploited for developing the present noble canes for North India.
- Fruit and rhizomes of certain weeds are used as vegetable and food material. Attempts are underway to convert weedy vegetation into useful manure, animal feed, paper-pulp, biogas, and edible proteins on commercial basis to make physical control of weeds more attractive.
- More recently, certain weeds have exhibited nematicidal properties. Their incorporation into the soil has been found to result in greatly reduced root-knot nematode population. Some promising weeds in this respect are Crotolaria, Parthenium, Calotropis and Eichhornia spp.
- Some entomologists have found that parasites and predators of certain crop pests also survive on insect pests of certain weeds. Thus, such weeds help in maintaining the continuity of life cycle of certain useful parasites.

However, these cannot dissuade a farmer from fighting weeds on and around his farm.

The cultivation of certain weedy plants as medicinal plants, greens, and forage is a completely different issue; not to be confused with their occurrence on our farm lands where they incur whooping yield and quality losses.

1.4 Characteristics of weeds

Weeds are also like other plants but have special characteristics that tend to put them in the category of unwanted plants. Knowledge about these features will help in developing suitable methods for their control by studying their most sensitive stage in their life cycle. Knowing the characteristics of weeds will help in studying the means of their adaptation as well as extent of loss which these weeds can render to human beings.

1. Weeds have rapid seedling growth and the ability to reproduce when young. Redroot pigweed can flower and produce seed when less than 8 inches tall. Crops cannot do either. *Phyllanthus niruri* has faster growth I groundnut.
2. Quick maturation or only a short time in the vegetative stage. Ephemerals have lifecycle of 1 month. Canada thistle can produce mature seed two weeks after flowering. Russian thistle seeds can germinate very quickly between 28° and 110°F in late spring (Young, 1991). It would spread more, but the seed must germinate in loose soil because the coiled root unwinds as it pushes into soil and is unable to do so in hard soil.
3. Dual modes of reproduction. Most weeds are angiosperms and reproduce by seed. Many also reproduce vegetatively (e.g., Canada thistle, field bindweed, leafy spurge, quackgrass). Cyperus rotundus can propagate through tubers.
4. Environmental plasticity. Many weeds are capable of tolerating and growing under a wide range of climatic and edaphic conditions. Weeds have the capacity to withstand adverse conditions in the field, because they can modify their seed production and growth according to the availability of moisture and temperature. They can germinate under adverse soil-moisture conditions, have short period of plant growth, generallygrow faster rate and produce seed earlier than most of the crops growing in association. Rumex spinosus can germinate in acidic soil
5. Weeds are often self-compatible, but self-pollination is not obligatory.
6. If a weed is cross-pollinated, pollination is accomplished by nonspecialized flower visitors or by wind.
7. Weeds resist detrimental environmental factors. Most crop seeds rot if they do not germinate shortly after planting. Weed seeds resist decay for long periods in soil and remain dormant.

8. Weed seeds exhibit several kinds of dormancy or dispersal in time to escape the rigors of the environment and germinate when conditions are most favorable for survival. Many weeds have no special environmental requirements for germination. Weed seeds remain viable for longer period without losing their viability, e.g. annual meadow grass (Poa annua) and scarlet pimpernel (Anagallis arvensis) remain viable for about 8 years; creeping thistle (Cirsium arvense) for 20 years and field bind weed (Convolvulus arvensis) for about 20-50 years. Cyperus rotundus have 78% viability.
9. Weeds often produce seed that is the same size and shape as crop seed, making physical separation difficult and facilitating spread by man. Cichorium intybus in berseem. Some weeds resemble morphologically with the crop and are difficult to identify at weeding or hoeing.
10. Some annual weeds produce more than one seed crop per year, and seed is produced as long as growing conditions permit.
11. Each generation is capable of producing large numbers of seed per plant, and some seed is produced over a wide range of environmental conditions. Most of the weeds especially annuals produce enormous quantity of seeds, e.g. wild oats (Avena fatua), produces 250 seeds per plant, whereas wild amaranth (Amaranthus viridis) produces nearly 11 million seeds. Striga juncea produces 50 lakh seeds/plant ; Amaranthus viridis produces 1.78 lakh seeds/plant. It has been observed that among 61 perennial weeds, the average seed production capacity was 26,500 per plant.
12. Many weeds have specially adapted long- and short-range seed dispersal mechanisms. Weed seeds have a tremendous capacity to disperse from one place to another through wind, water and animals including man. Many of times, weed seeds mimic with the crop seeds due to their size and get transported from one place to another along with them. There is formation of special structure for effective dissemination. Physallis minima forms balloon structure.
13. Roots of some weeds are able to penetrate and emerge from deep in the soil. While most roots are in the top foot of soil, Canada thistle roots routinely penetrate 3 to 6 feet and field bindweed (Convolvulus arvensis) roots have been recorded over 10-20 feet deep. Roots and rhizomes are capable of growing many feet per year.
14. Roots and other vegetative organs of perennials are vigorous with large food reserves, enabling them to withstand environmental stress and intensive cultivation.
15. Perennials have brittleness in lower stem nodes or in rhizomes and roots, and, if severed, vegetative organs will quickly regenerate a whole plant.
16. Many weeds have adaptations that repel grazing, such as spines (Solanum xanthocarpus), taste, or odor.
17. Weeds have great competitive ability for nutrients, light, and water and can compete by special means (e.g. rosette formation, climbing, allelopathy). For example Echinochloa colona is most competitive and aggressive in rice.
18. Weeds are ubiquitous. They exist everywhere we practice agriculture.
19. Weeds resist control/eradication, including resistance to herbicides.

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CHAPTER-2

Classification, reproduction/propagation and dissemination of weeds

2.1 CLASSIFICATION OF WEEDS:

1	Classification According (C. A.) to Ontogeny/life cycle of weeds	i. Annuals ii. Biennials iii. Perennials
2	CA to seed type/morphology/Cotyledon character	i. Monocot ii. Dicot
3	C. A. to the nature of shoot/stem/plant architecture	i. Woody and Semi woody ii. Herbaceous Spp
4	C. A. to Association	i. Season bound weeds ii. Crop- Bound weeds iii. Crop associated weeds
5	C. A. to habitat	
6	C. A. to the origin of weeds	i. Alien weed ii. Indigenous weed
7	C. A. to soil reaction	i. Acidophile ii. Basophile iii.Neutrophile
8	Facultative and Obligate weeds	i. Apophytes ii. Anthropophytes
9	Noxious and objectionable weeds	
10	C.A to response to photoperiod/day length	i. Short day weeds ii. Long day weeds iii. Day neutral weeds
11	C.A to relative position/presence	i. Absolute weeds ii. Relative weeds iii. Rogues iv. Volunteer weeds
12	C.A to morphology	i. Grasses ii. Sedges iii.Broad leaved

(1)Classification According (C. A.) to Ontogeny/life cycle of weeds:-

Depending upon their life cycle, weeds can be classified as:

(i) Annuals (ii) Biennials and (iii) Perennials

(i) Annuals weeds:

Annuals weeds grow and mature within a year of their germination, but more commonly they complete their life cycle in one season. Ex. Summer annual:- *Trianthema* spp. and *Digera arvensis*; Winter annuals :- *Chenopodium album*.

A weed like *Amaranthus viridis* may grow round the year near irrigation channels and other moist places, but primarily it is a summer annual plant.

A weeds like *Phyllanthus fratenus* ‗Niruri' completes its seed to seed cycle within two or four weeks. Such short – lived annuals are called *Ephemerals*.

General characteristics

i. Annual weeds reproduce by abundant seed production, however some like *Allium* Spp. wild onion and wild garlic may grow also from bulbs and bulbils.

ii. They fail to re-grow when they are cut close to the ground level. These are known as Simple annuals.
iii. Several annual weeds possess crown buds which sprout into new shoots soon after the mother plant is de-topped.
iv. Easy to control. Such weeds must be destroyed before they set seeds.
v. Annuals weeds usually produce thousands of seeds on each plant. Buried in soil by deep tillage. These weed seeds can remain dormant for several years.
vi. This makes weed eradication almost infeasible. Therefore, a farmer must be particular about not allowing the weeds to set seeds on his land.

(ii) Biennials Weeds:

They complete their life cycle in two years; in the first year they remain vegetative and in the second year they produce flowers and set seeds. The usual feature of biennial weeds to flower in the second year of growth limits their dispersal through seeds very much. It is so because they get harvested along with the crop plants before they get a chance to set seeds. (*Launaea nudicaulis*). The biennial weeds must be controlled in the first year of growth before these have a chance to store food in their roots.

(iii) <u>Perennial weeds</u>: They grow for 3 or more years.

i. Usually, perennials weeds flower for the first time in the second year of their growth and thereafter flower each year regularly.

ii. Besides seeds, they reproduce vegetative from underground specialized organs.

iii. In tropical areas these remain green throughout the year although in subtropical regions they may undergo dormancy during the low temperature periods.

Perennials are also endowed with several adaptive measure/mechanisms:

- Longevity of tubers,corms, bulbs, rhizomes, stolons, roots, stems, bulbils
- Presence of deep roots
- Presecnce of buds that sprout from basal portion of stem or below the ground. *e.g*. *Andropogon spp*., *Pennisetum spp*.
- Succelent stems with buds are able to grow when fragmented or cut. *e.g*. *Talinum triangulare.*

Perennial weeds may be classified as:

a. Simple perennials: They are perennials, but reproduce predominantly by seeds and have no natural means of spreading vegetatively unless injured or cut. *Sonchus arvensis* (Sowthistle), *Rumex Sp.* (dock), Lantana camera L. are examples of simple perennials.

b. Creeping perennials: They although have seed propagation, reproduce predominantly by vegetative means such as stolons, rhizomes, tubers, bulbs, corms, roots, stems and leaves and are most difficult to control. *Imperata cylindrical, cynodon dectylon, cyperus rotundus/esculentus* are creeping perrenials.

c. Woody perennials: They grow continuously and consistently over the seasons or years and have annual growth increament as per compound interest law giving rise to woody biomass, stems and branches. Lantana camera L. and Prosopis juliflora/cineraria are examples of woody perennials.

Depending upon the depth of their underground growth the perennial weeds may further be classified as:

(a) Shallow rooted perennials: - eg. C*ynodon dactylon* _Bermudagrass‘ quackgrass‘.

Their roots and rhizomes lie normally in the furrow-slice within 15 cm (6 inches) depth of the agricultural soil..

(b) Deep rooted perennials: - e.g. *Cyperus rotundus* ‗Purple nutsedge' and *Sorghum helepense* Johnsongrass' are deep rooted perennials.

Their roots go deeper even beyond 1-meter depth and the perennating structures lie very deep in soil. Difficult perennials weeds are also called **paracious** weeds.

The control of perennial weeds is much more difficult than that of annual weeds since neither tillage nor the present day selective herbicides can reach their deep roots and underground modified shoot systems. Therefore, attempts to suppress such weeds are usually made during the fallow seasons by deep summer tillage along with the application of herbicides.

(2) CA to seed type/morphology/Cotyledon character:-

(i) Monocots :- Weeds have one cotyledon and can be splitted into two halves Also known as narrow leaf or grass weeds. *Gramineae* is the most important family for monocotyledon weeds. eg. *Cynodon dactylon*.

(ii) Dicot :- Weeds have two cotyledon and cannot be splitted into two halves Also known as broadleaf weeds. *Asteraceae* is the most most important family for monocotyledon weeds ,e.g. *Digera arvensis*

Two exceptions to this are sedges and cattails which although narrow leaved, are not grasses.

They belong to the family C*yperaceae* and *Typhaceae*, respectively.

(3) C. A. to the nature of shoot/stem/plant architecture:-

(i) Woody and Semi woody (ii) Herbaceous Spp.

(i) Woody and Semi Woody weeds : They include shrubs and under-shrub and are collectively called **brush weeds**. *Lantana camara, Acacia arabia, Prosopis juliflora* and *Zizyphus rotundifolia* are the examples of brush weeds.

(ii) Herbaceous weeds: In variance with woody and semi-woody, herbaceous weeds have green, succulent stems and are of most common occurrence around us *Amaranthus viridis*, and *Chenopodium album* are the examples of herbaceous weeds.

(4) C. A. to Association:-

(i) **Season bound weeds: -** It grows in specific season of the year with disregard to the crop species cultivated. These weeds may be either summer annuals or winter annuals. In the case of perennial weeds the period of their major vegetative growth is taken as their growing season, e.g. Sorghum halepense is a summer perennial weed, whereas, Cirsium arvense is a winter perennial weed.

(ii) **Crop- Bound weeds:-** These are usually parasitic weeds. They depend for their survival upon their host plants partially or fully. Cuscuta spp. Orobanche spp. and Striga spp. are the most common crop bound weeds.

A. Based on root-parasitism :

a) Total root/holo-root parasite : They take away food from the host-roots and do not have any other source of gathering food. Therefore, they are also called —obligate root-parasite. For example, Orobanche sp (on tobacco, tomato, fababean, chickpea, mustard, etc).

b) Partial root/hemi-root parasite : Initially they depend upon host-roots for their food and living (sub-terranean/under-ground stage in case of Striga), but later after emergence from soil, they are green, chlorophyllous and can produce their own food. For example, Striga hermonthica/asiatica(=lutea) on sorghum, maize and Striga gesneroides on cowpea.

B. Based on shoot/stem-parasitism:

a) Total stem/holo-stem parasite: They take away food from the host-shoot/stem and do not have any other source of gathering food. Therefore, they are also called —obligate shoot/stem-parasite.‖ For example, Cuscuta campesstris/chinensis/epilinum (on alfalfa, niger and linseed,

respectively). Earlier Cuscuta was the only parasitic genus of the autotrophic family Convolvulaceae. But now-a-days Cuscutaceae, a separate family has come into being for this genus.

b) Partial stem/hemi-stem parasite: Initially they depend upon the host-shoot/stem for their food, but later for becoming green and chlorophyllous, can produce their own food. For example, Loranthus longiflorus is a green colour plant (on mango and other trees) and Cassytha filiformis (on orange, eucalyptus and other trees). Cassytha filiformis has circumnutation anticlock-wise like Cuscuta but is much greener than Cuscuta.

C. Parasitic weed:- Species of weeds which usually parasitize the host plant. It includes following.

Dodder / *Cuscuta*	**Loranthus / *Dandropthoe falcate***	**Broom rape / *Orobanche sp.***	**Witch weed/ *Striga sp.***
Total stem parasite	Partial stem parasite	Total root parasite	Partial/semi root parasite
Host crop- Lucerne	Host crops- Plantation crops	Host crops- Mustard, tobacco, chilli, brinjal, potato	Host crops- sorghum, maize, sugarcane, sunflower

(iii) Crop associated weeds:- These are also crop specific but they may be associated

with certain crops for one of the following reasons:

a. Need for specific micro climate:- Weeds like Cichorium intybus requires a for their best growth shady, cool and moist habitat which is amply available in crops like lucerne and berseem.

b. Mimicry:- Wild rice in paddy field, Wild oat and Canary grass (Phalaris spp.) in small grain crops survive because of their similarity in morphology with host crops. This mechanism is called mimicry.

Examples of mimicry weeds:- Wild rice (O. sativa var. fatua) in paddy Wild oat (A. fatua) and canary grass (Phalaris minor) in wheat.

Mimicry weeds survive well because of their similarity in morphology with host crops.

Possible causes of weed association with crops	Seed mimicry
	Phenotypic mimicry
	Chronological mimicry
	Biochemical mimicry
	Crop micro-climate

Weeds may mimic with crops in the following four ways.

i) **Vegetative/phenotypic mimicry:** Some weeds have similar morphology (leaf, stem) as that of the associated crop plant and therefore, it is difficult to identify and separate out them from crop plants until anthesis/inflorescence occurred. It is called —vegetative/ phenotypic mimicry‖ particularly at the seedling and early vegetative stage. As a result, they remain unweeded even by trained farmers/labourers and are harvested along with crops. For example, *Oryza sativa var fatua*, *Oryza longistaminata* (Wild rice), *Echinochloa colona/crus-galli* (jungle rice/barnyard grass) in rice, *Avena fatua/ludoviciana*, *Phalaris minor/paradoxa* in wheat, *Loranthus sp* in tea, *Saccharum spontaneum* (Wild cane) in sugarcane and *Sorghum halepense* (Wild sorghum) in sorghum.

ii) **Seed mimicry :** These weeds have seeds similar in shape, size and even to some extent by weight to that of some crop seeds called —seed mimicry‖. For example, seeds of *Lolium temulentum*, *Agrostemma githago* resemble wheat seed*, Avena fatua* seeds resemble cultivated oat seeds, *Commelina sativa* seeds resemble flax seeds, *Rottboellia cochinchinensis* (Itch grass) seeds resemble rice seed (upland) and *Cichorium intybus* seeds resemble berseem seeds. They are also called —satellite weeds.

iii) **Chronological mimicry :** These weeds have height and ripening time similar to that of the crop plants associated called —chronological mimicry‖. For example, *Phalaris minor/paradoxa* has almost similar maturity time with wheat crops and as a result, they are harvested along with crop and contaminate wheat grains. They are sown again with wheat in the next year.

iv) Biochemical mimicry: A crop plant is normally tolerant to a herbicide selective to it. A weed associated with the crop although controlled by it may develop resistance to that herbicide through biochemical and physiological alterations/modifications on continuous exposure to it in course of time and behaves like the tolerant crop. As a result, that weed may remain associated with the crop as long as that herbicide or herbicide with similar mode of action continues to be applied in that crop. This means that the weed which was earlier susceptible now mimicking the crop plants through biochemical means.

v) **Ready contamination of crop seeds with weed seeds**. *Allium* spp., Wild garlic and *P. minor* mature their seeds at the same height and time as winter grains and thus they easily contaminate crop seeds at harvest.

(5) C. A. to habitat:

1. Crop land weeds - *Digera arvensis*
2. Fallow land weeds – *(Zizyphus rotundifolia)* Jharber
3. Grassland, Pasture or Rangeland weeds - *Cyperus rotundus*
4. Non cropland weeds (Industrial weeds) - *Xanthium strumarium, Acanthospernum hospidum, Tribumsterrestris*
5. Aquatic weeds - *Eichhornia crassipes*
6. Forest & woodland weeds - *Lantana camera*
7. Lawn and garden weeds - Cyperus *rotandus, Euphorbia spp., Eragratis Major.*
8. rchard and Plantation weeds – *Cynodon dactylon, Cyperus rotandus*
9. Weeds of Road side - *Xanthium strumarium, Parthenium hysterophorus*
10. Weeds of canal & irrigation channel - *Cyperus spp., Cynodon dactylon*

Aquatic weeds:

Unwanted plants, which grow in water and complete at least a part of their life cycle in water are called as aquatic weeds.They are further grouped into four categories as submersed, emersed, marginal and floating weeds.

1. **Submersed weeds:** These weeds are mostly vascular plants that produce all or most of their vegetative growth beneath the water surface, having true roots, stems and leaves. Eg. *Utricularia stellaris, Ceratophyllum demersum.*
2. **Immersed weeds:** These plants are rooted in the bottom mud, with aerial stems and leaves at or above the water surface. The leaves are broad in many plants and sometimes like grasses. These leaves do not rise and fall with water level as in the case of floating weeds. Eg. *Nelumbium speciosum, Jussieua repens.*
3. **Marginal weeds:** Most of these plants are emersed weeds that can grow in moist shoreline areas with a depth of 60 to 90 cm water. These weeds vary in size, shape and habitat. The important genera that comes under this group are; *Typha, Polygonum, Cephalanthus, Scirpus, etc.*
4. **Floating weeds:** These weeds have leaves that float on the water surface either singly or in cluster. Some weeds are free floating and some rooted at the mud bottom and the leaves rise and fall as the water level increases or decreases. Eg. *Eichhornia crassipes, Pistia stratiotes, Salvinia, Nymphaea pubescens*.

(6) C. A. to the origin of weeds:

Many of our weeds in India originated in some other parts of the world. Such weeds are also called **"Anthrophytes / alien/ introduced weeds".** Weeds originating in a country, but got introduced to another country through process of dispersal in course of time are exotic/introduced weeds.

Exotic/introduced weeds may be further classified as:

a. **Naturalised weeds:** Weeds that have become adapted to the environment of the new/introduced country and have established itself adequately and vigorously with viable standing population almost all through the year are said to have become naturalized. For example, *Parthenium hysterphorus* (in India, Ethiopia, Australia and many other countries) and *Eichhrnia crassipes* (in India)

b. **Indigenous weeds:-** Weeds originated in a particular country and growing since long time in a larger number with considerable diversity are indigenous to that country is known as indigenous weeds. For example, *Striga hermonthica* is a native to Africa, *Striga asiatica* is a native to Asia. The origins of some important weeds are as under:

Weeds species	Probable Origin
Convolvulus arvensis	Eurasia
Cyperus rotundus	Eurasia
Eichhornia crassipes	Tropical America Brazil
Lantana camera	Central America/ Tropical America
Orobanche spp.	Europe
Sorghum halepense	Southern Europe and Asia
Tribulus terrestris	Southern Europe

(7) C. A. to soil reaction:

Of the several variable of soil, pH is implicated most frequently with the distribution of weed species over areas of similar agroclimate. On highly acid soils **acidophile** weeds such as

Rumex acetosella tend to dominate the weed flora. on saline and alkali soils **basophile** weeds like *Polygonum* spp. are found. However most of our common weeds are **neutrophiles.**

The texture of soil and consequently its water holding capacity also determines to a great extent, the weed flora of a place. For example, *Tribulus terrestris* and *Euphorbia* spp. dominant on course texture soil whereas *Sorghum halepense* grow abundantly on heavy moisture retentive soils. *Echinochloa colonum* requires wet soils for their best growth.

Prominence of certain weeds on particular texture soils is largely due to their ability to withstand moisture and air condition prevailing in the soil.

Some weeds tend to respond also to the nutrient status of the soil.

(a) High soil fertility eg. Nutsedge, Bhumasi

(b) Low soil fertility eg. Popati

(8) Facultative and Obligate weeds:

Facultative weeds are those weed species that grow primarily in wild communities but often escape to cultivated field, associating themselves closely with man's affairs eg. *Opuntia* spp. These are also known as **apophytes**.

Obligate weeds on the contrary occur only in cultivated or otherwise disturbed land. They cannot stand competition from volunteer vegetation in a closed community. eg. *Convoluvulus arvensis*. These are also known as **anthropophytes**.

(9) Noxious and objectionable weeds:

A noxious weed is a plant arbitrarily defined as being especially undesirable, troublesome and difficult to control. These weeds have immense capacity of reproduction and dispersal and they adopt tricky ways to defy man's efforts to get rid of them. These are sometimes also referred **special problem weeds**. E.g. *Cyperus rotundus, Orobanche spp. Striga spp., Parthenium spp.* and *Cynodon dactylon*. An objectionable weed is a noxious weed whose seed is difficult to separate once mixed with crop seeds. e. g. Jirado with Cumin.

(10) C.A to response to photoperiod/day length:

Short day weeds	**Long day weeds**	**Day neutral weeds**
The weeds, which start flowering when the day length is lower than some critical lengths (8-12 hrs)	The weeds, which start flowering in response to day Length longer than some critical lengths (> 10-12 hrs)	The weeds, which are unaffected by the variation in photoperiodic conditions
Ex:- Chenopodium album, Xanthium strumarium	*Ex:- Chromolaena*	*Ex:- Solanum nigrum*
Also known as long night weeds	Also known as short night weeds	

(11) C.A to relative position/presence:

a. Absolute weeds:- Weeds are wild plants or weedy plants in nature and have no value as crops or any use to farmers under any circumstance, e.g. *Polygonum sp. Rumex Spp.*

b. Relative weeds:- *They are not weeds in nature, but because of their sudden occurrence, or relative presence with certain crop of prime importance, are treated as weed, in strict sense, relative to that situation only. Elsewhere, it may be growing as a crop or other purpose.* ***Undesirable crop plants in the main crop field.*** *For example:- mustard is a weed in wheat field, maize in sorghum field.*

c. Rogues:- *Few plants of a variety of a crop growing here and there in a sattered manner in another variety of prime importance and preferably grown for a situation are treated as rogues.* ***Other varirty plant in the same crop****. For example:- HD 2329 wheat variety in HD 2285 wheat field and Alemaya Composite variety of maize in rare or Bukuri variety of maize are rogues.*

d. Volunteer weeds:- *Such weeds are grown from the fallen seeds of previous or preceding*

(12) C.A to morphology:-

Based on the morphology of the plant, the weeds are also classified in to three categories.

This is the most widely used classification by the weed scientists.

(a) Grasses: All the weeds come under the family *Poaceae* are called as grasses which are characteristically having long narrow spiny leaves. The examples are *Echinocloa colonum, Cynodon dactylon.*

(b) Sedges: The weeds belonging to the family *Cyperaceae* come under this group. The leaves are mostly from the base having modified stem with or without tubers. The examples are *Cyperus rotundus, Fimbrystylis miliaceae*.

(c) Broad leaved weeds: This is the major group of weeds as all other family weeds come under this except that is discussed earlier. All dicotyledon weeds are broad leaved weeds. The examples are *Flavaria australacica, Digera arvensis, Tridax procumbens.*

2.2 PROPAGATION OF WEEDS

(i) Propagation through Seeds:

The majority of weeds reproduce by distinct seed formation which is prolific, particularly in the annual and biennial species. Such weeds are capable of producing easily few thousands of seeds per plant every season at the termination of their vegetative phase. In the perennial species, on

the other hand, the viable seed production facility is much limited, like in *Cyperus rotundus* and *Cynodon dactylon* which produce only 40-170 seeds per plant. But there are exceptions to this generalization since the perennial weeds like Sorghum halepense and *Saccharum spontaneum* produce thousands of seeds per plant every year, in the same fashion as the annual weeds. In an undisturbed field, like in the no-tillage farming system, most weed seeds that fall on the ground tend to remain in the top about 1cm soil layer. But in the conventional farming system, tillage of the field tends to distribute these evenly in the plough layer of the soil. Some weed seeds may reach even deeper, up to 30 cm or more, by entering through the soil crevices. A weed like *Commelina benghalensis* places its seeds directly inside the soil since it produces both aerial and underground flowers and seeds. Within the soil the weed seeds are capable of retaining viability for 2to25 years, depending upon the weed species. For instance, *Rumex* spp. Seeds showed 63-90 % germination up to 2-7 years after these were burried 30 cm deep, while *Echinochloa*, *Poa* and *Chenopodium* spp. germinated even after 25 years of their similar burial in the soil.

(ii) Propagation through Vegetative Propagules:

In vegetative propagation of weeds either their stem or root fragments may grow into new plants, or the weed may produce some specific modified vegetative organs for this purpose, both above and under the ground. These modifications may be in the form of rhizomes, root stocks, runners, stolons, suckers, offsets, tubers bulbs or bulbils. Collectively these are termed as **Vegetative Propagules**.

The vegetative propagation is primarily a feature of perennial weeds which employ one or more of the above cited propagules to achieve the objective, depending upon the weed species. A weed like bermuda grass (*Cynodon dactylon*) uses rhizomes under the ground, and runners and stolons over the ground surface to propagate itself into new colonies. Its rhizomes form a dense network, largely in the plough layer of the soil. But in some other weeds like tiger grass (*Saccharum spontaneum*) and johnson grass (*Sorghum halepense*), the rhizomes travel much deeper into the soil. Purple nutsedge (*Cyperus rotundus*) propagates by its underground, prominent tubers which are, in fact, swollen ends of its wiry rhizomes. In weeds like opuntia (*Opuntia* spp.) and dodder (*Cuscuta* spp.), the detached stems gives rise to new plants. Field/bindweed (*Convolvulus arvensis*) and Canadathistle (*Cirsium arvense*) propagate typically by their extensive horizontal and vertical root system. Offsets are found in an aquatic weed like water hyacinth (*Eichhornia crassipes*). *Hydrilla* spp. Produce aerial buds called turions as additional means of its vegetative propagation.

Beside the perennial weeds, some annual weeds can also adopt specific vegetative propagation mechanism. Such weeds vigourate their crown buds to produce new plants when the parent plants are cut at the ground level. Carrot grass (*Parthenium hysterophorus*), lantana (*Lantana camara*), and arrowwood (*Pluchea lanceolata*) are some weeds of this type.

Weeds equipped with vegetative propagation mechanisms are extremely difficult to manage since their propagules are located in up to 100 cm soil depth where these are not easily approachable even with deep tillage or any available herbicide. Moreover, weeds which are able to regenerate from roots will almost always be able to recover from cultivation, howsoever deep.

2.3 DISPERASAL OF WEEDS:-

The dispersal of seeds and vegetative propagules of weeds away from the parent plants is nature's way of providing non-competitive sites to the new individuals. If all the mature weed seeds were to fall near their mother plants, the young plants would face severe competition amongst themselves, to their great disadvantage. But, fortunately, it is not so. Weeds disperse to new sites freely, with complete disregard to the field and geographical boundaries.

(1)Dispersal Of Weed Seeds:- Weed seeds may get dispersed with agents like

(1) ***Wind***:- Usually, the weed seeds (and fruits) that disseminate through wind possess special organs to keep them afloat. Some such organs are:

(a) Pappus, which is a parachute like modification of persistant calyx into hairs, as found in several Asteraceae weeds

(b) Comose, where weed seeds are covered with special hair, as occurring in *Calotropis* spp.;

(c) Feathery, persistent styles, such as found in certain species Anemone

(d) Balloon, which is a modified papery calyx that encloses the fruit loosely along with the entrapped air, as found in *Physalis minima*; and

(e) Wings, like those developed in Acer macrophyllum.

Besides the above adaptation, some weed seeds and fruits are so light may become air-borne with a storm without any special floating arrangement. The density and test weight of such weeds are very low. High velocity wind can sometimes disperse even heavy weight weed seeds in yet another interesting manner. It may detach the whole plant of the weed from the ground and roll it over long distances, dispersing its seeds all along the way. This mode of dispersal of weed seeds is common with *Carthamus oxyacantha* wild safflower and Salsola kali ‗Russian thistle'. In Argemone mexicana ‗Mexican poppy', the wind swings the intact plants and forces their mature pods to disperse their seeds some distance away from the mother plants. The mechanism is called **Censer-Mechanism.**

(2) ***Water***: - Aquatic weeds disperse primarily through water. They may drift either as whole plants, plant fragments, or as seeds with the water currents. Terrestrial farm weeds also frequently disperse with water in irrigation and drainage channels down the stream to new fields.

(3) ***Animals***: Many weedy fruits and seeds are eaten by birds and animals. Depending upon the digestion mechanism of the animals and the nature of the weed species, 0.2 to9.6% of the ingested weed seeds are passed in viable form with the animal excreta, which is dropped wherever the animal moves. This mechanism of weed dispersal is called **endozoochory.** Chicks digest the weed seeds most efficiently. Several birds pick up the weed fruits and seeds on their wings, feet, and beaks and drop these during their flight. Dissemination of lantana seeds, for example, is chiefly through two birds the Indian Myna and the Chinese turtledove. Parasitic Loranthus seeds stick to the beaks of the birds which are transferred to new branches of the trees when they rub their beaks against them.

Farm animals carry weed seeds and fruits on their skin, hair, and hooves. This is aided by special appendages, such as hooks (ex. *Xanthium stumarium*), stiff hair (ex. *Cenchrus* spp.),Sharp spines (ex. *Tribulus terrestris*), scarious bracts (ex. *Achyranthus aspera*), and sticky grands (ex. *Boerhavia repens*). Ants carry a large number of certain weed seeds possessing attractive secretions, from one place to another.

(4) ***Man***: Careless acts of man are greatly responsible for the dispersal of weeds. For example, when farm machinery is carried from one field to another without proper cleaning, it carries numerous weed seeds with it. Weed seeds and fruits are carried on wheels of carts, automobiles, and aeroplanes. Too, man has carried weeds with him throughout the globe during his travels. Numerous weed seeds and fruits are dispersed by man with raw agricultural produce. This usually occurs in the case of weeds that mature at the same time and height as the host crop, and have similar size and shape of their seeds (orfruits) as the crop seeds. Such weeds are called **satellite weeds,** for instance, *Avena fatua*, *Phalaris minor*, *Oryza* spp., *Cichorium intybus*, and *Cuscuta* spp. They form an integral part of specific crops.

(5) ***Manures and Silage***: Farm-yard manure can be an important source of dissemination of weeds since after numerous viable weed seeds are present in the dung of farm animals. Also, there are often direct additions of mature weeds to the compost pits as farm wastes. Even under optimum temperature and acidity conditions of the compost pits, the seeds of a weed like Convolvulus arvensis (field bindweeds) have been reported to retain viability to the extent of 4% in the first month of composting, and up to 1% two months later.

(2) Dispersal of Vegetative Propagules of Weeds:

Careless cultivation of land is perhaps the foremost factor in the dispersal of vegetative propagules of weeds.

1. Cultivation detaches underground organs of weeds such as rhizomes, rootstocks, and tubers and drags them to uninfested spots where they grow into new colonies. The aerial bulbs of *Allium* spp. (Wild onion) disseminate with seeds of small grains.
2. Transplants of crops often carry weed seeds, rhizomes, and tubers hidden in their root soil. A weed like *Echinochloa* spp. _Barnyard grass` mimics rice plants so well that in may leave rice nurseries along with the crop seedlings and get transplanted in the main field in large numbers.
3. Aquatic weeds (whole plant, plant fragments, or vegetative propagules) disseminate largely with water current, boats, and ships.

2.4 PERSISTENCE OF WEEDS:-

High persistence of weeds results from their multifacet mechanisms. Important among these are:-

(i) Prolific Seed Production:-

Seed Production Capacity of Certain Common Weeds

Weed species	**Average No. of seeds per plant**	**Immediate germination %**
Amarathus spp.	196000	Not recorded
Brassica nigra	58000	Not recorded
Chenopodium album	72000	Not recorded
Cuscuta spp.	16000	Not recorded
Cynodon dactylon	170	6
Cyperus esculentus	820	38
C. rotundus	40	0
Datura stramonium	13900	5
Eleusine indica	41200	61
Portulaca spp.	193000	6
Trianthema spp.	52000	Not recorded

(ii) Dormancy of Weed Seeds and Other Propagules in Soil:

Within the soil weed seeds can remain dormant for three reasons:-

(a) Enforced Dormancy: - Enforced dormancy in weed seeds is due to their placement deeper than 5 cm, resulting usually from tillage of the field. Weed seeds under this kind of dormancy germinate readily whenever these are restored to the top 3 to 5 cm layer of soil by tillage, provided adequate soil moisture and congenial temperatures were available in this zone of the soil. Enforced dormancy is a non-specific character of the seeds and it is caused by the absence of red light ® under the ground, which otherwise induces germination in seeds.

(b) Innate Dormancy:- Innate dormancy is a genetically controlled character and it is a feature of specific weed seeds. Innate dormant seeds will fail to germinate even if they were present in the top 3 to 5 cm soil and adequate soil moisture and temperature conditions were provided to them. Innate dormancy usually results for reasons of either hard seed coat. In certain weed seeds, particularly those of xerophytic origin, the presence of specific germination inhibitors

is responsible for their innate dormancy. In nature the innate dormancy of weed seeds is overcome with either passage of time, or under the influence of some climatic pressure.

(c) Induced Dormancy:- Induced dormancy results from some sudden physiological change in otherwise non-dormant weed seeds under the impact of factors like a marked rise in soil temperature, increased CO_2 content of the soil, low O_2 pressures, water logging, etc. Certain weed seeds, like those of wild oat exhibit all the three kinds of dormancies.

(iii) Vegetative Propagation:- Many weeds are extremely persistent because of their ability to propagate by vegetative means. When the above ground parts of such weeds are destroyed, their deeply placed vegetative propagules put forth new shoots as soon as the external stresses are removed and favorable conditions revive. Even if some kind of deep tillage is employed in an attempt to destroy these, it will be a futile exercise since fragments of the weed propagules get easily dispersed to new areas where they initiate fresh colonies.

(iv) Rapid Dispersal:- Dispersal is a very important means of persistence of weeds. It exposes them to different ecosystems so that each weed species can choose its most favorable environment and put up a hard struggle for existence in nature. Dispersal is the key factor in developing a persistent weed population for every possible niche in the environment. Dispersal aids persistence of weeds in proportion to the dispersal agents and adaptations available to them.

(v) Inherent Hardiness:- To be widely successful a weed species must adapt itself to diverse environmental conditions. Weeds seem to possess some kind of built-in mechanism to survive against the vagaries of nature, like extreme cold, heat, drought, biotic stress, and soil abnormalities. This is inherent hardiness of weeds.

(vi) Evasiveness:- Many a weed is capable of evading destruction by animals and man because of their bitter taste, disagreeable odor, spiny nature, and mimicry.

(vi) Self Regeneration:- Weeds are self-sown plants. They don't require any artificial, friable seedbeds for their germination. Detached from the mother plants, weed seeds and other propagules germinate profusely on un disturbed soils whenever the environment is favorable for the purpose.

(vii) Selective Invasion:- Weed species differ widely in their soil and climatic requirements. But in the first instance, the weed flora composition depends upon the chance a particular weed had to reach a particular site. The nature then makes a critical selection out of the lot and allows only those weed seeds to germinate at a time which were most adapted to the environment prevailing then. The seeds of rest of the weed species wait in soil till the environment outside changes. At this stage, suddenly another set of weed species takes over the ground. The major environment factors which determine the weed species composition on the ground comprise the available soil moisture, soil pH, temperature, photoperiod, and solar energy.

(ix) Weed Succession:- In nature, the individuals of a weed species often have chance to cross breed to variable levels. This leads to the development of a few plants of different genetic make-up, forming new races within a species. Such races of weeds are called **agricultural ecotypes.** When herbicides (or bio agents) are used continuously to destroy the —normal‖ races of a weed species, their newly developed ecotypes may sometimes prove tolerant to the herbicides used; whence they get chance to gradually expand in numbers, each season. Such agricultural ecotypes are then called **chemo types.** The chemo types greatly aid a weed species to persist. Weed succession can also occur amongst different weed species themselves in response to long term adoption of an agricultural practice, including the use of herbicides. This leads to the destruction of the susceptible group of weed species, leaving behind few plants of the resistant species to gradually build up their population and finally emerge as the dominant weed flora of the area.

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CHAPTER-3

Herbicide classification

(A) Based on Mode of action

Selective and Non Selective Herbicides

Selective: - A selective herbicide is one that will kill some plant species when applied to a mixed plant population without causing serious injury to other species. e.g. 2, 4, D, Atrazine etc.

It is used in crop areas, loans, gardens and grasslands. Certain selective herbicides when applied at higher rates act as non-selective plant killers, for instance, simazine and duran. Today the field of selective herbicidal control has reached such as advanced stage when a weed of grass family can be controlled in a crop of the same family, for instance, *Avena fatua* _wild oat' in wheat. Besides such occasional inherent selectivity among herbicides, man has been able purposefully induce selectivity in some herbicides to specific crops by modifying their mode of application.

Non- Selective :- A non- selective herbicide is one that kills plant without regard to species for example, paraquat, glyphosat, sodium chlorate etc. these herbicides are employed for general vegetation control on industrial sites, fallow land and in aquatics.

(B) Based on spectrum of weed control

Narrow Spectrum and Broad Spectrum Herbicides

Narrow Spectrum: - The narrow spectrum herbicides prove active on one or a very limited number of plant species. Most of other plants remain tolerant to such herbicides. These herbicides are very useful against specific noxious weeds like Avena and Phalaris spp. Metoxuron, difenzoquat and diclofop are very successful examples of narrow spectrum herbicides. A limitation of narrow spectrum herbicides is the need to employ several herbicides to control different weed species. This may contribute to environmental pollution.

Broad Spectrum Herbicides: - These herbicides control a wide spectrum of weed flora. Most of our herbicides today belonging to this group of herbicides.

SN	Narrow Spectrum herbicide	Broad Spectrum herbicide
1.	Controls particular group of weeds	Controls a wider array of weeds constituting grasses, broad leaved and sedges
2.	Ex- 2,4-D, metsulfuron-methyle	Ex- Glyphosate, paraquat
3.	Their range of activity is narrow	Their range of activity over the species of weed is broad
4.	They could be useful against a specific problem weed	They could be useful for grasses, broad leaved and sedges

(C) Based on Method of application/Surface or site of application

Soil Active and Foliage Active Herbicides

Soil Active: - It is applied primarily to the soil rather than to the vegetation. Inside soil it kills weeds as they germinate or inhibits sprouting of their rhizomes, stolons and tubers. Therefore, in crop fields a soil-active herbicide eliminates early weed-crop competition for the period it remains active in soil. This period is usually 4 to 8 weeks, depending upon the herbicide and its rate used. These herbicides are largely applied at the time of planting of crops, but in some cases these may also be applied to the weed-free inter-rows of established crops to obtain extended weed control e. g. Simazine, Alachlor, Trifluralin and EPTC. On non-cropland, the soil-active herbicides used are largely sterilent and fumigant.

Foliage Active: - These herbicides are applied to weeds after their emergence from soil. They are absorbed by plant foliage and in many cases these are translocated to other plant parts. At normal rates the foliage active herbicides are most effective against young weeds in their seedling stage but at high rates these may kill even the established weeds. e.g. Paraquat, Amitrol. There may be some herbicides that are both soil and foliage active e. g. 2, 4, D, Atrazine and Picloram.

Soil-Active Herbicides are more popular – Why?

i) It controls weeds even before they germinate, thus eliminating early period weed competition.

ii) They maintain weed control for considerable period after application.

iii) It provides better selectivity to the treated crops.

(D) Based on mobility/mode of action Contact and Translocated Herbicides: -

Contact -It kills pants primarily by contact with plant tissue rather than as a result of translocation. Thus a contact herbicides applied to the foliage of a plant will not kill its roots, though in simple annuals the roots of treated plants may die because they are deprived of their shoots. The established weeds will regrow from their crown buds, roots or rhizomes, shortly after treatment with contact herbicides. e.g. Paraquat, Diquat, Propanil and Petroleum oils.

Translocated: - These herbicides move within the plant from the point of treatment to other plant parts. It kills the entire plant even if only a portion of the plant was treated with the herbicides. Therefore, trans located types of herbicides are of particular importance in controlling the perennial weeds. Also, the trans located herbicides can be applied in low volume sprays to control annual weeds because they need to wet only a portion of the plant foliage against contact herbicides which must drench the weeds fully for their effective kill.

Some herbicides may exhibit both contact and translocation properties. e. g. Atrazine is Tranlocated herbicides when absorbed from soil but contact herbicides when sprayed on plant shoots.

SN	Contact herbicide	Translocated herbicide
1	Not absolutely contact, but have limited mobility	Highly mobile through plant sytem
2	Less efficient in controlling perennial weeds having underground vegetative structure	More efficient in controlling perennial weeds having underground vegetative structure
3	Less risk in cropped situation if applied by mistake	More risk in cropped situation if applied by mistake
4	Ex- Paraquat,diquat	Ex- Glyphosate

(E) Based on residual action in soil

Residual and Non- Residual Herbicides: - Residual: -

Residual herbicides maintain their phytotoxic effects in soil for a considerable time after their application. This period may be 3 to 4 weeks in some herbicides, such as 2, 4, D and EPTC and much longer up to several months in others. In intensive crop rotations usually herbicides with 3 to 6 weeks of residual activity in soils are used.

Non-Residual:

These herbicides are inactivated in soil immediately or within a few days after they reach the soil. e.g. Paraquat, Glyphosate, Diquat, Amitrol and weed oil. These herbicides are good for a quick knock down of the existing weeds, they do not provide any extended period of weed control. In agriculture, their chief importance lies in destroying weed infestation occurring either before planting or before germination of the crops.

They are called non-residual because they get usually adsorbed to soil colloids as soon as they fall on the ground and become inactivated. The droplets falling on the soil are simply a waste. Therefore, they should be targeted mainly to the canopy/foliage of weeds.

(F) Based on duration of weed control (Mainly under Non-crop Situation)

Soil Sterilants and Fumigants

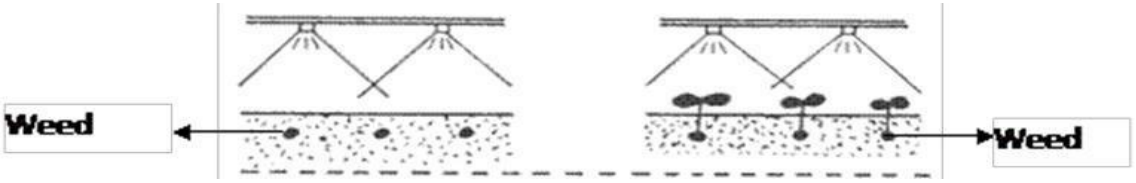
Soil Sterilant:

A soil sterilant type of herbicides will prevent the growth of plants when present in soil. Their soil sterilizing effects may be either temporary or relatively permanent. Temporary soil sterilants sterilize the soil for up to 16 weeks whereas the permanent ones remain active for a much longer period, sometimes for two or more years. Temporary soil sterilants are usually volatile compounds which leave the soil in vapour form after a few days to a few weeks of its application. During this period these are supposed to have killing all live plant parts in the soil. Such sterilants are also called **soil fumigants.** e. g. MB, Methan and Dazomet. Permanent soil sterilants on the other hand find their chief use in causing bare ground in industrial and other non-crop areas for one or more season. Sodium chlorate, substituted ureas, several symmetrical triazines, arsenics and borates are major permanent soil sterilants in use currently.

Sr No.	Temporary soil sterilant herbicide	Permanent soil sterilant herbicide
1.	They sterilize the soil for relatively short period of time usually for 15-16 weeks	They remain active in soil for relatively long period of time, sometimesfortwoormore seasons/years
2.	Ex- Methyle bromide, carbon disulphide, chlorfenac	Ex- Triazines, sodium chlorate
3.	They could be used in the nursery beds for rice, tobacco and TP vegetables	They are recommended mainly for industrial and non-cropped areas
4.	Time- 15-16 weeks	Time- two or more seasons/years

(G) Based on Time of application
Pre - plant application (PPI)

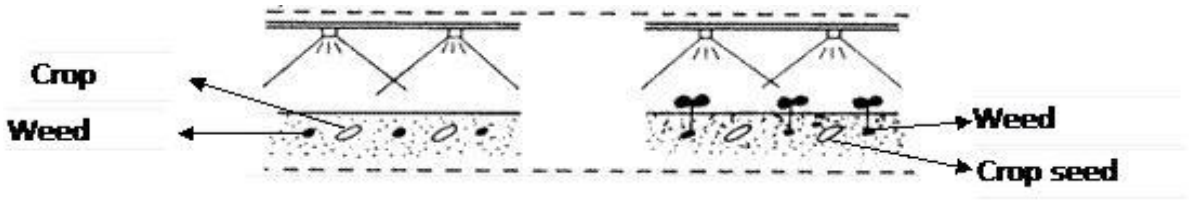
Application of herbicides before the crop is planted or sown. Soil application as well as foliar application is done here. For example, fluchloralin can be applied to soil and incorporated before sowing rainfed groundnut while glyphosate can be applied on the foliage of perennial weeds like Cyperus rotundus before planting of any crop.



Pre – emergence

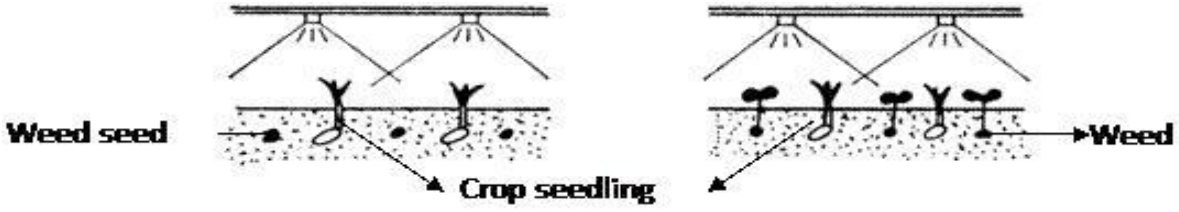
Application of herbicides before a crop or weed has emerged. In case of annual crops application is done after the sowing of the crop but before the emergence of weeds and this is referred as pre-emergence to the crop while in the case perennial crops it can be said as pre-emergence to weeds. For example soil application by spraying of atrazine on 3rd DAT to

sugarcane can be termed as pre-emergence to cane crop while soil application by spraying the same immediately after a rain to control a new flush of weeds in a inter-cultivated orchard can be specified as pre-emergence to weed. Eg. Atrazine, Pendimethalin, Butachlor, Thiobencarb, Pretilachlor.



Post – emergence

Herbicide application after the emergence of crop or weed is referred as post-emergence application. When the weeds grow before the crop plants have emerged through the soil and are killed with a herbicide then it is called as early post-emergence. For example spraying 2,4-D Na salt to control parasitic weed striga in sugarcane is called as post-emergence while spraying of paraquat to control emerged weeds after 10-15 days after planting potato can be called as early post-emergence. Eg. Glyphosate, Paraquat, 2,4-D Na Salt.



Early post emergence: Another application of herbicide in the slow growing crops like potato, sugarcane, 2-3 week after sowing is classified as early post emergence.

(F) Based on Chemical Nature or Composition

Compounds having chemical affinities are grouped together. This is useful in liting and characterising herbicides.

i) Inorganic Herbicides:

Contain no carbon actions in their molecules. These were the first chemicals used for weed control before the introduction of the organic compounds, example are:

a) Acids: Arsenic acid, arsenious acid, arsenic trioxide sulphuric acid.

b) Salts: Borax, copper sulphate, ammonium sulphate, Na chlorate , Na arsenite , copper nitrate.

ii) Organic Herbicides:

Oils and non oils contain carbon and hydrogen in their molecules.

a) Oils: Diesel oil, standard solvent, xylene-type, aromatic oils, polycyclic , aromatic oils etc.

b) **Aliphatics:** Dalapon, TCA, Acrolein, Glyphosphate methyl bromide.

c) Amides: Propanil, butachlor, alachlor, CDAA, Diphenamide, Naptalam, Propachlor.

d) Benzoics: 2,3,6 TBA, Diacamba, tricamba, chloramben, Fenac.

e) Bipyridyliums: Paraquat , diquat.

f) Carbamates: Propham, chloropham, barban.

g) Thocarbamates: Butylate, dilate, triallate, EPTC, molinate, pebulate, vernolate, benthlocarb, aslum, cycolate.

h) Dithiocarbamates: CDEC , Metham.

i) Nitralin (Benzonitrates) : Dichlobenil , bromoxynil, ioxynil.

j) Ditroanilines (Toluidines) : Benefin, nitralin, trifluralin, butralin, dinitramine, fluchlorine, oxyzalin, penoxalin.

k) Phenoxy: 2,4-D, 2,4 , 5-T, MCPB, 2,4-DB, 2,4- DP, 2,4 , 5-TP (silvex)

l) Triazines: Atrazine, simazine, ametryne , terbuteryne, cyprazinc, Metribuzin, prometryn, propazine.

m) Ureas: Monuron, diuron, fenuron, neburon, flumeturon, mothabenzathiazuron- buturon, chlorbromuron, chloroxuron, norea siduson, metoxuron.

n)Uracils: Bromacil, terbacil, lenacil.

o) Diphenyl Ethers: Nitrogen, flurodifen.

p) Organic Arsenicals: Cacodlic acid, MSMA, DSMA.

q) Others: Bentazon, Piclaram, Pyrazon, Pyrichlor, endothall, bensulphioe, MH, DCPA.

(G) Based on window of application

a) Narrow-window herbicide: Narrow-window herbicides have length/range of time of application highly reduced/limited to just before sowing or from sowing to before emergence of crop or at a specific time after crop emergence as post-emergence. They are, therefore, pre-planting, pre-emergence or post-emergence herbicides, e.g. trifluralin, fluchloralin, pendimethalin, fenoxaprop-p-ethyl, clodinafop-propargyl, sulfosulfuron, tralkoxydim etc. Once a crop is left untreated at the specified period, almost all these herbicides cannot be used again in other growth stages of that crop.

b) Wider-window herbicide: Wider-window herbicides as desired should have length/range of time span of application wider, for example, from before sowing or after sowing to longer period of crop growth may be up to 40 days after emergence of crop in certain cases. They, therefore, are herbicides with extended period of activity along the crop growth cycle. In fact, there is hardly any herbicide in the world today, which is wider-window in true sense. Atrazine and butachlor because of their pre- and post-emergence activities may loosely be held as wider-window herbicides. Chlorimuron-p-ethyl can be used as PPI, pre-emergence or post-emergence in a few crops particularly soybean and may be assumed to be a wider-window herbicide for soybean.

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CHAPTER-4

Concept of adjuvant and surfactant

ADJUVANTS

An adjuvant is an additive (usually in relatively low amounts compared to the carrier) that improves or enhances application, performance, safety, storage, or handling of an active ingredient. Adjuvants include materials such as:

1. Surfactants (spreaders, stickers, emulsifiers, wetting agents), which increase surface contact, reduce runoff, and increase penetration through leaf cuticle
2. Anti-drift agents
3. Color and/or odor additives to discourage ingestion
4. Anti-freeze or other stabilizing chemicals to promote storage

An adjuvant is any material added to a herbicide spray solution that modifies or enhances the action of that solution. Many herbicides already contain adjuvants as part of their formulations. Some of these formulations can be used directly whereas others need to be applied in conjunction with one or more adjuvants. There are over 3,000 adjuvants available for use. These can be grouped into three general types of adjuvants, including activators, spray modifiers and utility modifiers.

An adjuvant is a chemical added to a pesticide formulation or tank mix to improve mixing and application or enhance performance. With judicious use of adjuvants, the effectiveness of the pesticide compound may be increased as much as 5 or 10 fold. Most pesticide formulations contain at least a small percentage of adjuvants. Wetting agents and spreaders are the adjuvants most frequently added by pesticide users. A small number of products, however, require avoiding adjuvants altogether. One should read the pesticide label before adding any surfactant to the spray mixture.

Common adjuvants and their functions are as follows:

Wettings agents: It allows wettable powders to mix with water.

Emulsifiers: It allows petroleum-based pesticides (ECs) to mix with water.

Invert emulsifiers: It allows water-based pesticides to mix with petroleum carrier.

Spreaders: It allows pesticide to form a uniform coating layer over the treated surface.

Stickers: It allows pesticide to stay on the treated surface.

Penetrants: It allows pesticide to get through the outer surface to the inside of the treated area.

Foaming agents: It reduces drift.

Thickeners: It reduces drift by increasing droplet size and reducing volume of spray contained in drift-prone droplets.

Safeners: It reduces the toxicity of a pesticide formulation to the pesticide handler or to the treated surface.

Compatibility agents: It aids in combining pesticides effectively.

Buffers: It allows mixing of pesticides of different acidity or alkalinity.

Antifoaming agents: It reduces foaming of spray mixtures that require vigorous agitation.

Spray additives

Adjuvants are often added to spray mixtures to modify or enhance herbicidal activity or aid in the spraying operation. Use of adjuvants, other than as formulation agents, is primarily restricted to

postemergence herbicide applications. Adjuvants can be divided into two general categories: spray modifiers and activators. The most common type of adjuvants is

1. Activity enhancers, such as surfactants, oils, organosilicanes, and fertilizers,
2. Spray modifiers such as stickers and drift control agents, and
3. Utility modifiers such as compatibility and antifoam agents.

However, not all adjuvants are always beneficial; some may have no effect or even decrease the desired effect. Therefore, adjuvants should not be placed in the spray mixture unless suggested on the label or recommended by knowledgeable authorities.

Activity Enhancers

Surfactants derive their name from the term surface-active agents. Most surfactant molecules are composed of a lipophilic long-chain hydrocarbon (alkyl) group and a hydrophilic polar group. Surfactants are generally classified according to the nature of the polar segment of the molecule. Among the types of surfactants are

1. Cationic (positive charge),
2. Anionic (negative charge)
3. zwitterionic (having both a positive and a negative charge, depending on the water pH), and
4. Non-ionic (no charge).

Non-ionic surfactants dissociate little in water, whereas the others are charged when dissolved in water. Because adjuvants contain both lipophilic (oil-like) and hydrophilic (water like) properties, they can interact with the lipophilic plant surfaces, lipophilic herbicides, hydrophilic herbicides, and water. The most common surfactants for use with herbicides are non-ionic, and most emulsifiers are blends of anionic and nonionic types. In general, a blend with a high proportion of the anionic types will improve performance in cold water and soft water, whereas a blend with a predominance of nonionic types will usually perform better in warm water and hard water.

At low to normal spray volumes, adjuvants usually increase the effectiveness of herbicidal sprays by increasing the coverage of the plant surface; herbicide absorption is thereby also increased. However, at high spray volumes adjuvants may decrease effectiveness by causing excessive —runoff‖ from the plant onto the ground. Herbicidal selectivity may be lost by the addition of an adjuvant if the desired selectivity among species depends on differential wetting and thus absorption.

Spray Modifiers

Spray modifiers, such as stickers, increase the adhesion of spray solutions to treated plant surfaces and are often used in conjunction with wetting agents (referred to as spreader-stickers). Film-forming vegetable gels, emulsifiable resins, emulsifiable mineral oils, waxes, and water-soluble polymers have been used as stickers.

Drift control agents are materials that thicken the spray solution and thereby increase droplet size and reduce the number of very small satellite droplets. These materials include swellable polymers and hydroxyethyl cellulose or polysaccharide gums and are used at concentrations of 0.1 to 1.0% of the volume. Invert emulsions are also used to reduce spray drift.

Drift control agents are of great value when herbicide applications are made near sensitive nontarget plants, even though they increase application costs. The appropriate spray equipment and operating conditions must be used with these thickened solutions.

Utility Modifiers

Utility modifiers are adjuvants that are used to reduce or avoid application problems and/or increase the usefulness of a formulation. Emulsifiers and other surfactants of herbicide formulations can cause foaming with agitation of the spray mixture. Thus, antifoam agents are

used to prevent or reduce excessive foaming in the spray tank. Antifoam agents are typically silicones and are used at 0.1% by volume. Kerosene or diesel fuel added to the spray tank at the same rate can often inhibit foaming.

Compatibility agents are used to help with mixing and/or application problems that may occur when a combination of pesticides is used. They can also be used when herbicides and applied in combination with a suspension, slurry, or true solution of fertilizers. Compatibility agents can counter separation problems that occur with hard or cold water.

Surfactant:- Surface Acting Agent/Reduces SurfaceTension

A surfactant is a material that exhibits activity at the surface or interfaces. Surfactant is key component of formulation and their role differs from product to product. In WP, WDP and WDG formulations, they act as wetting, dispersing and suspending agents; in EC and EW as emulsifying agent; in SC as suspending agents.

Surface tension:

The molecules at the surface do not have other molecules on all sides of them and therefore are pulled inwards. This creates some internal pressure and forces liquid surfaces to contract to the minimal area.

Surfactants: are substances that absorb to surfaces or interfaces, causing a marked decrease in the surface tension.

Surfactant structure

All surfactants are characterized by having two regions in their molecular structure:

A) a hydrophobic group, such as a hydrocarbon chain, that has no affinity for aqueous solvents

B) a hydrophilic group that has an affinity for water. A molecular or ion that possesses this type of structure is termed amphipathic (amphiphilic).

Characteristics features of surfactants: -

- **Amphipathic structure:** It consists of two parts, hydrophilic and hydrophobic and on account of this nature, it works as wetting agents, spreaders, penetrants, translocate pesticides in different parts of plants or insect cuticle.
- **Solubility:** Soluble at least in one of the phase of the liquid system.
- **Adsorption and orientation at interface:** micelle formation helps adsorption and orientation
- Increases emulsifying, spreading, dispersibility, wetting, sticking, cuticular penetration and absorption by plants.
- Tank mix adjuvants modify atomization, retention, sorption and chemical stability.
- A surfactant has critical micelle concentration (CMC) and Kraft Point.
- **CMC** is defined as the concentration of surfactants above which micelles are spontaneously formed.
- **Kraft Point** is an important property of micelles and is defined as the temperature at which the solubility of surfactant is equal to its CMC.
- **Hydrophile-lipophile balance (HLB):-** Hydrophile-lipophile balance : surfactants contain both hydrophilic groups and lipophilic groups with one or the other being more predominant, the hydrophile-lipophile balance (HLB) number is used as a measure of the ratio of these groups. It is a value between 0-40 defining the affinity of a surfactant for water or oil. HLB value of nonionic surfactants ranges from 0-20. HLB numbers >10 have an affinity for water (hydrophilic) and number <10 have an affinity of oil (lipophilic).

- **Usefulness and limitations of surfactants:**
- Surfactants may be increase or decrease total spray retention
- Increase spray retention at key sites
- Increase penetration by increasing area of contact with the leaf surface by greater droplet spread and eliminating air film between droplets and leaf surface.
- Reduce interfacial tension and surface tension
- Act as humicants and solubilizing agents
- Facilitate movement along cell walls after entry by lowering interfacial tension
- Helps in redistribution of chemicals upon rewetting
- Provide safety to operators

Different surfactants used for herbicides

Non-ionic	Anionic	Cationic
Non-ionic surfactants are widely used in agriculture and work well in warm water and hard water	Anionic surfactants are widely used in agriculture and work well in cold water and soft water	Cationic surfactants are Compatible with cationic herbicides, *e.g.* paraquat, diquat, glufosinate-AM
It comprise of carboxylic amide, ethoxylated alkyl phenol, anhydro sorbitol ester	It comprise of carboxylate, sulphonate, sulphate and phosphate ester.	Quaternary ammonium compound is an example.

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CHAPTER-5

Herbicide formulation and their use

Herbicide formulations

Herbicide formulations contain active ingredients (the component of the herbicide formulation responsible for being phytotoxic to the weed) and inert ingredients. Inert ingredients include anything other than the active ingredient and can usually be divided into two categories including solvents and adjuvants. Common solvents include substances such as water, petroleum distillates and clay.

WHAT ARE HERBICIDES?

- Herbicides, also commonly known as weed killers, are weedicides used to kill unwanted plants in the cropped areas.
- Herbicides are the substances that are toxic to plants, used to destroy unwanted vegetation.
- Herbicides used to clear waste ground, industrial sites, railways and railway embankments are not selective and kill all plant material with which they come into contact. Smaller quantities are used in forestry, pasture systems, and management of areas set aside as wildlife habitat.
- Just as a pesticide is used to rid an area of unwanted pests, the herbicide is used to get rid of unwanted plant life, like weeds, brush, unproductive bushes or trees, and other growth that takes nutrients away from crops and other useful plants.
- Herbicides are available in two main types: non-selective and selective. The non-selective variety is used to kill all growth and is generally reserved for agricultural use or for clearing large or heavily overgrown areas. On the other hand, a selective herbicide is used to target certain types of plant life. This form works to curb growth, usually through some type of hormone disruption, and should not affect other vegetation.

What is herbicide formulation?

- The active ingredient in a herbicide is the chemical that controls the target weed. The herbicide product you purchase is rarely made up only of active ingredients. Often the herbicide is diluted in water or a petroleum solvent, and other chemicals are added before the product is offered for sale. These other chemicals may include wetting agents, spreaders, stickers, extenders, or diluents. They usually make the product easier to apply and more convenient to handle. This mixture of active and inert ingredients (inactive) is called a formulation of herbicide.
- An herbicide formulation is the total marketed product and is typically available in forms that can be sprayed on as liquids or applied as dry solids. It includes the active ingredient(s), any additives that enhance herbicide effectiveness, stability or ease of application such as surfactants and other adjuvants, and any other ingredients including solvents, carriers or dyes. The application method and species to be treated will determine which formulation is best to use.

Formulation of herbicides

The different formulations of herbicides are:

- Dry formulations
- Liquid formulations
- Adjuvants
- Salts & Esters

Dry formulations

- **Granules (G):** Granules consist of the active ingredient absorbed onto coarse particles of clay or other substance, and are most often used in soil applications. These formulations can persist for some time and may need to be incorporated into the soil. The amount of a.i. ranges from 1 to 15%. Ex: Top-Site, Sprakill 13, Arsenal 0.5 G.
- **Pellets (P) or tablets (TB)** : Pellets are similar to granules but tend to be more uniform in size and shape. Pellets provide a high degree of applicator safety. Example: Spike 20P
- **Dust (D)** : A dust is a finely ground pesticide combined with an inert or inactive dry carrier. They can pose a drift or inhalation hazard.
- **Wettable Powder (WP or W):** Wettable powders are finely ground solids, typically mineral clays, to which an active ingredient is absorbed. They provide an effective way to apply an active ingredient in a water spray that is not readily soluble in water. These dry preparations look like dust, contain a high percent active ingredient (usually 50 percent or more) and are mixed with water for application. Wettable powders form a suspension rather than the true solution when added to water. Good agitation (mixing) is needed in the spray tank to maintain the suspension. Example: Spike 80W.
- **Soluble Powder (SP):** This is a dry formulation that contains a high percent (usually above 50 percent) active ingredient. Soluble powders look like wettable powders but they form a true solution when added to water. Agitation in the spray tank will help this formulation to dissolve. After dissolving, no more agitation is usually needed. Few herbicides are available in this formulation because few active ingredients are soluble in water. Soluble powders are nonabrasive to equipment. Inhalation hazard is a characteristic of this formulation. Example: Solution
- **Water-Dispersible Granule or Dry Flowable (WDG or DF):** Dry flowable are manufactured in the same way as wettable powders except that the powder is aggregated into granular particles. They are mixed with water and applied in a spray exactly like a wettable powder. This dry formulation usually contains 70 to 90 percent active ingredient. The formulation pours easily without the windblown dust associated with wettable powders and readily disperses in water to form a suspension. Constant agitation is required. Example: Diuron 80, Escort, Karmex, Oust, Sahara, Velpar DF.

Liquid formulations

Liquid formulations do not exhibit the variety of physical forms possible with dry formulations. However, liquid formulations differ markedly in the nature of their characteristics that influence selection, rate and method of application, and environmental impact.

- **Water-Soluble Concentrate (WSC):** Water-soluble concentrates to form a true solution when added to water and is applied with water as the carrier. These herbicides usually have an amine (ammonium salt) or mineral salt in the molecule that enables water solubility. These formulations are essentially nonvolatile. There are usually 2 to 6 pounds of active ingredient per gallon of the formulation. Agitation is not necessary to maintain the herbicide in solution. Example: Arsenal, Formula 40, Garlon 3A, Krenite, Roundup Pro, Tordon K, Vanquish, Veteran 720.
- **Emulsifiable Concentrate (E or EC):** An emulsifiable concentrate formulation usually contains the active ingredient, one or more petroleum solvents, and an emulsifier that allows the formulation to be mixed with water. Emulsifiable concentrates usually contain 2 to 8 pounds of active ingredient per gallon. These concentrates are soluble in oil and form an emulsion in water. There usually is a dermal (skin contact) hazard associated with this formulation. Example: Garlon 4
- **Flowable or Aqueous Suspension (F, L or AS):** In this formulation, very finely ground solid material is suspended in a liquid. Liquid flowable usually contain a high concentration (4

pounds or more) of active ingredient and are mixed with water for application. The formulation has the same major characteristics as a wettable powder; it forms a suspension when added to water, and it enables the application of water-insoluble herbicides in water. They seldom clog spray nozzles and they need only moderate agitation. Example: Diuron 4L

- **Liquid suspensions (L for liquid or F for flowable) :** That are dispersed in water include: suspension concentrates (SC), aqueous suspensions (AS), emulsions of water-dissolved herbicide in oil (EO), emulsions of an oil-dissolved herbicide in water (EW), micro-encapsulated formulations (ME), and capsule suspensions (CS). All these products consist of a particulate or liquid droplet active ingredient suspended in a liquid. They are easy to handle and apply, and rarely clog nozzles. However, they can require agitation to keep the active ingredients from separating out.

Advantages and Disadvantages of Different Types of Formulations

Each formulation has advantages and disadvantages in terms of safety, effectiveness, and ease of use. A letter designation for formulation is usually on the label. The major herbicide formulation categories include: Soluble concentrates (SC), soluble powders (SP), emulsifiable concentrates (EC), wettable powders (WP), water dispersible powders (WDP), water dispersible granules (WDG), and granules (G).

Soluble concentrate (sc)/soluble powder (sp)

[+] Advantages

- Mix readily with water
- No agitation required for water soluble herbicides when mixed with water
- Non-volatile
- Not abrasive
- Do not plug screens or nozzles
- Equipment cleans easily
- Soluble powders are easy to store, transport and handle

[-] Disadvantages

- Inhalation hazard when pouring soluble powders
- Some products may react with unlined steel spray tanks
- Eye irritation with some salts

Emulsifiable concentrate (ec)

[+] Advantages

- Relatively easy to handle, transport, and store
- Not abrasive
- Do not plug screens or nozzles
- Little visible residue on treated surfaces
- Flexible application options which may include basal applications

[-] Disadvantages

- Some agitation required – can settle out if left in tank for a long period of time
- May be more phytotoxic to non-target plants
- More easily absorbed through skin of humans or animals
- Solvents may cause rubber or plastic hoses, gaskets, and pump parts and surfaces to deteriorate
- May cause pitting or discoloration of painted finishes
- May be corrosive
- May be volatile
- Equipment cleaning more difficult

Wettable powders (wp)

[+] Advantages

- Ease of transport and storage
- Less skin and eye absorption than ECs and other liquid formulations

[-] Disadvantages

- Inhalation hazard to applicator while pouring and mixing the concentrated powder
- Require constant agitation (usually mechanical) in the spray tank and quickly settle out if agitation is turned off
- Some may be abrasive to pumps and nozzles, causing them to wear out quickly
- Difficult to mix in very hard or very alkaline water
- May clog nozzles and screens
- Residues may be visible

Water dispersible powders (wdp)/water dispersible granules (wdg)/ dry flowables (df)

[+] Advantages

- Easy to handle, transport and mix
- Seldom clog nozzles
- Reduced applicator exposure when mixing and loading

[-] Disadvantages

- Require moderate agitation
- May be abrasive to sprayers
- May leave a visible residue

Granules (g) and pellets (p)

[+] advantages

- Ready to use—no mixing
- Drift hazard is low, and particles settle quickly
- Little hazard to applicator—no spray, minimal dust
- Size can be large which carries the formulation through foliage to soil or water target
- Simple application equipment, such as seeders or fertilizer spreaders
- May break down more slowly than WPs or ECs through a slow-release coating

[-] Disadvantages

- Do not stick to foliage or other non-level surfaces
- May need to be incorporated into soil or planting medium
- May need moisture to start herbicide action
- May physically move off-target during rainfall or other moisture events, especially on steep slopes
- May be difficult to spread uniformly around target plant or obstacles

Benefits of herbicides

- They kill unwanted plants.
- They can be safely used whereas in some cases manually removing weeds can destroy the crop.
- Herbicides can be used on closely planted crops where other methods cannot be used.
- Most of the time one application of the herbicide is enough whereas other methods have to be continually used.

- They are easy to use
- They work fast. They can be removed quickly in critical situations.
- Herbicides are relatively cheap, and most of the time cheaper than manual weeding.
- Non-selective herbicides can effectively clear fields, where houses and roads can then be built.
- They can destroy plants bearing diseases.
- They help the crops grow by destroying the weed that is robbing the crops water, nutrients and sunlight.
- They are relatively safe on lands which may erode.

Limitations of herbicides

- Some herbicides are non-biodegradable and are harmful for a long period of time.
- They are all slightly toxic.
- They can cause illnesses. Glyphosate, a herbicide, can cause eye and skin problems and upper respiratory effects in the user. Paraquat can cause irritations to the skin and may also lead to death, accidental and even suicidal. Many other diseases and illness can be caused such as cancer, nausea, headaches, chest pains, and fatigue.
- The can be carried into streams by runoff rainwater or leached into underground water supplies polluting them.
- Herbivores may eat the plants treated with herbicides and then carnivores eat the herbivores. The toxic herbicide would be passed up the food chain increasing in concentration each time resulting in cancers and even deaths.

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CHAPTER-6

Introduction to mode of action of herbicides and selectivity

Mode of action

The term mode of action refers to the sequence of events from absorption into plants to plant death. The mode of action of the herbicide influences how the herbicide is applied. For example, contact herbicides that disrupt cell membranes, such as acifluorfen (Blazer) or paraquat (Gramoxone Extra), need to be applied postemergence to leaf tissue in order to be effective. Seedling growth inhibitors, such as trifluralin (Treflan) and alachlor (Lasso), need to be applied to the soil to effectively control newly germinated seedlings.

To be effective, herbicides must

1) be adequately contact plants;

2) be absorbed by plants;

3) move within the plants to the site of action, without being deactivated; and

4) reach toxic levels at the site of action.

The application method used, whether pre-plant incorporated, pre-emergence, or post-emergence, determines whether the herbicide will contact germinating seedlings, roots, shoots, or leaves of plants.

Why Know Herbicide Modes of Action?

- Better understanding of how herbicides perform
- Improve herbicide performance
- Diagnose herbicide injury
- Prevent and manage herbicide resistance

The herbicide families listed below are grouped on the basis of how they affect plants (their mode of action)

1. **The Growth Regulator Herbicides** (2,4-D, MCPP, dicamba, and triclopyr). These are mostly foliar applied herbicides which are systemic and translocate in both the xylem and phloem of the plant. They mimic natural plant auxins, causing abnormal growth and disruption of the conductive tissues of the plant. The injury from this family of herbicides consists of twisted, malformed leaves and stems.
2. **The inhibitors of amino acid synthesis** (glyphosate, halosulfuron, imazethapyr, and sulfometuron). Both foliar and soil applied herbicides are in this family. Glyphosate translocates in the phloem with photosynthate produced in the leaves. Others in this family move readily after root or foliar absorption. These herbicides inhibit certain enzymes critical to the production of amino acids. Amino acids are the building blocks of proteins. Once protein production stops, growth stops. Symptoms are stunting and symptoms associated with lack of critical proteins.
3. **Cell membrane disrupters** - with soil activity (oxyfluorfen, lactofen, and acifluorfen). Soil and foliar applied with limited movement in soil. These herbicides enter the plant through leaves, stems, and roots, but are limited in their movement once they enter the plant. Membrane damage is due to lipid peroxidation. Symptoms are necrosis of leaves and stem.
4. **Lipid biosynthesis inhibitors** (diclofop, fluazifop, sethoxydim, and clethodim). Foliar applied Diclofop has both soil and foliar activity. Herbicides in this family move in both the xylem and phloem of the plant and inhibit enzymes critical in the production of lipids. Lipids are necessary to form plant membranes which are essential to growth and metabolic processes. Symptoms include stunting and death of tissue within the growing points of plants.

5. **Pigment inhibitors** (norflurazon, fluridone, and amitrol). Soil applied and move in the xylem except amitrol, which moves in both phloem and xylem. These herbicides inhibit carotinoid biosyntehsis, leaving chlorophyll unprotected from photooxidation. This results in foliage which lacks color. Symptoms include albino or bleached appearance of foliage.
6. **Growth inhibitors of shoots** (thiocarbamate herbicides including: EPTC, cycloate, pebulate, and molinate). Soil applied and somewhat volatile, requiring incorporation. Enter the plant through the roots and translocated through the xylem with the transpiration stream to the growing points in the shoot. Mode of action is unclear, but affects developing leaves in growing points of susceptible plants. Symptoms include stunting and distortion of seedling leaves.
7. **Herbicides which disrupt cell division** (trifluralin, DCPA, dithiopyr, oryzalin, pronamide, pendimethalin, and napropamide). All are soil applied, with limited movement in the soil. Absorbed through roots or emerging shoot tips. Once absorption takes place, movement is limited (site of action is near the site of absorption). These herbicides inhibit cell division or mitosis, except pronamide and napropamide which stop cell division before mitosis. Symptoms include stunting and swollen root tips.
8. **Cell membrane disrupters** - no soil activity (paraquat, diquat, glufosinate, acids, oils, soaps). These herbicides are foliar applied with no soil activity. They enter the plant through the leaves and stems and do not move significantly within the plant once absorbed. These herbicides either act directly on cell membranes (acids, soaps. oils) or react with a plant process to form destructive compounds which result in membrane damage. Symptoms include rapid necrosis of the leaves and stem.
9. **Inhibitors of photosynthesis** (atrazine, simazine, metribuzin, cyanazine, prometryn, diuron, linuron, tebuthiuron, and bromacil). These are soil applied herbicides, however, all except simazine also have foliar activity. They move readily in the plant in the xylem with the transpiration stream where they concentrate in the leaves at the site of photosynthesis. Once there they block the electron transport system of photosynthesis, causing a buildup of destructive high energy products which destroy chlorophyll and ultimately the leaf tissues. Symptoms include chlorotic (yellowing) leaves which become necrotic.

Herbicide Resistance

Herbicide resistance probably develops through the selection of naturally occurring biotypes of weeds exposed to a particular family of herbicides over a period of years. A biotype is a population of plants within the same species that has specific traits in common. Resistant plants survive, go to seed, and create new generations of herbicide resistant weeds.

Mechanisms for resistance vary depending on herbicide family. Resistant biotypes may have slight biochemical differences from their susceptible counterparts that eliminates sensitivity to certain herbicides. Also, while photosynthesis is inhibited in triazine herbicide susceptible biotypes, because of a slight change in a chloroplast protein, triazine resistant biotypes are able to continue normal photosynthesis upon exposure to triazine herbicides. The potential for developing herbicide resistant biotypes is greatest when an herbicide has a single site of action.

Regardless of the mechanism for resistance, becoming familiar with the herbicide mode of action can help design programs that prevent the introduction and spread of herbicide resistant weeds. Management programs for herbicide resistance should emphasize an integrated approach that stresses prevention. Dependence on a single strategy or herbicide family for managing weeds will surely increase the likelihood of additional herbicide resistance problems in the future. Some guidelines for an integrated approach to managing herbicide resistant weeds are given below.

Strategies for preventing or managing herbicide resistance

- Practice crop rotation.
- Rotate herbicide families and use herbicides with different modes of action.

- Use herbicide mixtures with different modes of action.
- Control weedy escapes and practice good sanitation to prevent the spread of resistant weeds.
- Integrate cultural, mechanical, and chemical weed control methods.

Effect of sub lethal dosage

When herbicides are applied on the soil, neighbouring fields may be affected by drift. The high doses of herbicides applied to previous crop may be harmful to the succeeding crop. However, these sub lethal doses may be occasionally helpful based on crop and the herbicide used.

Herbicides show stimulatory effects on crops and toxic effects on sensitive crops even at sub lethal doses. Which show stimulatory effects are phenoxys, triazines, ureas and uracils. In fact, 2, 4-D was first used for its hormonal effect before its herbicidal properties were discovered.

Phenoxy herbicides have growth promoting activities at lower doses similar to indole acetic acid (IAA). They are active at the meristamatic tissues causing increased metabolic activities and consequently higher grain protein content and yield. Protein content of wheat is increased by dusting 5g/ha of 2,4-D mixed with micronutrients like iron and copper. Even higher dose, say 0.5 to 1.3 kg/ha applied to the soil as herbicide before sowing increases the protein content of wheat. The other crops which show stimulatory effect due to herbicide application are beans, potato, sugarcane, soybean etc.

Among triazines, simazine and atrazine produce favourable effects at sub lethal doses. They increase nutrient absorption, chlorophyll and protein content. Simazine at 0.06 ppm increased nutrient uptake and yield of maize, but at 0.3 ppm conct. the yield decreased. The sub lethal effects caused by drifts are rarely toxic except to sensitive crops. Spray drift of 2,4 D causes epinasty on cotton plants. Amitrole at 10 to 100 ppm sprayed on tobacco or wheat causes chlorosis due to chloroplast malformation and reduction in chlorophyll and carotenoids. Soil residues of herbicides applied to the previous crops may affect germination of sensitive crops

Selectivity of herbicides

Selective herbicides have been used extensively since the introduction of 2,4-D in the late '40s. They have been one of the miracles of modem agriculture, releasing thousands of people from the drudgery of hand weeding. A selective herbicide is one that kills or retards the growth of an unwanted plant or "weed" while causing little or no injury to desirable species. 2,4-D used in turf will kill many of the broadleaf weeds that infest turf while not significantly injuring the turfgrass. But selectivity is a fickle, dynamic process. Excessive rates of 2,4-D applied to stressed turfgrass may injure the turf. Selectivity has always depended on proper herbicide application. Normally herbicides work selectively within a given rate of application. Too little herbicide and no weed control, too much and crop injury may occur. But selectivity is more complex than this. It is a dynamic process that involves the interaction of the plant, the herbicide, and the environment.

An examination of the available literature on the subject reveals that herbicidal selectivity can be either 1. Innate or 2. Induced. The **innate selectivity** results from specific plant morphological, physiological, and biological features in relation to the herbicide structure. The **induced selectivity**, on the other hand, is bought about either by hindering from reaching the site of its action in plants or by bringing about a genetic change in plants to develop specific biochemical tolerance mechanisms.

Plant species often respond differently to different herbicides, one species responds differently to different herbicides and the plants of one species but in different areas respond differently to same herbicide. This phenomenon is called herbicidal selectivity.

The fundamental principles of herbicide selectivity is that more toxicant reaches the site of action in active form inside target plants than in the non-target species. This may occur due to:

1) Differential absorption

2) Differential translocation

3) Differential deactivation of the applied herbicide.

Besides, some plants may exhibit innate protoplasmic resistance to specific herbicides.

(1) Differential Absorption of Herbicides: It may occur due to

a) Differences in morphology of plants:-

Certain morphology features of crop plants will allow limited retention of aqueous sprays of herbicides on their foliage. This offers an opportunity to obtain selective control of weed species of variable morphology that may allow easy leaf wetting with the aqueous sprays. Important limited spray retention characteristics found in certain plants are

(i) Narrow upright leaves

(ii) Corrugated or finely ridged leaf surfaces

(iii) Waxy leaf surfaces and

(iv) Pubescent leaves.

Aqueous sprays either bounce off as droplets from their foliage or wet them only in small spots. Crops like wheat and sugarcane are further protected against herbicide sprays by their covered growing points. The growing point in wheat plant is located at the base and initially below the soil surface while in sugarcane, it is hidden by the upper leaf sheaths.

The limited spray retention provides plants protection only against contact selective herbicides that are sprayed in carrier water without any wetting agent.

With translocated herbicides limited spray retention is of not much help in protecting the non-target plants from herbicide injury. It is because the translocated type of herbicides, even when they wet plant surfaces in small areas, can be absorbed and translocated to other plant parts and thus injures the whole plant.

(b)Differences in growth Habits of plants:-i) Shoot growth differences:-

When crop rows have a clear advantage in height over the inter row weeds directed spraying of herbicides is a common method of achieving selective control of weeds.

In slow germinating crops, like potato and sugarcane weeds often established themselves even before crop emergence. These weeds can be controlled selectively by spraying a contact type of herbicide before more than 10 % of the crop plants are seen over the ground. Before emergence of crops translocated type of herbicides can be used.

ii) Root growth difference:-

In general, weed seeds germinate from top 1.25 to 1.5 cm of soil whereas many crop seeds are planted 5 to 7.5 cm deep. When a recommended pre-emergence herbicide is applied on the soil surface and the soil moisture condition are suitable to leach it to about 2.5 to 3.0 cm soil depth, it is readily available for absorption to the germinating weeds. Crop plants that grow their roots beyond 5 cm depth obviously avoid herbicide absorption and escape phytotoxicity. This is the basic principle of selectivity of most of the pre-emergence herbicides and it is a function of herbicide structure, formulation and rate besides the soil texture organic and inorganic colloids and the rainfall. When any one of these factor is unfavourble the herbicide may either injure crop plants or result in poor weed control. Sometimes both the adverse effects may occur together when the phenomenon is called **„reverse selectivity"**.

(c) Use of Adsorbent and Antinodes

i) Adsorbents:-

If germinating crop seeds and seedling are surrounded by a layer of activated charcoal within the soil; they can be made to escape absorption of many soil applied herbicides.

In dibbled vegetables activated carbon can be placed over seeds in seed holes. Pre-emergence herbicides sprayed later are retained by carbon, thus avoiding their absorption by the germinating crop seeds.

In recent years seed pelleting with activated carbon has been developed. In this method carbon is coated over crop seeds using gum or PVA (polyving acetate).

(iii) Safeners (Antinodes):-

Safeners also known as antidote or crop protectant is a sort of physical barrier (extensively active) or a chemical (internal active), which protects a crop from being injured on application of a herbicide normally non-selective to it. The antodotes, which act as physical barriers towards uptake of the herbicide by crop plants are basically adsorbent.

Safeners are chemicals discovered to antagonize phytotoxicity of specific herbicides to specific plant species. Otto L. Hoffman is considered the father of safeners. As early as 1948 he observed antagonism of 2, 4-D on tomato plants. By 1969 he discovered and reported NA (1, 8,-Naphthaline anhydride) as highly successful safener of EPTC as butylate in Maize. Later a more maize specific safener of EPTC as butylate, namely R-25788 was discovered. It could be applied to soil as a tank mix with EPTC without fear of protecting any EPTC susceptible weeds. NA being not so specific must be used strictly as a seed-dress only. Its effective dose is 0.5 g/kg seed. The dose of soil applied R-25788 is 0.6 kg/ha. CGA-43089 is perhaps the latest safeners.

It is likely that NA and possibly other safeners enter the target plants and compete there with herbicide molecules for a binding site on some native enzyme. Thus for safeners have proved successful only against herbicides that affect cell division in one way or the other and not against the photosynthetic inhibiting herbicides.

Usefulness of Antidotes:

- Non-selective herbicides could be used for selective weed control
- Higher doses of herbicide can be used since antidotes normally increase the safety
- A composite culture of a weeds similar or dissimilar to crops can be controlled
- Ready-mix/in-built combination of antidotes in the formulation or their tank-mixes may save crops from damage of the non-selective herbicides applied accidentally
- Antidotes offer grater insurance/reliance against crop damage particularly under situations like susceptible crop varieties, soil conditions or adverse weather condition, where crops are likely to receive phtotoxicity

Limitations of Antidotes:

- Using herbicide antidotes may increase the cost of weed control in particular and the cost of crop cultivation in general since antidotes incur some cost
- Their antagonism with certain herbicide may protect some important weeds of a crop
- Their use with herbicides increases the toxicity load to the environment
- The effect of antidote is not constant/uniform, but varies across climates and soils based on temperature, moisture, texture etc.

(d) Use of granular formulations:-

Development of granular formulations of herbicides is a step forwards achieving a general selectivity between established crop plants and associated germinating weeds by giving weeds the opportunity of selective absorption of the toxicant. The granules filter through the crop foliage, leaving little herbicide for absorption by it. They then settle on the moist ground where germinating weeds absorb the herbicide released slowing by the granule. An important desirable character of herbicides embodies in the granules is their low leachability in soils, else the toxicant may move down to the crop roots.

(2) Differential translocation of Herbicides

It is true that a plant can translocate through it only as much herbicide as it absorbs, and no more. But there are instances when equal amounts of herbicides are absorbed by plants still they are translocated at different rates.

Better mobility of herbicides in plants, however, does not always mean a quicker plant kill actually, in certain instances it may aid the plant in escaping specific herbicide action for instance, diphenamid is found selective to *Convolvulus arvensis* because this plant translocates the herbicide rapidly from the roots to the shoots where it is metabolized. The Avena sativa on the contrary, was found susceptible to diphenamid because it failed to translocate diphenamid away from its roots which are always the site of phytotoxic action of this herbicide.

(3) Differential rates of deactivation of herbicide by plants

Experimental evidence is growing that herbicide selectivity is primarily a function of differential rates of deactivation of the toxicant by the target and the non-target plants before they reach their respective site of action. This deactivation may be a process of

(i) metabolism

(ii) reverse metabolism or

(iii) Conjugation.

A tolerant plant species deactivates the herbicide molecular rapidly, whereas a susceptible species does so slowly. In some instances reverse metabolism may be an important venue of herbicide dissipation.

i) Metabolism :-

Metabolism involves a change in the molecular structure of the applied herbicides inside plants to yield non-phytotoxic products. *Ribes nigrum* which is susceptible to 2,4-D metabolized the herbicide at a rate of 2% of the applied amount in 96 hours whereas the tolerant *R. sativum* metabolized 50% of it during the same period.

ii) Reverse metabolism

When in metabolic reactions of herbicides the intermediate chemical structures prove more phytotoxic than the parent compound, the process is called **reverse metabolism**. Herbicides like 2,4-D and MCPB per se are non-phytotoxic. But the metabolism of these compounds in plants yielded phytotoxic acetic acid intermediates namely 2,4-D and MCPA, respectively. This reverse metabolism of 2, 4-D and MCPB is an enzymic B-oxidation process. It occurred in many non leguminous plants. Certain legumes like pea lucern berseem and other clovers on the other hand either lacked the necessary B-oxidation system or operated it sluggishly. Consequently, these legumes proved comparatively tolerant to 2,4-D and MCPB.

iii) Conjugation

Conjugation is coupling of intact herbicide molecules with some plant cell constituent in living plants. Conjugation takes the toxic herbicide concentration out of the main stream of plant, and plants capable of rapidly doing so obviously prove tolerant to it.

In plant susceptible to chloramben the conjugation was found to be so slow that the herbicide translocated from roots to the shoots where it proved phytotoxic. The tolerance of grasses and certain ecotypes of Convolvovulus arvensis to the foliar application of 2,4-D has also been explained at least in part on the basis of its conjugation with glucose and certain amino acids in these plants.

Now it is known that simazine and atrazine are also deactivated in maize, apple, sugarcane and certain millets by the process of conjugation rather than by earlier believed mechanism of metabolism.

(4) Differential protoplasmic resistance

Plants show tolerance to dalapon withstands pantothenic acid deficiency and resist precipitation of their cell proteins. Likewise, plasma lemma of epidermal cells of carrot leaves resists the solubilizing action of crop oils much longer than many of the associated weeds. Biophysical features of plant cells such as protoplasmic viscosity, streaming and physical continuity also respond differently to variable herbicides structures.

(5) Multifactor herbicide selectivity in plants

Wheat is tolerant to post-emergent ioxynil and bromoxynil because of three concurrent selectivity mechanics, namely

(i) limited spray retention

(ii) slow translocation or

(iii) rapid herbicides metabolism.

Distribution of herbicides molecules within plants can also be an important factor in selectivity. Perfluidone and Pichloram for instance accumulated at the site of action in the susceptible plants but in tolerant species there are evenly distributed.

Besides the many inherent plant factor, method of planting of crops may also determine herbicide selectivity. The ridge planted potato is found more tolerent to pre-emergent 2,4-D than the flat planted crop.

(6) Other selectivity components

i) Rate of herbicide

Under rates of herbicides improve their selectivity to crops at the cost of satisfactory weed control, while their over rates are most likely to reduce selectivity and cause variable crop injury.

ii) Growth stages of Plants

2,4-D is selective to winter grains first at their 3 to 6 leaf stage and again at the drought stage. At other growth stages 2,4-D may induce in these crops malformation like onion leafing and missing spiklets ears.

x-x-x-x-x

CHAPTER-7

Allelopathy and its application for weed management

Definition:

Allelopathy is derived from two Greek words, —allelon or allelo‖ means —mutual or each other‖ and —pathos or patho‖ means —suffering or to suffer.‖ Molisch (1937) coined the term allelopathy, which includes all stimulatory and inhibitory reciprocal biochemical interactions among plants including microorganisms. Some authors, however, prefer to describe it purely an inhibitory effect of one plant species upon another. Rice (1974) too opined the same. However, an allelochemical that inhibits the growth of some plants or microorganisms at certain concentration may stimulate the growth of same or different plants or microorganisms at its lower concentration. Therefore, this biochemical interaction cannot be solely an inhibitory phenomenon. That is why Rice later (Rice, 1984) inclined to the same definition of allelopathy as propounded by Molisch (1937).

The term allelopathy was first introduced by Hans Molisch in 1937 and refers to chemical interactions among plants, including those mediated by microorganisms. The concept of allelopathy received new attention in 1974, after the publication of the first book in English on the allelopathy by Elroy L Rice, where he defined allelopathy as the effect(s) of one plant on another plants through the release of chemical compounds into the soil environment (Rice, 1984).

Allelopathy is the detrimental effects of chemicals or exudates produced by one (living) plant species on the germination, growth or development of another plant species (or even microorganisms) sharing the same habitat.

Allelopathy does not form any aspect of crop-weed competition, rather, it causes Crop-Weed interference, it includes competition as well as possible allelopathy.

Allelo chemicals are produced by plants as end products, by-products and metabolites liberalised from the plants; they belong to phenolic acids, flavanoides, and other aromatic compounds viz., terpenoids, steroids, alkaloids and organic cyanides.

Table . Several definitions of allelopathy

SN	Definitions of allelopathy	References
1	Allelopathy refers to all biochemical interactions, stimulatory or inhibitory, among plants including microorganisms.	Molisch (1937
2	Allelopathy is the detrimental effects of chemicals) or exudates produced by one living plant species on the germination, growth or development of another plant species or microorganisms sharing the same habitat	Evenari (1949) (cited In Akobundu, 198
3	Allelopathy refers to the deleterious effects that one higher plant has on another through the production of chemical retardants that escape into the environment.	Martin and Rademacher (1960, Muller (1966))
4	Allelopathy refers to any direct or indirect inhibitory effect by one plant including microorganisms on another through the production of chemical compounds that escape into the environment.	Rice (1974)
5	Allelopathy includes inter-specific (antibiotics) as well as intra-specific(auto -toxic) chemical co- action	--

Kinds of allelopathic interactions

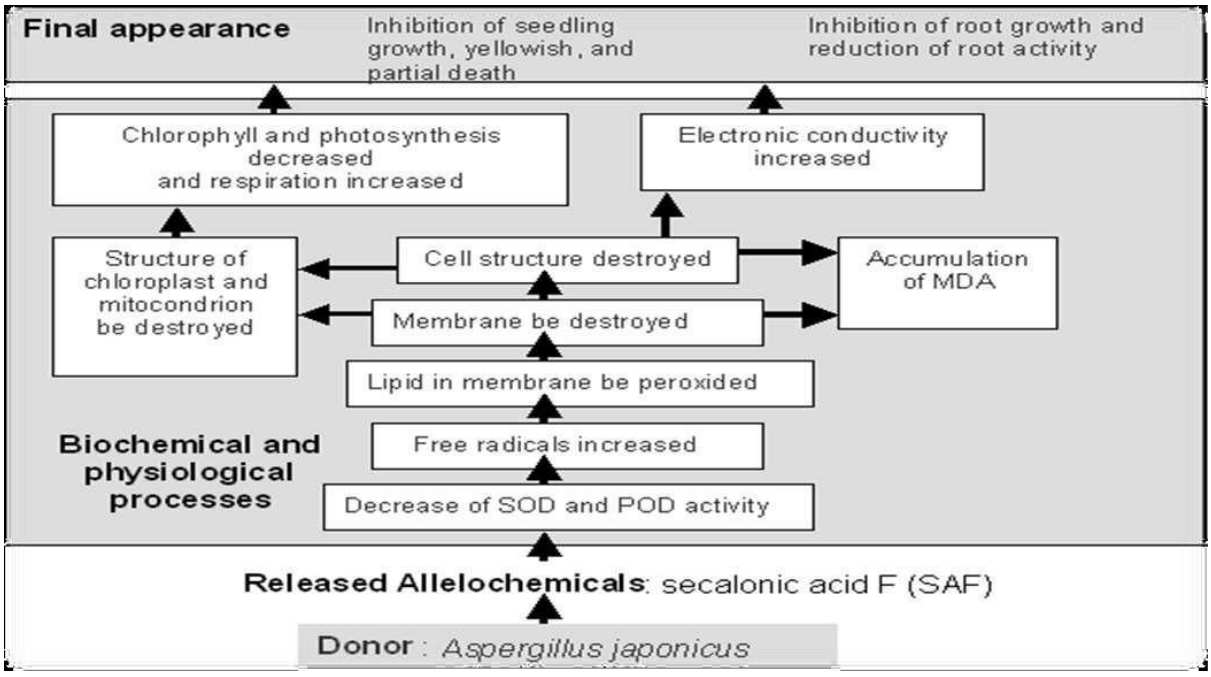
Allelopathy may be alloallelopathy and autoallelopathy, true and functional allelopathy (Aldrich, 1984) and concurrent/direct and residual allelopathy. Alloallelopathy is inter-specific chemical co-action, whereas autoallelopathy intra-specific chemical co-action. The cases of alloallelopathy are : maize is allelopathic to *Chenopodium album, Amaranthus retroflexus*; sorghum to *Abutilon theophrasti, Amaranthus hybridus, Setaria viridis, Bromus pectinatus* ; rye to *Digitaria sanguinalis, Ambrosia artemisiifolia, Chenopodium album* ; cucumber to *Echinochloa crusgalli, Amaranthus retroflexus* ; and sweet potato to *Cyperus rotundus, Cyperus esculentus* (Putnam, 1985). The cases of autoallelopathy are : wheat, alfalfa, cowpea, rice, apple, clover and sweet potato are autotoxic. The soil where these crops were previously grown, is inhibitive to their growth when replanted or their residues proved autotoxic to them when incorporated. Similarly *Trifolium repens* (weed) has autotoxicity.

True allelopathy refers to the release into the environment of chemical compounds that are toxic in the forms they are produced by the plants, but functional allelopathy is the release into the environment of compounds that are toxic after chemical modification by microorganisms. Concurrent/direct allelopathy refers to instantaneous direct effect of released toxins from the living plants to another growing in vicinity, whereas residual allelopathy is the effect obtained on the plants growing in succession from the decaying residues, leaf litters, stems, roots of the previous plants. Concurrent allelopathy is differently called as —live plant effect,‖ e.g. sorghum suppresses many weeds growing in vicinity. Live barley plants and their root exudates are more inhibitory than aqueous leachates of dead roots (Overland, 1966). This might support the concept of active metabolic secretion of allelochemicals by the live/standing plants. Lentil residues are phytotoxic to wheat and sunflower and mustard residues to several crops (Putnam, 1983, 1985). Similarly sorghum is allelopathic to wheat and *Phalaris minor* and sweet potato to cowpea. These are example of residual allelopathy.

Allelopathic Chemicals

- Phenolic acid, Coumarins, Terpinoids, Flavinoids, Scopulatens

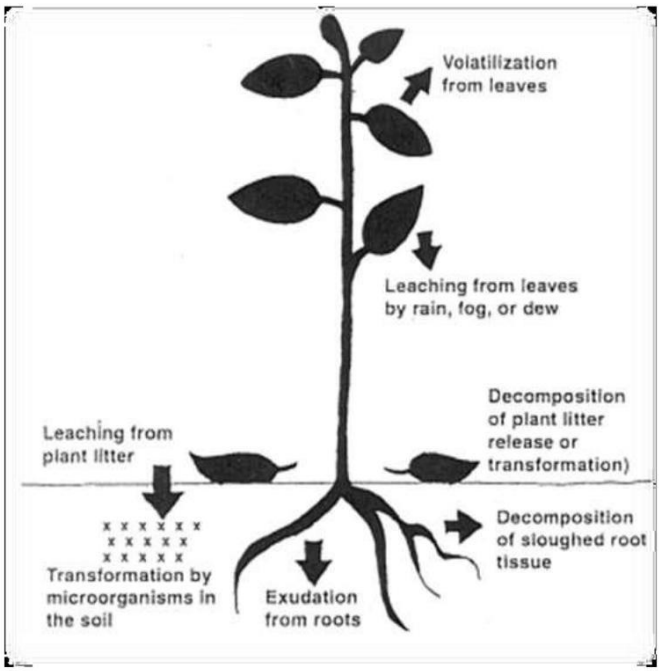
Mode of Action of Allelochemicals



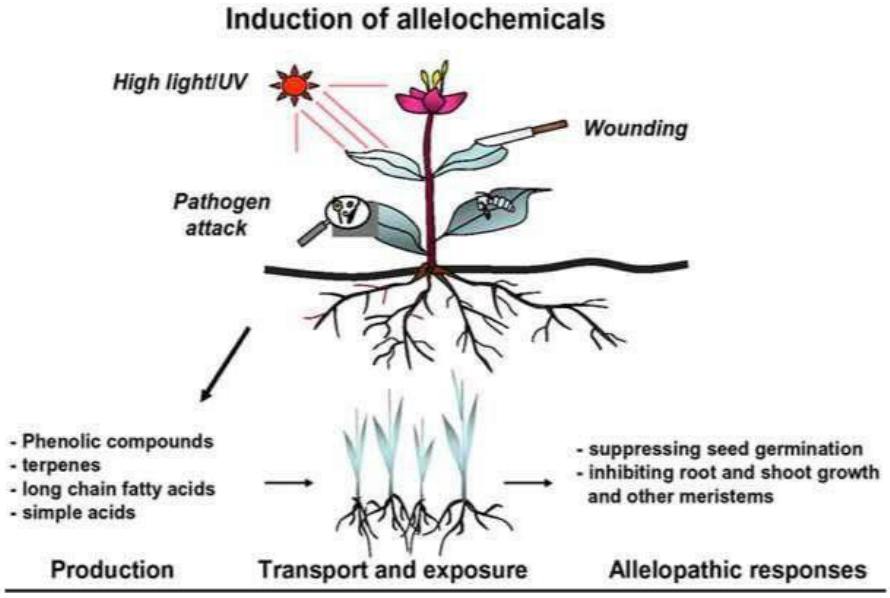
Ways of releasing Allelochemicals

Allelopathic chemicals are released from the plants as:

- Vapour – from root and leaf (through
- stomata)
- Foliar
- Root
- Breakdown/ decomposition product of dead plant parts
- Seed extract



How allelochemicals introduced into plant??



Forms of Allelopathy

Weed on Crop

Weed on Weed

Crop on weed

Allelopathic Effect of Weeds on Crops

(1) Maize

- Leaves & inflorescence of *Parthenium* sp. affect the germination and seedling growth

- Tubers of *Cyperus esculentus* affect the dry matter production

(2) Sorghum

- Stem of *Solanum* affects germination and seedling growth
- Leaves and inflorescence of *Parthenium* affect germination and seedling growth

(3) Wheat

- Seeds of wild oat affect germination and early seedling growth
- Leaves of *Parthenium* affects general growth
- Tubers of *C. rotundus* affect dry matter production
- Green and dried leaves of *Argemone mexicana* affect germination & seedling growth

(4) Sunflower

- Seeds of *Datura* affect germination & growth

Allelopathic Effect of crop plants on weeds

(i) Root exudation of maize inhibits the growth of *Chenopodium album*

(ii) The cold water extracts of wheat straw when applied to weeds reduce germination and growth of *Abutilon* sp.

Allelopathic effect of weeds on weeds

- Extract of leaf leachate of decaying leaves of *Polygonum* contains flavonoides which are toxic to germination, root and hypocotyls growth of weeds like *Amaranthus spinosus*
- Inhibitor secreted by decaying rhizomes of *Sorghum halepense* affect the growth of *Digitaria sanguinalis* and *Amaranthus* sp.

Factors influencing allelopathy

a. Plant factors

i. Plant density: Higher the crop density the lesser will be the allelo chemicals it encounters

ii. Life cycle: If weed emerges later there will be less problem of allelochemicals

iii. Plant age: The release of allelochemicals occurs only at critical stage. For eg. in case of *Parthenium*, allelopathy occurs during its rosette & flowering stage.

iv. Plant habit: The allelopathic interference is higher in perennial weeds.

v. Plant habitat: Cultivated soil has higher values of allelopathy than uncultivated soil.

b. Climatic factors: The soil & air temperature as well as soil moisture influence the allelo chemicals potential

c. Soil factors: Physico-chemical and biological properties influence the presence of allelochemicals.

d. Stress factors: Abiotic and Biotic stresses may also influence the activity of allelochemicals

Factors affecting the allelopathic effect :

Allelopathic effects might also depends on a number of other factors that might be important in any given situation

Varieties: there can be a great deal of difference in the strength of allelopathic effects between different crop varieties.

Specificity:

Mechanism of action of allele-chemicals

- Interfere with cell elongation
- Interfere with photosynthesis
- Interfere with respiration
- Interfere with mineral ion uptake

Advantages of Allelopathy:-

- Limit competition for space, light, nutrients, water
- Autotoxity (Chemical produced inhibits germination of it's own seeds
- Allelopathic Weed Suppression Through the Use of Cover Crops

Interfere with protein and nucleic acid metabolism

Use of Allelopathy in biological control of weeds:

1. Use of cover crop for biological control
2. Use of alleopathic chemicals as bio-herbicides

Effect of weed competition on crop growth and yield

1. Crop growth and yield is affected
2. Crop suffers from nutritional deficiency
3. Leaf area development is reduced
4. Yield attributes will be lowered
5. Reduce the water use by the crop
6. Affect the dry matter production
7. Lowers the input response
8. Causes yield reduction
9. Pest and disease incidence will be more

Forms of Allelopathic Interactions

Crop against other crops

Crop against crop allelopathic interaction is likely operative in multiple crop culture like inter-cropping. mixed-cropping, parallel multiple cropping, multi-storeyed cropping and agro-forestry. Therefore, selection of suitable pairs of crops having no allelopathic effect with each other is of paramount importance in crop diversification or crop mixture programme. Enough in the field for a long period to determine crop compatibility and

This will serve as one basis/pre requisite for selection of crops for mixture apart from other considerations like nature and kind of crop (cereals, pulses and legumes, oilseeds etc.), rooting pattern, height, branching/tillering hahit etc. For example sunflower has been found allelopathic to groundnut under intercropping situation. Tree crops like Eucalyptus also shows some allelopathic interactions to vegetables and some field crops grown as intercrop with it. Crop residues of lentil are phytotoxic to wheat and of sunflower and mustard to several crops (Putnam, 1983, 1985). Similarly sorghum is allelopathic to wheat and *phalaris minor* and sweet potato to cowpea, but mung/green gram, urdbean/black gram and cowpea are stimulatory to the growth of wheat.

Crop against weeds

Several crops show allelopathic effects on weeds 〔Table). For example, sorghum releases hydrocyanic/prussic acid (IICN) and suppresses many weeds growing in vicinity. Barley is more competitive to weeds than wheat. Live barley plants and their root exudates were

more inhibitory than aqueous leachates of dead roots (Overland, 1966). This might support the concept of active metabolic secretion of allelochemicals by the live/standing plants. Barley produces "gramine," an alkaloid, which inhibits weed growth. The allelopathic effects of many leguminous plants and trees/shrubs, e.g. *Azadirachta indica* (neem), *Prosopis julifora/cineraria*, *Delonix regia*, *Eucalyptus globulus/citriodora on Parthenium* hysterophorus are also reported (Dhawan er. al, 1994; Dhawan and Dhawan, 1995).

Allelopathic effects of crops on weeds

SN	Crops	Weed species	Source of inhibitors
1	Maize	*Chenopodiam athun, Amaranihus retroflexns*	Roots
2	Cassava	*Amaranihus dubius, Digitaria sarguinalis*	Leaves
3	Sorghum	*Abutilon theophrasti, Amaranthus hybridus, Setaria viridis. Bromus pectinatus*	Shoots and foliages
4	Rye	*Digitaria sanguinalis, Ambrosia artemisiifolia, Chenopodinm album*	Shoots and foliages
5	Cucumber	*Eehinochloa crusgalli. Amaranthirs retroflexus*	----
6	Sweet potato	*Cyperus rotundus, Cyperus esculentus*	----

Weeds against crops

Many weeds impose allelopathic influence (Putnam, 1983, 1985; Thompson, 1985; Rice, 1974, 1979, 1984) on certain crops (Table). They also may associate them with a number of crops in the field and, therefore, further researches are to be carried out for knowing whether they show similar allelopathy on those crops

Allelopathic effects of weeds on crops

SN	Weeds	Crops	Source of inhibitors
1	*Euphorbia sp*	Flax	Root exudates
2	*Commelina alyssum*	Flax	Leaves
3	*Setaria faberi*	Maize	Whole plant
4	*Cyperus rotundus*	Sorguhm, soybean	Tubers
5	*Polygomum persicaria*	Potato	Roots
6	*Salvinia occidentalis*	Coffee	Roots
7	*Imperata cylindrical*	Several crops	Whole plant
8	*Abutilon theophrasti*	Alfalfa	Shoot and foliage
9	*Cynodon dactylon*	Coffee	---
10	*Chenopodium album*	Alfalfa, cucumber, oat, maize	Shoot and foliage

Weed against other weeds :

Parthenium hysterophorus is allelopathic to many weeds whose listing may be impossible considering their vast diversity and large number. Wherever *parthenium* invades, it forms a territory of its own replacing all existing flora, grasses and broad-leaved weeds mainly because of its allelopathic effect (Kohli. 1992) and competition. Very little or no vegetation could be seen in parthenium-dominated areas. similarly there are many weeds/wild species, vi.A*maranthus spinosus, Tagetes minuta, Mirabilis jalupa, etc*. which pose strong allelopathic effect on parthenium. Weed against weed allelopathy has enough importance and could be exploited to result to oust parthenium in Karnataka State, India (Mahadevappa, 1997). Rumex sp shows allelopathic effects to *Amaranthus spp.*

Crop against same crop

The important step towards avoiding/removing the allelopathic effect of some crops on the crop species is to stop the continuous mono-cropping of those crops over the years and to encourage crop rotation with diverse crop species. Several crops like wheat, alfalfa, cowpea, rice, apple and sweet potato are autotoxic. The soil where these crops were previously grown,has been found inhibitive to their growth when replanted or their residues proved

autotoxic to them when incorporated. However, it is still to be established whether there operates autotoxicity from the live existing stand of these crops in the field.

Weed against same weed

The allelopathic effect of weed against same weed is another important intraspecific chemical co-action, which results in weaker stand of a particular weed. However, there is equal possibility that chemical autotoxic to a certain weed, may be toxic to other plants specifically crop plants, otherwise, it will accumulate in soil and develop soil sickness in the long run. *Trifolium repens* (weed),for example has autotoxicity.

Allelopathic Problems in Agriculture, Horticulture and Forestry

Since the same crops are grown year after year on the same piece of land in certain areas/regions,certain crop residues (e g. rice) get piled up, left on the field or incorporated. farmers use different kinds of mulches, multiple cropping systems, crop mixtures or crop diversifications programme adopted, afforestation launched. allelopathy has got a definite role to play under such circumstances. Isolation of allelopathic interaction is e g. crop against weeds, crop against other crops, crap against other weeds. weeds against other weeds and weed against same weed) occurring in crop field is not possible considering the complexity of crop-weed situation. However, their concurrent, cumulative effects altogether exert the ultimate influence on the usual crop culture/cultivation of an area These interactions may coexist, balance or compensate for each other. Of course, allelopathy cannot be a sole contributing cause of these, but it definitely adds to other causes. Several problems occurring in agriculture, horticulture and forestry.

i) Soil sickness

Soil becomes sick in two ways, first by direct or indirect use of synthetic chemicals (e.g. pesticides, inorganic fertilizers and other chemicals) in excessive rates for crop production and protection and secondly by allelochernicals released from plants (roots, stem, foliage or whole plant) and microorganisms. Tukey (1969) reported that soil sickness causes decline in the quality and yield of a crop when grown on the same land year after year. In sick soil, root growth is arrested/ warranted, microbial activity gets reduced and soil's inherent capacity to supply and release plant nutrients through mineralization is weakened. Adsorption of allelochemicals to soil colloids may lead to break-up of soil structure and alteration of other physicochemical properties, namely pH. Eh of soil.

Monocropping practiced for a long period experiences soil sickness, which results in gradual decline of yield of that crop in the successive years. The sickness is more pronounced under monocropping because similar or same allclochemicals accumulate over the years and their concertation gradually increases and reaches to a toxic level. On the contrary, under crop mixture or crop rotation. the allelochemicals released by different crops are likely different and their concentration may not build and reach to a toxic level rapidly. Soil sickness is. therefore, plant species-specific, Continuous monocropping of wheat. barley, oat, rice, cowpea and clover causes soil sicknes. Initially allelochemicals remain intact as plant metabolites, but later change to humic substances like phenolic acids and other related aromatic compounds.

Farmers in the temperate regions normally practise monocropping with or without rotation and hardly take a second crop in the same year on account of chilling winter. Therefore, residues get enough time all through the fall winter season for apparently complete decomposition and removal from soil and sickness appears to be very less in such soil. On the contrary, if irrigation facility exists in the tropic and sub-tropical areas, climate supports year-round cropping and two or more crops could be g a year with a little time (15-20 days) gap between the harvest of previous crop and the sowing of next crop. The decomposition of previous crop residues coincides with the seed germination and seedling establishment of next crop and therefore, the decomposition products likely influence the germination and seedling growth of next crop. Hence, allelopathy has greater role to play in the crop-weed ecosystem particularly under tropical and sub-tropical situations than in the temperate conditions.

ii) Autotoxicity under same crop monocropping

Autoroxicity operates as a predominant mechanism for crop yield decline over the years in many monoculture annual and pereenial crops.Root extudates, decomposing crop residues and sometimes the microorganisms attacking them are the sources of allelochemicals being accumulated in soil over the years. Wheat soil extract is inbibitory to wheat and similarly alfalfa soil extract is inhibitory to alfalfa growing in succession.

Coffee and sugarcane ratoon are good examples where autotoxicity operates. Caffeine produced in coffee fruits decreases coffee seed germination and seedling growth. Decomposition of roots and foliages of the previous sugarcane crop produces chemicals phytotoxic to successive rattons and decreses plant stand by nearly 10%. *Fusarium oxysporum* colonizes in higher population in the rhizosphere of poor ratoon sugarcane and produces fusaric acid, which inhibits shoot and root growth of sugarcane. *Fusarium oxysporum* and *Trichoderma harzianum* also proliferate on added sugarcane residues in soil.

iii) Increased crop weed interference

Allelopathy being a component influences and intensifies crop-weed interference Occurring in the field and partly responsible for the decline in crop yield caused by weeds Nearly 130 weed species are reported having allelopathic effects. Most of them are inhibitory to crops barring a stimulate seed germination, growth and yield of crops. Seeds, decomposing residues, root leaf leachates and volatilization of weeds usually release allelochemicals.

iv) Growing susceptibility of plants to diseases/pests

Allelochemical-rich soil may make plant roots gradually weak or injured on their continuous exposure to if and forcefully induce vulnerability to diseases or pests in them. e.g. the occurrence of root rot disease in tobacco, cotton, sugarcane and beans increase under such conditions. Initial primary root injuries pave the way for secondary root infection and further decay

The same may apply to pathogens, which fall susceptible or are controlled under allelochemicals rich soil and hence allelopathy could reduce disease infestation too. For example, Sulphur-containing volatiles from decomposing crucifer residues are inhibitory to *Aphanomyces euteiches* and reduce root rot of peas.

v) Reduced nitrification and biological N fixation

Nitrification is the last step of nitrogen mineralization in soil where conversion of NH^{4+} into NO_3^- takes place. This is an important step/process since NO3- is an available form of N apart from NH^{4+} and taken up for metabolic activities by a majority of crops. Several allelochemicals, namely ferulic an p-coumaric acids released from the decomposing plant residues inhibit *Nitrosomonas* population and hence nitrification due to which a gradual accumulation of NH^{4+} takes place in soil. Maize residues let on the soil surface for a long period induces low nitrification. The concentration of NH^{4+} -N increases over NO_3^- -N in maize-mulched soil compared to non-mulched soil.

Similarly nitrogen fixation of many legume crops, for example, soybean decreases due to decomposing residues of the previous rice crop, which releases phenolic compounds. The attributed to poor growth of N-fixing bacterium, *Brady-rhizobium japonicum* and reduction in nodule number. There is, however, no effect if rice residues are burnt, rather soybean yield increases compared to rice residue decomposition. The aqueous extracts of weeds, namely *Chenopodium album* and *Digitaria sp* inhibited growth of nitrifying as well as N-fixing bacteria (Rice, 1984)

vi) Reduced nutrient uptake

It is needless to mention that there is a large number of studies in India and abroad, which adequately substantiate that crop's nutrient uptake is affected due to weed interference in the field. Although allelopathy becomes a part of this, could hardly be quantified or demonstrated. However, in isolated laboratory studies, phenolic acids have been found to inhibit P and K uptake due to increased membrane permeability of certain inonganic ions. Walker et al (1989) reported that decaying some get potato residues reduced Ca. Mg and S uptake by other plants

vii) Weed seed decomposition delayed/prevented

Chemicalization of soil affects the activity of microorganisms, which in turn affects the decomposition of weed seeds in soil. Rice (1984) indicated that allelopathy contributed to weed seed longevity through two mechanisms, a) chemical inhibitors in the seeds prevented decay by microorganisms. and b) inhibitors kept the seed dormant, but viable for many years. Several anti-microbial compounds as unsaturated lactones .phenolics and germination inhibitors.e g. phenolics, flavonoids, glucosides tannins are present in weed seeds with varying concentrations.

viii) Poor success on replanting of tree crops

New/fresh saplings of apple, peach, plum, cherry, apricot, citrus, grape when planted in soils previously grown with these fruit crops. encounter loss of vigour and/or poor establishment (Borner 95% Rice 1974: Putnam, 1985). In peach the toxicity is caused by cyanide (HCN) formed by microbial break down of amygdalin in the barks of old roots. The new saplings planted are also attacked by pathogens, e.g. fungi, nemalodes, which inhabit on old peach roots and release phytotoxins apart from causing certain diseases.

ix) Failure of vegetative propagation (e.g. grafting, budding)

Grafting and budding are important horticutural techniques for fruit crops improvement. Allelopathic interactions may cause several problems such as dwarfism, changing maturity time, size. colour and uniformity of fruits. This kind of allelopathic interaction generally stems from rootstocks and the use of non-allelopathic or less-allelopathic rootstocks can bypass these problems to a great extent

x) Suppression effect from trees

It is frequently observed that flora or vegetation hardly grow or if at all grow, remain very erratic and sparse surrounding the trunk of old trees. This effect could be attributed partly to competition for sunlight, moisture and nutrients and partly to allelopathy. Most crops (potato, tomato, alfalfa, turnip. corn, beans) failed to grow under black walnut (*Juglans nigra*) trees because of juglone (5-hydroxy 1,4-naphthaquinone) present in the leaves and fruits of these trees. Rain-washed juglone is oxidized to oxyjuglone, a toxic metabolite in soil. Potato and tomato plants wilted (Cook, 1921) and alfalfa and tomato plants wilted and died when their roots came in close contact with the roots of these trees (Massey, 1925)

Application of allelopathy in weed management

i) Development of novel biopesticides, namely herbicides, insecticides or fungicides from allelochemicals or allelopathic agents assumes paramount importance.

a) Bialaphos, a microbial toxin/allelochemical is found in a bacterium *Streptomyces hygroscopicus*. Its synthetic analogue glufosinate-AM is extensively used for weed control in cropped and non-crop situations.

b) From *Salvia sp* (sage), 1,8-cineole is released, which has phytotoxic effect. Cinmethylin is a synthetic herbicide and has structural similarity with it. Cinmethylin controls annual grasses and some broad-leaved weeds and is recommended for weed control in rice.

c) A natural herbicide AAL-toxin is a metabolite produced by *Alternaria alternata* f. sp. *Lycopersici*, a pathogen (fungus) causing stem canker of tomato (Zimdahl, 1999).

ii) A number of crops have been reported with their alleged allelopathic effects and attempts have also been made to find crop cultivars with a competitive allelopathic basis (Putnam, 1985; Rice, 1979 & 1984; Thompson, 1985). Therefore, adoption of crops or crop‘s cultivars more allelopathic to weeds may reduce the cost of weed control in particular and the cost of cultivation as a whole. For example, sorghum residues have been applied to control weeds in subsequent rotational crops (Putnam, 1885).

iii) Application of the residues of allelopathic crop plants as mulches or adoption of an allelopathic crop in rotational sequence and allowing the residues to remain in the field has enough importance to bring down weed population to lower level.

iv) Utilizing a companion crop/plant ((Putnam, 1885; Zimdahl, 1999) that is selectively allelopathic to weeds and does not interfere appreciably with crop growth has enough bearing towards weed control in the fields. In several intercropping situations such as sorghum + cowpea, maize +cowpea/soybean and agro-forestry/agro-silvi-pastoral systems, a clear advantage in weed control is obtained, but it requires to be authenticated and quantified through enough research.

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CHAPTER-8

Bio-herbicides and their application in agriculture

BIOLOGICAL CONTROL OF WEEDS

Definition:

The biological control of weeds involves the use of living organisms. Such as insect, herbivorous fish, other animals, disease organisms, and competitive plants to limit their infestations.

An important aspect of biological weed control is that at a time, it is applicable to the control of only one major weed species that has spread widely. With perennial weeds the main objective of bio-control is the destruction of the existing vegetation, in the case of annual weeds prevention of their seed production is generally more important.

Biological control is defined as the control of an organism (weeds, insect pests or pathogens in agriculture) employing living organism or biological entity to a population/density lower than what naturally occurs in the absence of the employed organism.

Advantages of biological control:-

- No chemicals are used so there's less pollution, disruption of the food chain and risk to people eating the food that has been sprayed
- There's no need to keep repeating the treatment like you would with chemical pesticides
- It is economical in the long run, although initially monetary investment is high
- It preserves bio-diversity since weed control by biological means/agents is hardly achieved to the level of 100%

Disadvantages of biological control:-

- High cost
- Damage on economic crops
- Limited use
- Very low action
- Eradication not possible
- Warranting pesticide use
- Weed flora shift
- Small/narrow span of the activity

Comparison between Chemical control of weeds and Biological control of weeds

S.N.	Chemical control of weeds	Biological control of weeds
1.	It may leave residue in dangerous level in the crop produce	On the contrary, does not leave any harmful residue in crops
2.	It is a destructive method and may pose a grave pollution to man, animal and environment in the long run	Does not pose pollution to environment.

3.	It may lead to development of resistance to herbicide by weeds	No resistance development by weeds
4.	It is repetitive and not self-perpetuating over the years.	It is self-perpetuating if the bio-agent selection is proper and they could adapt well to that climate.
5.	It may lead to shift in weed flora in certain situation	No shift in weed flora as yet reported, but there is chance.
6.	Preponderance of perennial weeds in crop field due to constant use of herbicides.	No preponderance of perennial weeds
7.	Maintaining plant/weed biological diversity on earth is quite difficult by chemical method since certain herbicide may result in 100% kill or eradication of weeds.	It likely helps to maintain the biological diversity on earth since it does not envisage complete eradication of weeds.
8.	It may exert negligible and invisible phytotoxicity to crops even though the herbicide is selective.	It does not exert any phytotoxicity to crop plants.

Approaches to biological control of weeds

3.4.4.1 Classical/Inoculative approach

Classical/inoculative approach involves the release of bio-agents (insects, pathogens) just for once in the belief that it will readily adapt to the prevailing climate and multiply enough to keep pace with the multiplication rate of weed in question. Therefore, repeated release of bio-agent unless failed, is not advocated. No augmentation and large-scale mass production of the bio-agent are practised. In this approach, a small amount of inoculum (pathogen) or a small number of insects, say, one insect per 20-40 weeds or 1 insect per 3-5 m2 area based on the assessment of weed problem and prevailing situation, is initially released in the standing population of weeds and allow it to multiply and feed on the weeds.

3.4.4.1.1 Steps for introduction/release of bio-agents (mainly for exotic/introduced weeds)

The following steps are to be adopted while introducing insect bio-agents :

i) First assess area-wise gravity of the problem of the weed for which bio-agent is to be introduced.

ii) Survey all native organisms (insects, diseases pathogens, vertebrate pests etc.) that attack the weed in the area where the bio-agent is to be introduced.

iii) Find out the origin of that weed geographically and organisms those attack it there.

iv) Search for natural enemies in its place of origin or native land.

v) Test for host specificity of the bio-agent by means of multiple choice and starvation tests.

vi) Importation of the specific bio-agent based on performance of the bio-agent in above-mentioned tests.

vii) Further testing and screening of the natural enemies for parasites in quarantine.

viii) Adaptability test and based on that, mass rearing of the bio-agents in the place where to be introduced.

x) Release and assessment of the effect of bio-agent on that weed.

3.4.4.2 Augmentative/Inundative/Bio-Herbicide Approach

Inundative approach pursues *in vitro* augmentation of the pathogen inoculum and its culturing in artificial medium in the laboratory on the belief that target weeds may fall susceptible to it when applied in a large concentration (considering the number of active bio-agent molecules) over its existing population. This inoculum is bio-herbicide. Bio-herbicides are native pathogens mostly fungi and hence called mycoherbicide. Several inoculums such as fungi, bacteria, parasitic nematodes, viruses having tested control ability over a weed species may be applied/sprayed like herbicides

Some of the Mycoherbicide products in use in the world

S.N.	Product, year & country	Bio-herbicide description	Target weeds and diseases caused	Crop where used and reference
1.	DeVine, 1981, USA	*Phytophthora citrophthora* p.v. *palmivora*. Soil-borne pathogen and can remain for 3-4 years in soil by one spray	*Morrenia odorata* (Strangler vine), (Lethal root-rot)	Citrus, USA; (Kenny, 1986)
2.	Collego 1982, USA	*Colletotrichum Gleosporioides* f. sp. *Aeschynomene*	*Aeschynomene Virginica* (Nothern joint vetch), (Stem and foliage blight)	Rice and soybean, USA; (Bowers, 1982)
3.	Biomal, Canada	*Colletotrichum gleosporioides* f. sp. *Malvae*	*Malva pusilla* (Round-Leaved mallow), (Anthracnose)	Cotton, Canada; (Makowski and Mortenson, 1992)
4.	Lubao II	*Colletotrichum gleosporioides* f. sp. *Cuscutae*	*Cuscuta sp* (Dodder)	**----**
5.	VELGO	***Colletotrichum coccoides***	***Abutilon theophrasti***	Cotton, Canada
6.	CASST	*Alternaria cassiae*	*Cassia obtusifolia, Cassia occidentalis & Cassia alata* (Blight disease)	Cotton, soybean & groundnut, Florida, USA; various crops in Australia
7.	Bipolaris	*Bipolaris sorghicola*	*Sorghum halepense* (Johnson grass)	**----**

The comparison between classical and augmentative approaches.

S. N.	Classical approaches	Augmentative approaches
1.	Initially small population of insects/bio agent is released and allowed it to adapt and multiply keeping pace with weed multiplication rate and growth	Initially a large concentrations of inoculum is sprayed directly to the weed in the belief that the weed will become susceptible to inoculum since it is augmented in vitro and cultured artificially
2.	Rearing of the bio agent in the laboratory is in a limited scale	Mass rearing/culturing of the inoculum takes place in the laboratory
3.	No repeated application	Repeated application
4.	Mainly exotic or introduced insects and fungi are deployed in this approach	Mostly native fungi, bacteria, viruses and even nematodes are adopted through this approach
5.	No spraying like herbicide or other chemicals	Inoculum is sprayed like a herbicide over the standing population of weeds

Criteria of Successful Bio agent:-

A successful bio agent is (i) host specific, (ii) adjustable to the new environment, (iii) rapid destroyer of the target weed, (iv) easy to multiply, and (v) effective on several texa of the weed in question.

(i) ***Host Specificity***: - Bio control agents recommended for weed control should be host-specific, i.e. they should not attack other plant species, particularly the economic ones. The bio-agents released so far (chiefly insects) had successfully passed the _starvation tests' before they left the laboratories for field use. They were found to prefer to starve to death rather than feed upon plant species other than the target weed. Starvation test is a good safeguard against an introduced bio-agent becoming a pest on some economic crop plant.

(ii) ***Bio agent Hardiness***: It is important that a classical bio agent withstands elements of its new environment in which it is transplanted. This includes freedom from its own parasites and predators. Further, the bio agent should be hardly enough to survive short and long periods of food shortage when the target weed population is brought to a low level.

(iii) ***Feeding Habit***: Great stress has been placed on the selection of insects as bio agents that attack both the flowers and seeds of the weed or bore into their stems. Insect bio agents with such feeding habits have been found more host specific and efficient in controlling weeds than the leaf or root feeder. But lately certain leaf eating insects have been found equally valuable in the control of weeds, particularly of the perennials. Likewise, insects that attack roots are likely to be very effective on perennial weeds but insufficient attention has been paid to them. In any case, the destructive capacity of a bio agent on the weed should be very high so that its small population could destroy large weed infestations.

(iv) ***Ease of Multiplication***: High rate and ease of natural reproduction of bio agent is important in insects, pathogens, snails, and competitive plants. But it is very much unwanted in the case of carp employed for aquatic weed control because their excessive population may compete with cultivated fish.

(v) ***Effective on several taxa of the weeds:*** The bioagent should be effective on several taxa of weeds

Kinds of Classical Bio agents: - Four kinds of bio agents have thus far been successfully used for controlling weeds, both terrestrial and aquatic. These are (i) insects, (ii) carpfish, (iii) fungi, and (iv) competitive plants.

(i) **Insects:** Insects have been more frequently used than other animals for the biological control of weeds. The first successful example of weed control with deliberately introduced insects was reported from Hawaii in 1902 when a project for the control of Lantana camara L. was initiated with a moth, Crocidosema lantana Busck. Since then insects belonging to widely different families and genera have been employed to control some other noxious weed species.

Insects selected as bio control agents of weeds are largely host specific i.e. one insect species is employed to destroy only one weed species.

(ii) **Carp-fish**: Certain fresh water carp-fish consume large quantities of aquatic weeds and they are very suitable for relieving waterbodies of their massive growth of noxious, aquatic vegetation. Unlike insect bio agents, the herbivorous fish are not much food-specific. They feed upon a wide range of plants and, therefore, they control a variety of aquatic weeds, simultaneously. This food habit of grass carp may be undesirable in water bodies having some plants of economic value, like water chestnut (Trapanatans) and lotus (*Nelumbo* spp.) which, of course, are also classed as weeds in most situations.

(iii) **Plant Pathogens**: Many fungi are observed to attack specific weed species, but examples of successful, practical weed control with fungi are few. Of late, it has been

discovered that *Acacia glauca* could be controlled successfully by injecting a suspension of spores of *Cephalosporium zonatum* Sawada.

(iv) **Competitive Plants**: Certain plants may be highly competitive in nature; capable of suppressing some specific weeds without causing any meaningful hindrance to our interests.

Outstanding Examples of Classical Bio-control of Weeds:-

(i) **Lantana (*Lantana camara* L.):** Lantana was the first weed controlled successfully with certain insect bioagents in Hawaii. This bushy weed is a native of Central and North America. In Hawaii it had invaded such large area of rangelands that it was causing great concern. Of these, Crocidosema lantana Busck, a moth, was found prominent in destroying flowers and seeds of lantana, which formed the chief organ for dispersal this weed. The insect greatly curtailed the spread of lantana and thinned its existing infestations. Fifty years later, the entomologists in Hawaii made further attempts to find and introduce new insect species to destroy lantana; this time from areas other than the native land of the weed. They found seven more insects feeding on lantana. Of these, *Hypena jussalis* Guenoe was an excellent feeder of lantana leaves. It defoliated all sizes of lantana plants rapidly. Since then many other insects have been screened for the destruction of lantana in Hawaii, and the weed has been brought under control on her different islands.

(ii) **Prickly pear (Opuntia spp.):** In Australia, biocontrol of *Opuntia inermis* with a moth, *Cactoblastis cactorum* (Berg) transformed 24 million ha land from wilderness to a scene of prosperous endeavour. At the present, in Australia only occasional plants and few larger patches of pricklypear can be found. The recovered land has returned to useful agriculture there. In TamilNadu and Maharastra (India), 40,000 ha of land infested with *Opuntia dillenii* was recovered from the weed by releasing *Dactyloplius tomentosus* Auct. (*D. ceylonicus* Green) ‗cichineal scale insect' as its bioagent.

(iii) **Alligator weed (*Alternathera philoxeroides*):** Alligatorweed is a very prolific, aquatic plant of the tropics and sub-tropics. In Florida, (U.S.A.) it has been very effectively controlled with fleabeetle (*Agasicles hygrophyla* Selman Vogt) and several bayous have been cleared of this weed there. The fleabeetle larvae feed on the leaves of alligator weed and finally bore into its bare stems to pupate.

(iv) **Water hyacinth (*Eichhornia crassipes*)**: Water hyacinth, a world-wide aquatic weed, infests transplanted paddy fields in many countries, including India. Several attempts have been made on the biological control of this weed; both by pathogens and insects. Most success in this respect has been met in Florida (USA) with a hyacinthmoth, *Sameodes albiguttalis* B. Benner, which is a native of South America. The bioagent exhibits its rapid reproduction ability in field conditions. Its larvae feed upon young leaves and apical buds of water hyacinth, rather severly.

(v) **Salvinia (*Salvinia molessta*)**: In Kerala (India), fresh water courses and paddy fields have been cleared of this noxious fern, using culionid beetle (*Cytrobagous salviniae* Sands) as a very effective bioagent. The beetleis is native of South America. It is released in water ways by collecting some beetle-infested Salvinia plants from either the beetle rearing ponds or some old infestations, and scattering these on the target, salvinia infestations. It takes 4-6 months for the salvinia mats to turn yellow, and another six months to sink, completely. The young larvae of the beetle damage the terminal buds, rhizomes, and petioles of salvinia. The biological control of salvinia has made lives of over 5 million people in Kerala more comfortable than before.

A **bioherbicide** is a biologically based control agent for weeds. Bioherbicides may be compounds derived from microbes such as fungi, bacteria, viruses, or protozoa; or phytotoxic plant residues, extracts or single compounds derived from other plant species. In the industry,

bio-herbicides and other bio-pesticides are often referred to as "naturals". When the active ingredient used is a fungus, the product is called a mycoherbicide.

Almost every agricultural pest has at least one naturally occurring enemy that will reduce its population. Bioherbicides utilize such naturally occurring enemies, rather than depending on man-made chemicals. This can be important because agents of biological control ordinarily have many fewer, and much milder, effects on the environment than do synthetic chemicals. What is more, they tend not to lead to the public health problems that chemicals are associated with. These two advantages of biological control agents, including bioherbicides, do not however mean that they need not also be subjected to careful tests for environmental and public health safety.

Plant pathogens can be used to control weeds in a similar way to chemical herbicides. Bioherbicides can be applied in many ways, e.g. as aerial sprays, through _cut and paste' application or in a powder applied to the soil.

In contrast to the fungi typically used in classical biological control, the pathogens exploited as mycoherbicides are often native to the area where they are utilized, and do not need to be specially imported. Under natural conditions disease epidemics occur and damage plants from time to time, but the potential of these fungi is frequently limited. For example, the environment is not always conducive to good disease development and the pathogen may be limited in its dispersal capabilities. The inundative approach, where these fungi are turned into mycoherbicides, allows people to overcome some of these constraints and create disease epidemics when and where they want. After application the fungi do not usually persist at high levels for long and have often returned to background levels 1–2 years later. This means that, like other herbicides used to kill plants, bioherbicides often need to be reapplied. The pathogens used in inundative control often need not be as highly host specific as classical biological control agents because their use can be restricted to certain areas.

History of bioherbicides

Mycoherbicide research to control agricultural and environmental weeds began in the 1940s. The earliest experiments simply involved moving indigenous fungi between populations of target weeds (e.g. the fungus *Fusarium oxysporum* used against prickly pear cactus (*Opuntia ficus-indica*) in Hawai'i, before the release of the *Cactoblastis cactorum* moth).

In the 1950s the Russians mass-produced the spores of *Alternaria cuscutacidae* and applied them to the parasitic weed dodder (*Cuscata* spp.). In 1963 the Chinese mass-produced a different fungus (*Colletotrichum gloeosporioides* f. sp. *cuscutae*) for the same weed. They called their mycoherbicide _LuBao' and an improved formulation is still in use today. Since then more than 100 bioherbicide projects have been undertaken worldwide, but only a small percentage of these have resulted in commercially available, registered products. It should be borne in mind that the chemical industry routinely screens thousands of inorganic compounds to find a single commercially feasible new chemical herbicide.

Formulation is often the stumbling block when difficult to get living organisms to behave predictably and reliably in the field given the variety of conditions they encounter. Mixtures that look promising in laboratory trials often prove unsatisfactory in the field. It can take many years of experimentation to develop a workable formulation. Each country has its own rules regarding registration, and meeting the requirements can be an expensive and complex process (e.g. it took 5 years to register BioMal®). Commercialisation can also be difficult, especially if the target market is small and the product extremely effective (if the product does not need to be reapplied, its market gets smaller).

Benefits of bioherbicides over other herbicides

Because the plant pathogens used in bioherbicides usually occur naturally in the areas where they are utilized, they tend to be less harmful to the environment than chemical herbicides.

The fungi are oft1en more selective in their mode of action so the risk of damage to other plants is reduced. Bioherbicides are, as a rule, less toxic to people and animals than chemical herbicides.

Principles of microbial weed control

Approach

Classical – agent selection, inoculation, selfperpetuating, long term protection.

- **Inundative –** mass production, application at high inoculum levels over a localized area, short term, and repeated application.
- **Augmentation** – re-establishment of a classical agent.
- **Mycoherbicide –** fungal pathogen
- **Bioherbicide –** fungi and bacteria

Why bioherbicide ?

- Demand for decreased use of pesticides
- Large areas where herbicide application not possible or not cost effective
- Damage to the environment
- Contamination of our water supply
- High yield losses still occur $619 million in vegetable, $441 million in fruit and
- nut crops in the US

Ideal characteristics of a bio herbicide:-

- Produce abundant and durable inoculum in culture
- Be target specific Be genetically stable
- Be capable of killing a significant portion of the weed population under a variety of environmental conditions (weed densities)
- Herbicide resistant weed population
- Detrimental effects on non target organisms
- Native plants

Agents used as bioherbicide:- Fungi, Bacteria and viruses

Major characteristics of a bio herbicide:-

Trait	Bacteria	Fungi	Virus
Culture	Easy	Easy	Host
Specificity	Excellent	Good	Excellent
Field performance	Variable	Variable	Unknown
Formulation	Variable	Excellent	Unknown
Effectiveness	Variable	Variable	Excellent
Genetic stability	High	Medium	Unknown

Risks associated with bioherbicides.

In most instances the potential risks associated with the use of Bioherbicides may includes certain concerns Such as:-

- worker exposure and safety

- Plant host range
- effects to nontarget organism (competition/displacement of beneficial microbes in the community)
- production of chemicals that are persistent or toxic to mammalian systems

Steps in developing a bioherbicide

1. Check that a bioherbicide product is needed and that there is sufficient industry and commercial backing to proceed.
2. Look for suitable pathogens (if not already known).
3. Identify highly pathogenic (disease- causing) isolates that produce no or few toxins, and are unlikely to damage non-target species.
4. Develop an efficient way of mass-producing the pathogen and ensuring stability and shelf life.
5. Determine the optimum conditions for infection and disease development.
6. Check that the pathogen can be used in a manner that will minimise any harmful effects.
7. Develop an appropriate formulation and application technology.
8. Test in the field and improve formulation if necessary.
9. Obtain registration for the product, and market and distribute product.

Bioherbicide philosophy of weed control:-

Bioherbicides are pathogens cultured artificially and made available in sprayable formulations; just like a chemical herbicide. The pathogen selected for the purpose is usually from the native place of the weed, but it could also be from other places. The bio-herbicides are also sometimes called myco-herbicides. A myco-herbicides can be both, specific and non-specific.

Some Commercial Myco-herbicides in use Abroad.

Product	Content	Weed controlled
De-Vine	A liquid suspension of fungal spores of *Phytophthora palmivora* Butler. It causes root rot in the weed.	Stranglevine (*Morrenia odorata*) in citrus orchards.
Collego	Wettable powder containing fungal spores of *Colletotrichum gloesporiodes* Penzig and Sacc. Sub sp. Aeschynomone	Jointvetch (*Aeschynomone* sp.) in rice fields. The bioherbicide causes stem and leaf blight in the weed.
Bipolaris	A suspension of fungal spores of Bipolaris sorghicola.	Johnsongrass (*Sorghum halepense*)
Biolophos	Amicrobialtoxinproducedas fermentation product of *Streptomyces hygroscopicus*	Non-specific, general vegetation
BioMal®:	*Colletotrichum gloeosporioides f. sp. Malvae*	Round-leaved mallow(Malva pusilla) in wheat, lentils & flax. No longer commercially available but made on request

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CHAPTER-9

Concept of herbicide mixture and utility in agriculture

CONCEPT

The concept of herbicide mixture probably dates back to 1960s when the phenoxyalkanoic acids used to be formulated together. The researchers on herbicide mixture, however, have gained momentum after there were reports of weed flora shift and herbicide resistance in weeds in some countries of the world. Herbicide mixture is believed to be an important tool towards management of herbicide-resistance in weeds. It, if not completely prevents the development of resistance in weeds, certainly delays it. Formulating a herbicide mixture, therefore requires a clear understanding of the compatibility and interaction of the component herbicides to be used in mixture. For weed control in cereals, new herbicides such as chlorsulfuron, metsulfuron-methyl, bensulfuron-methyl, chlorimuron-ethyl of the sulfonylureas, almost from the beginning, have been developed in combinations with other herbicides or viewed as additive by the trade and farmers (Martin, 1987). Mixed formulation of chlortouron+bifenox, isoproturon+trifluralin, isoproturon+bromoxylin + ioxynil, isoproturon + bromoxynil+ioxynil+mecoprop and isoproturon+bromoxynil+mecoprop are also available for the combined control of grass and broad leaved weeds in cereals. However, studies relating to bio-efficacy, selectivity and persistence of herbicide mixture require to be taken up more in the forth-coming years and similarly the farmers may be advised to resort to herbicide mixtures instead of using single herbicide repeatedly.

Herbicide mixture, in spite of having immense beneficial role, has some limitations. Two selective herbicides may turn non-selective and hence become more toxic than either of the component herbicides. As a result, the normally tolerant crops may fall susceptible to a herbicide mixture. However, this demerit could be a merit under non-crop situations to manage difficult-to-control weeds with reasonably lower total active ingredient. The herbicide mixture may also show antagonistic response and there may exist physical incompatibility between the component herbicides as well.

DEFINITION

On principle, mechanical or chemical mixing of two or more herbicides having different mode of action and varying level of activity and selectivity, forms —herbicide mixture.‖

KINDS/TYPES OF MIXTURE

Herbicides mixtures are of two kinds: factory-mix/pre-mix/ready-mix and field-mix/tank-mix.

FACTORY-MIX/PRE-MIX/READY-MIX

It is the mixture of desired herbicides prepared in the factory itself with definite proportions, e.g. isoguard *plus* (isoproturon+2,4-D), aniloguard *plus* (anilofos+2,4-D), primagram (atrazine 250 g FW + metolachlor 250 g FW), primextra (atrazine 200g FW+metolachlor 300 g FW), Atlantis [Mesosulfuron-methyl (3%)+iodosulfuron-methyl sodium (0.6%)] etc. One ready-mix Pursuit Plus® [pendimethalin (30%)+imazethapyr (2%)] for broad-spectrum weed control in soybean is also available in India. Almix [metsulfuron-methyl (10%)+chlorimuron-ethyl (10%)+0.2% surfactant] is another ready-mix recommended for rice.

FIELD-MIX/TANK-MIX

It, on the contrary, is a mechanical mixing of two or more herbicides with their required quantities in the spray tank right before applying to the field. For example, atrazine+alachlor, atrazine+pendimethalin, isoproturon+tralkoxydim, sethoxydim+ chlorsulfuron, sethoxydim+thiometuron, fluometuron+chlorsulfuron, are compatible enough

to be mixed together for greater efficacy and broad-spectrum weed control in crops in which the respective pair of herbicide is selective.

The number of ready-mix product is less in the market. They are not manufactured as such unless there is sheer urgency towards weed control in certain crop. Ready-mix formulations may fall short towards imparting selectivity to a large number of crops. For example, pendimethalin is a versatile chemical and could be selective to nearly 60 different crops, but its ready-mixes with certain herbicides reduce the mixture's selectivity for use in that many number of crops. Thus herbicide mixture limits the choice of crops and becomes more crop-specific than a single herbicide. Tank-mix formulation, on the other hand, is mixing of chemicals in the tank before use in the field and, therefore, could be prepared as and when required with exact amount calculated for two or more herbicides. The exact amount calculated based on recommendation is, however, not easy to maintain in ready-mixes. Ready-mixes are, however, more useful to illiterate farmers than tank-mixes. Once the mixture response is known as synergism or at least additive in certain crop, it would be wiser to resort to tank-mix application.

KINDS/TYPES OF MIXTURE INTERACTION

Relationship of one chemical against another in a combination/mixture is called interaction. In a mixture, herbicides may interact in different ways, but the three major types of interaction are:

1. PHYSICAL INTERACTION

The mixture components may interfere with each other for some physical properties/processes in them, *e.g.* flowability, sticking, penetration/absorption through plant surface.

2. CHEMICAL INTERACTION

The mixture components may react with each other chemically in the spray tank and/or inside the plants and may result in new products with variable activities.

3. PHYSIOLOGICAL / BIOCHEMICAL INTERACTION

When two or more herbicides are introduced into cellular environment of a plant, conditions for an interaction are created (Akobundu et. Al., 1975a). The physiological/biochemical interaction of the mixture components thus takes place after entering into plants, which may be manifested in the blockage/inhibition or stimulation of some plant processes mainly translocation, activation and/or deactivation of one or all the component herbicides. All these interactions may yield synergism, antagonism, additivity or enhancement effect depending on target weed species and kind, rate, time and method of application of herbicides, but it is always ideal and highly desirable that a herbicide combination should be synergistic to weeds and antagonistic to crops.

These interactions may affect (facilitate or de facilitate) the following phenomena, which may be one way or the other responsible for the observed response in plants from herbicide mixture.

- Mutual interaction of the herbicides in mixture may result in increased uptake of one or all the component herbicides.
- Increased uptake may result in increased translocation of one or all the component herbicides to the respective site of action inside the plants.
- Bio-activation as operative in certain herbicides after entering into plants, may be influenced and accelerated.
- Detoxification of the mixture herbicides inside the plants may be prevented or inhibited.

- Increased binding of one or all the component herbicides at their respective molecular sites of lamellae (site of action) due to enhanced uptake and translocation.
- Additional site of action may be generated inside the plants due to new chemicals or toxic metabolites formed on chemical interaction between the component herbicides.

BENEFICIAL ROLE OF HERBICIDE MIXTURE 1.
Mixture controls a broad-spectrum of weeds

Herbicide appears to be an important tool for weed control in crops. There are over 400 herbicides available today. However, many of them have narrow-spectrum activity and control a specific group of weeds whereas there exists a composite stand/culture of weeds in the crop fields. Therefore, applying a single herbicide may not provide desired level of broad-spectrum weed control. Moreover, the chances of a new broad-spectrum herbicide discovery are decreasing in the world taking into consideration of crop selectivity, wide range of weed control, specific weed problem, wider-window of application, persistence and residual hazards. Added to this, fluctuation in weed flora makes it difficult to aim at specificity. The broad-spectrum herbicides in true sense are a few in this world. Even a so-called broad spectrum herbicide pendimethalin controls mainly broad-leaved weeds and a few grasses, although it is known as a good broad-spectrum herbicide. Here lies the importance of a herbicide mixture, which serves the purpose of a broad-spectrum herbicide. Several herbicide mixtures offering broad-spectrum activity are:

a) Atrazine+alachlor as pre-emergence in maize
b) Atraqzine+pendimethalin as pre-emergence in maize and sorghum
c) Fenoxaprop-p-ethyl+2,4-D as post-emergence in wheat
d) Fenoxaprop-p-ethyl+isoproturon as post-emergence in wheat
e) Clodinafop-propergyl+2,4-D as post-emergence in wheat
f) Clodinafop-propergyl+isoproturon as post-emergence in wheat
g) Sulfosulfuron+2,4-D as post-emergence in wheat
h) Sulfosulfuron+isoproturon as post-emergence in wheat
i) Isoproturon+2,4-D as post-emergence in wheat
j) Isoproturon+tralkoxydim as post-emergence in wheat

2. Mixture prevents/avoids weed flora shift

Continuous use of narrow-spectrum herbicide for years together may result in shift in weed flora. For example, a crop field dominated by grass weed for many years may gradually turn into broad-leaved weed domination if continuously a grass-killer herbicide is used for the sake of control of grass weeds only. The reverse may be true if there was continuous use of broad-leaved-killer herbicide. The world has already experienced it. In wheat, broad-leaved weed domination in the late 1960s and early 1970s changed to grass weed (*Avena ludoviciana/fatua, Phalaris minor, Poa annua, Snowdenia polystachia*) menace due to continuous use of broad-leaved-killer herbicides like 2,4-D, MCPA (Phenoxyalkanoic acids) in India and world. Repeated killing of the broad-leaved weeds by these herbicides gradually eliminated competition from the natural enemy weeds, i.e., broad-leaved weeds for the existing grass weeds and as a result, the grass weeds, in course of time, came up with virulence and posed their dominance. The use of herbicide mixture may, however, prevent it.

3. Mixture avoids/delays the development of resistance in weeds

Herbicide mixtures, in true sense cannot completely prevent, but certainly delay the process of development of resistance in weeds. The development of resistant biotypes within the wed species seems to happen rather slowly and herbicide mixture of those having different site of action helps to avoid the problem. The frequency of occurrence of resistance usually becomes compounded and lowered in mixture compared to the frequency of occurrence of resistance by a single herbicide (Gressel and Segel, 1990). For example, if the frequency of resistance for one compound is 10^{-7} and for other is 10^{-8}., the compounded frequency of occurrence of resistance to either of the chemicals in mixture would be reduced to 10^{-15} ($10^{-7}\times10^{-8}$). This is mainly because of lower selection pressure owing to reduced rate of application in mixture. Sulfonylureas and imidazolinones are widely used herbicides recently in number of crops and they are more vulnerable for resistance development. Therefore, they should be judiciously used preferably in mixture with less-resistance-prone herbicides.

To prevent herbicide resistance in weeds, a mixture should have component herbicdides which are less resistant-prone. Wrubel and Gressel (1994) suggested that mixtures to be efficient in preventing resistance, the less resistance-prone herbicide partner/component should have following traits compared to the vulnerable one:

1) It must control same spectrum of weeds as the vulnerable partner.
2) It must have a mode of action different from that of vulnerable partner.
3) Both mixing partners (less resistance-prone and the vulnerable one) must have similar effectiveness in weed control. It may not be that useful if, at the rate used, the mixing partner effectiveness in weed control. It may not be that useful if, at the rate used, the mixing partner kills 75% of the weeds and the vulnerable kills 95% unless the 20% remaining are severely inhibited such that they have less reproductive capacity than wild type. Otherwise, resistance could quickly evolve in remaining 20% of weeds.
4) It must have similar persistence as the vulnerable partner. Otherwise, the target weed having periodicity in germination almost all through the cropping season may not be exposed to the mixture, but to either of them which persists till that period.
5) It should not be degraded in the same manner/pathways as the vulnerable partner.
6) It will put extra advantage if the less-resistance-prone mixing partner exerts negative cross-resistance.

It is the realization of corn farmers in USA that atrazine+alachlor, atrazine+metalachlor mixtures and other herbicide rotations kept away the development of resistance in weeds after firat few reports of resistance (Chittapur *et. al.*, 1997). This could be due to alachlor and metalachlor reduced the doses of triazines, which reduced selection pressure. Also there are reports (Martin, 1987) that some resistant weeds have become susceptible to herbicide mixture when applied to the field.

4. Mixture increases weed control efficiency

Herbicide mixtures are likely to control a broad-spectrum of weeds quite effectively at relatively low rates then their component‘s sole application rate. Therefore, there likely occurs less phytotoxicity to crop and the overall performance of crop in terms of growth and yield increases in absence of weed competition. This may render increases efficiency and benefit per unit cost of investment in mixture compared to a single herbicide applicatuion. Reddy et. al. (1995) reported that combination of fluchloralin+metolachlor (0.5 kg/ha+0.75 kg/ha, respectively) as pre-plant incorporation improved weed control efficiency in sunflower. Nagaraju (1994) observed that anilofos+2,4-D mixture was more remunerative than sloe application of recommended herbicides. Anilofos predominantly being a grass killer and 2,4-D a broad-leaved killer. Their mixture brings about a broad-

spectrum weed control and results in greater efficacy. Similar increase in greater efficacy. Similar increase in weed control efficacy may also be obtained in benthiocarb+2,4-D mixture in rice.

Weeds fall susceptible to herbicide mixtures (Martin, 1987)

	Herbicides			
Weed species	Methabenzthiazuron	Trifluralin+Linuron	Terbutryne	Isoxaben
Galium aparine	R	MS	R	MS
Vernonia hederifolia	MR	S	MR	S
Stellaria media	S	S	S	S
Poa annua	S	S	S	R

R-Resistant; S-susceptible; MS-Moderately susceptible; MR-Moderately resistant

5. Mixture reduces cost of application of herbicides

To achieve a desired level of broad-spectrum weed control and greater efficacy, there is required a good broad-spectrum herbicide, which is normally less available and even if some are available, crop selectivity may warrant their application. The next possibility/option is that herbicides having different spectrum of weed control have to be used independently as a followed-by application consecutively giving no interval (if both are pre-emergence ones) or with certain gaps, as applicable, of 15, 20, 25, or 30 days after first application (if one is pre-emergence and the other is post-emergence). Their separate application in pursuit of greater efficiency will unnecessarily increase the cost application. On the contrary, by almost 50% while the weed control efficacy may remain similar to higher.

6. Mixture reduces the requirement of active ingredient (toxicant)

A suitable mixture having good compatibility between the candidate herbicides may result in synergism and potentiation action and reduce the doses of individual herbicide. Therefore, a desired level of weed control may be achieved by mixing herbicides even at lower doses than what required when they are applied independently. For example, almost 50% reduction in active ingredient of atrazine+alachlor mixture in maize and atrazine+pendimethalin mixture in maize and sorghum has been experienced for a desired level of weed control has achieved by their individual separate application (Yaduraju et. al., 1998). Similar is the case with fluazifop-p-butyl+clethodim applied as tank-mix in flax. Their reduced rates (50+18 g/ha, respectively) were as effective as full rates of either of the herbicides applied alone and resulted in 20% reduction in total amount of active ingredient required.

7. Mixture reduces residue hazard in crop and environment

Less residue build-up in the crop, soil and water accrues mainly from reduced rate of application of the component herbicides in mixture. To achieve this, a lot of trial and error has to be exercised on the compatibility of herbicides with reduced rate of application and choosing herbicides of lower persistence in soil. In a mixture, if the summed-up dose of component herbicides is equal to or even greater than their independent application dose, residue build-up would definitely be reduced in mixture because of the reduced doses of component herbicides. For example, in the mixtures of atrazine+pendimethalin, atrazine+alachlor and atrazine+tridiphane, the residues are likely to reduce mainly because of the lower dose of atrazine, which is a persistent herbicide and persists even for 6 months. Simazine has also similar persistence as atrazine.

8. Mixture increases the chance of growing a sensitive crop in rotation

Maize-wheat rotation is a predominant system in USA. It is also practiced in some areas of North and north-western India. A single higher dose, usually 1.5-2.0 kg/ha of atrazine to maize for having a desired level of weed control may leave enough residue in soil for the

succeeding wheat crop since atrazine has higher persistence in soil. This may bring phytotoxicity to wheat if grown in rotation. However, the reduced dose of atrazine (0.5-0.75 kg/ha) in mixture with pendimethalin or alachlor may permit wheat to be grown with no risk of damage to it.

Herbicide mixtures for crops:-

a) Rice

In rice, particularly under direct-seeded condition, weeds comprising of grass, broad-leaved and sedge are of often problem and cause serious yield reduction, whereas under lowland transplanted situation, the weed problem is normally less except some extreme situations. However, herbicides are used invariably in both these situations.

Fujiyama *et al.* (1987) reported that mixture of 120 g/ha MON-7200 (dithiopyr) + 25 g/ha bensulfuron-methyl or 21 g/ha pyranosulfuron-ethyl gave wide spectrum of weed control at low doses including *Echinochloa crus-galli.* This mixture did not cause severe injury to rice, although they could be injurious if basal stem was exposed to flood water. Temperature and soil type did not affect the activity. Activity against *Echinochloa crus-galli* persisted until 70 days transplanting.

Several combinations are given below, although, their best use can be made through further trial and error method. Of course, there may not be any objection regarding their compatability, but interaction has to be modified towards more synergistic response through manipulation of the doses of the component herbicides.

- Anilofos (0.4 ka/ha) + 2,4- DEE (0.50 ka/ha)
- Butachlor (1.0 ka/ha) + propanil (2.0 ka/ha)
- Butachlor (1.0 ka/ha) + 2,4- DEE (0.50 ka/ha)
- Benthiocarb (1.0 ka/ha) + 2,4- DEE (0.50 ka/ha)
- Anilofos (0.3 ka/ha) + chlorimuron (0.004 ka/ha)
- Anilofos (0.3 ka/ha) + metsulfuron-methyl (0.004 ka/ha)
- Bentazon + propanil (1604 + 3404 g/liter)
- Pretilachlor + 2,4- DEE at 4 days after sowing of upland rice.

b) Wheat and barley

Wheat and barley are grown in the winter as well as spring season through out the temperate world. Both have got similarity in respect to the use of herbicides and the weed flora present in the field. So, both crops with respect to the use of herbicides mixture and combinations may be used as tank-mix at 28-35 days after sowing of wheat (post-emergence application)

- Diclofop-methyl (750 g/ha) + fluroxypyr (100 g/ha)
- Diclofop-methyl (750 g/ha) + isoproturon (500 g/ha)
- Isoproturon (750 g/ha) + 2,4-D (250 g/ha)
- Isoproturon (750 g/ha) + 2,4-D (500 g/ha)
- Tralkoxydim (350g/ha) + 2,4-D (500 g/ha)
- Tralkoxydim (350g/ha) + isoproturon (500 g/ha)
- Clodinafop (60 g/ha) + 2,4-D (500 g/ha)
- Clodinafop (60 g/ha) + isoproturon (500 g/ha)

- Fenoxaprop-p-ethyl (120 g/ha) + 2,4-D (500 g/ha)
- Fenoxaprop-p-ethyl (120 g/ha) + isoproturon (500 g/ha)
- Sufosulfuron (30 g/ha) + 2,4-D (500 g/ha)
- Sufosulfuron (30 g/ha) + isoproturon (500 g/ha)

c) Maize, Sorghum and Pearl Millet

Atrazine (Triazines) has been used in maize since long ago. The weed control effect of atrazine in maize is well appreciated and well acclaimed. Therefore, people used to call it as —Maize herbicides‖. However, there are many broad-leaved weeds developed resistance to atrazine in the recent years. Therefore, researchers have to be diverted towards greater weed control efficiency in maize by applying mixtures of herbicides. The following combinations have been found highly useful for broad-spectrum weed control in maize.

- Atrazine (0.5 kg/ha) + alachlor (1.0-1.5 kg/ha) in maize. They may be formulated as lasso-atrazine (ready-mix).
- Atrazine (0.75 kg/ha) + pendimethalin (0.75 kg/ha) in maize, sorghum and pearl millet. (tank-mix).
- Atrazine + tridiphane in maize. (tank-mix).
- Atrazine + 2,4-D in maize, sorghum and pearl millet. (tank-mix).

d) Soybean

In soybean, many herbicides could be used as tank-mixes.

- Oxadiazon (0.5 kg/ha + metolachlor (0.5 ka/ha) as pre-emegance
- Fluazifop-p-butyl (0.75 kg/ha) + fomesafen (0.25 kg/ha) at 20 days after sowing
- Haloxyfop-methyl (0.20 kg/ha) + fomesafen (0.25 kg/ha) at 20 days after sowing
- Metribuzin + chlorimurom- ethyl as pre –emergence
- Imazephapyr + pendimethalin- as pre –emergence

e) Groundnut

Acifluorfen + bentazon +2,4-Dbat 2 weeks (post-emergence)

f) Sunflower

Fluchloralin (0.5 kg/ha) + metolachlor (0.75 kg/ha) as pre-plant incorporation

g) Mustard and rapeseed

Pendimethalin (1.0 kg/ha) + fluchloralin (1.0 kg/ha) as pre-plant incorporation (this is not an ideal mixture)

h) Cotton

- Pendimethalin (1.5 kg/ha) + diuron (1.0kg/ha) as pre-emegence
- Diuron + paraquat as post-emergence directed spray

i) Sugarcane

- Diuron + 2,4-D
- 2,4-D + atrazine/simazine as as pret-emergence or post-emergence
- Paraquat +2,4-D as post-emergence directed spray
- Glyphosate + 2,4-D as post-emergence directed spray

j) Potato

- Atrazine (0.125 kg/ha + paraquat (0.25 kg/ha) as pre emergence
- Atrazine (0.125 kg/ha + paraquat (0.25 kg/ha) as post-emergence directed spray

k) Tea and coffee

- Paraquat + 2,4-D mixture in tea and coffee usually offers additive response. They are applied as tank-mix and post-emegence to weeds.
- Paraquat + diuron mixture, although results in antagonistic effect since paraquat prevents the uptake and translocation of diuron by rapid destruction of foliage and transport system., the residue of diuron in soil remains effective for a considerably long period.

For achieving maximum weed control efficiency through herbicide mixture, attention should be directed the search for good compatibility, ideal formulation. Low cost of manufacture and application and the carry-over effect to the next crops. Herbicide mixture to control broad-spectrum weeds, delay herbicide-resistant weeds and to check weed flora shift, has immense potentiality which will not be tapped fully unless the above factors are studied.

x-x-x-x-x

CHAPTER-10

Compatibility of herbicides with other agro chemicals

Under the current agricultural production practices, crops receive, in a single season, multiple seed treatments, preemergence and post emergence herbicides, insecticides, fungicides, nematicides, fertilizers and sometimes plant growth regulators. Most of these chemicals, whether applied as mixtures, simultaneously or sequentially, may undergo a change in physical and chemical characters which could lead to enhancement or reduction in the effect of one or more compounds. A normally safe herbicide may become toxic to a crop or an effective product may show reduced activity on a weed species. These interactions between chemicals are of common occurrence in today's agriculture. Their significance is more evident when the interaction effects are seen much later in the growing season or the following season and year due to build up of persistent chemicals or their residues in the soil. Application of a pre plant insecticide to soil may prove to be toxic when a post emergence herbicide is applied several weeks later. Knowledge of the interaction of herbicides with various chemicals will help in formulating and adopting a sound and effective weed management programme. It can also help to exploit the synergistic and antagonistic interactions between various herbicides to evolve an effective and economical eradication of weeds.

INTERACTION RESPONSES

Interaction is the term used to express the relationship of one agent against the other in a combination. When two or more chemicals accumulate in the plant, they may interact and bring out response different from those obtained when they are used alone. These responses are generally described as additive response, synergistic response (synergism) and antagonistic response (antagonism).

Additive Response:

Additive response is the total effect of a combination which is equal to the sum of the effects of the two components taken independently

Synergistic Response:

In synergistic response, the total effect of a combination is greater or more prolonged than the sum of the effects of the two taken independently.

Antagonistic Response:

In antagonistic response, the total effect of a combination is smaller than the most active component applied alone.

PHYSIOLOGICAL BASIS OF HERBICIDE INTERACTION

Enhancement or reduction of the activity of a given herbicide on a target plant brought about by the prior or simultaneous application of another chemical is the result of changes in the amount of herbicide reaching, or after reaching, the site of action in the active form. In a mixture, one component influences the toxicity of another component by interfering with the patterns of its penetration, translocation and biotransformation in plants. The physiological mechanisms explaining the synergistic, antagonistic and other interactions of herbicides with other agrochemicals in higher plants are briefly discussed below.

Mechanisms of Synergistic Interaction

Several classes of agrochemicals including adjuvants, fertilizers, herbicides, insecticides, growth regulators and other additives are known to synergize the activity of several herbicides on certain plant species.

Mechanisms of Antagonistic Interaction

The mechanisms by which chemicals would reduce the activity of a given herbicide on a target plant species can be generally classified into four groups. They are biochemical antagonism, competitive antagonism, physiological antagonism and chemical antagonism.

HERBICIDE-HERBICIDE INTERACTIONS

Use of two or three-way mixtures is quite common in modern weed managements programmes. The synergistic herbicide mixtures offer the following immediate and long-term benefits.

1. Provide more effective weed control.
2. Increase the spectrum of weeds controlled. The most successful combinations are those based on the pairing of a grass effective herbicide with a broadleaf weed effective herbicide in order to complement the phytotoxicity of each other at the physiological level.
3. Reduce the environmental impact of each herbicide in a mixture. The soil receives lower amounts of herbicides, resulting in far less amounts of herbicides reaching groundwater.
4. Improve crop safety (selectivity) as a result of application of reduced rates. Allow crops to be planted sooner after herbicide application; because of lower initial rates, herbicides will be more rapidly dissipated to non toxic levels.
5. Cause delay in the evolution of weed resistance to herbicides.
6. Allow zero or minimum tillage and chemical fallow practices achieve effective and economical weed control.
7. Reduce danger of human toxicity directly and through crop residues because of reduced rates of application.

There are two types of herbicide mixtures:

a) premixed formulations, made by manufacturers, and

b) tank mixes made by farmers before application with desired and recommended herbicides and rates.

The success of a herbicide mixture can be undermined by physical, chemical and biological incompatibility. This incompatibility leads to reduced performance of the mixture. Physical incompatibility results in the formation of agglomerates, crystals, phase separation, or thickening in the herbicide mixture. Thus, incompatibility is a frequent contributor to the variability of herbicide performance, particularly in the case of tank mixtures. Compatibility charts serve as an excellent source of information to help avoid these mixing problems. When making tank mixtures of herbicides, their compatibility needs to be tested. This may be done by premixing the materials by making slurry of small quantities (equal proportion) before adding to the tank. If required, a compatibility agent, which is non-ionic in nature, may be used.

Herbicide-herbicide mixtures have been widely used for over 30 years. Scores of factory-made premixes have been developed and farm level tank mixture recommended during this period to control some of the most problematic weeds in agriculture.

HERBICIDE-SAFENER INTERACTIONS

Herbicide safeners (also referred to as antidotes, protectants, antagonists, or modifiers), increase the tolerance level of crop plants to herbicides. As a result, the herbicide-safener mixture allows for improved control of weeds. Certain herbicides, when applied alone, would

either not be sufficiently active on the weeds at lower rates, or would cause injury at the higher rates required for satisfactory weed control. Safeners help in mitigating the problem by allowing herbicide application at higher rates.

HERBICIDE-INSECTICIDE INTERACTIONS

Herbicides and insecticides are often applied simultaneously or serially to crops within a short period. These chemicals are usually not harmful when used as per recommended practices. The tolerance of plants to a herbicide may be altered in the presence of an insecticide and vice versa.

HERBICIDE INTERACTIONS WITH FUNGICIDES AND PATHOGEN

Unlike herbicide-insecticide interactions, herbicide-fungicide interactions tend to be antagonistic.

Herbicide-fungicide interactions are not as widespread as herbicide-insecticide interactions. Herbicides interact with fungicides as well as the disease-causing organisms. Dinoseb was shown to reduce the severity of stem rot (white mould) in groundnut.

HERBICIDE-FERTILIZER INTERACTIONS

There is growing evidence of herbicide-fertilizer/plant nutrient interactions occurring in agriculture. The addition of ammonium nitrate greatly increases the absorption of solutions of isooctyl ester of 2,4,5-T by tree leaves.

Fertilizers have a significant effect on herbicide absorption. For example, the complete fertilizer involving N, P and K reduced atrazine absorption by plants, thus reducing phytotoxicity. Atrazine was more toxic in the presence of P and K than in the presence of N and P or N and K due to increased absorption of the herbicide by plants. Conversely, herbicides also affect the absorption of plant nutrients.

HERBICIDE-ADJUVANT INTERACTIONS

An adjuvant refers to any substance included in the formulation of a herbicide or added to the spray tank to enhance herbicide characteristics or application characteristics. Surfactants and phytobland oils are the two types of chemicals commonly used as adjuvants in herbicide formulations. Once a herbicide is commercialized, it may not be necessary to use additional adjuvants. However, addition of extra surfactants may be needed to improve the herbicide efficacy at low rates of several water-soluble herbicides applied to the foliage. The applied adjuvant enhances herbicide activity either favourably or unfavourably depending on the interaction of herbicide-adjuvant-plant combination. Adjuvants enhance herbicide uptake by the plant and its translocation to the site of action. As more herbicide is likely to be available for its effect, herbicide-adjuvant interactions are generally synergistic. The effects of adjuvants on herbicide activity are the opposite of safeners.

HERBICIDE-BIOHERBICIDE INTERACTIONS

The mixtures of bioherbicides (bioagents) and organic herbicides interact and bring out synergistic responses. Synergism has been found for a diverse group of herbicides, bioehrbicides and weed hosts. At the same time, mixing herbicides with certain bioherbicides may have a detrimental effect on the living microbes. This problem can be mitigated if the herbicide and bioagent are applied sequentially. The combinations of herbicides and living organisms normally provide additive, synergistic and antagonistic effects on weed control.

x-x-x-x

CHAPTER-11

Integration of herbicides with non-chemical methods of weed management

WEED PREVENTION

Weed prevention comprises all measures which deny the entry and establishment of new weeds in an area. It also includes farm hygiene that prevents the every year production of seeds, tubers, and rhizomes of the weed species already present on the farm.

Some major aspects of weed prevention on farmland are as follows:-

(1) **Use Weed free crop seeds:-** one important way the weeds spread on the farmlands is through crop seeds, contaminated with the weed seeds. Some weed seeds always go with certain crop seeds, for example, *Avena fatua* and *Brassica* spp. with small grains.

The prevention of weeds that disperse with the crop seeds can be achieved in two ways, viz. (I) by the production of weed free crop seeds at the Government farms or at the farmer's field itself, and (II) by cleaning the crop seeds of weeds before storage as well as at the time of sowing.

(2) **Avoid contamination of manure pits:-** It is a common practice of adding mature or even blooming weeds and their vegetative propagules to manure pits in the hope of recovering their manurial value. In most cases the weed seeds do not lose their viability in the manure pits and the resulting farm-yard manure serves as a notorious source of adding weed seeds to crop land.

(3) **Prevent Movement of weeds with other farm resources:-** Do not permit livestock to move from the weed-infested areas directly into clean areas because they can always drop weed seeds and fruits attached to them or those ingested by them earlier. The farm machinery, for similar reason, should be cleaned properly before moving it from one field to another. Same is true of the movement of nursery stock, gravel, sand, and soil from weed-infested areas to the new ones.

(4) **Keep non-crop areas clean:-** The irrigation and drainage ditches, fence lines, farm boundaries, bunds, and other like un-cropped areas are often neglected by farmers. These places offer a perpetual weed nursery for the cropped plots. This should be prevented by extending the weed control efforts to non-crop areas on the farm.

(5) **Keep vigilance:-** A farmer should inspect his farm areas periodically for some strange looking weed seedlings. The search for them should be extended into standing crops even if herbicides or cultivators were used to control weeds there. No sooner than any strange looking weed seedling are noticed, they should be uprooted by digging as deep as their roots may have penetrated the soil, and the soil in these spots should be treated with a suitable sterilant.

(6) **Legal measures:-** Legal measures are necessary to check inter-state and inter-country movement of noxious weeds if the cost of having to control additional alien weeds is to be saved. Unfortunately, thus far, in most parts of the tropical and sub-tropical world, noxious weeds have not been subjected to strict quarantine laws. This has resulted in the introduction and spread of some of the costliest weeds of the world.

Control and Eradication

Weed control is the process of limiting weed infestations so that crops could be grown profitably and other activities of man conducted efficiently. The word ‗crop' is not restricted here in its meaning to maize, sugarcane, or wheat, but it means any plant community that is serving some useful purpose to man and his affairs at the place of its occurrence.

In weed control we seek to limit the growth of unwanted plants, both in space and time, with-out any attempt to eliminate them from the scene. The extent to which any weed growth is desired to

be limited will depend upon the cost of weed control and the benefits anticipated from the operation. The aim of weed control is to manage the vegetation on land and in water bodies in such a way as will encourage the growth of plants beneficial to our interests at a particular place and time and will suppress the remaining relatively unwanted plant species.

In variance with weed control, weed eradication is complete removal of all live plant parts and seeds of a weed from an area, which may be a field/farm/village/geographical region, depending upon the need. Although very attractive, it is a very expensive adventure sine it will often cost more than the land was worth. Moreover, total destruction of weeds is considered undesirable even from crop fields since many weeds harbor predators of crop pests, or secrete in soil nematicides, while all of them hold soil nutrients against their leaching losses during fallow periods. Heavy expense of weed eradication is justified against noxious weeds such as Striga, Cuscuta, and *Lantana* spp., to prevent their dispersal to additional millions of hectares of useful land and water bodies. Against the common weed, we employ only control measures. But when required, a weed eradication programme should begin when the weed growth is still limited. Once the weed has invaded large, continuous areas, its eradication becomes uneconomical. The weed eradication is accomplished in more than one year; it requires intensive initial efforts to destroy all plant parts followed by many years of vigilance to prevent the new weed seedlings from establishing into adult plants. In variance with it, weed control is an every year, constant rate programme. Of course, with proper preventive measures, efforts required to control weeds can be reduced to a very low level, in due course of time.

Methods of weed control

(A) Physical Control of Weeds

(B) Crop Husbandry Control of Weeds

(C) Herbicidal Control of Weeds

(D) Crop Breeding For Weed Control

(E) Non-living Mulches

(F) Burning and Flaming

(A) CROP HUSBANDRY CONTROL OF WEEDS:-

Good crop husbandry is more than half the weed control envisages on farm land. While directly it induces a healthy growth of crop, indirectly it maintains a crop environment that is as detrimental to weeds as possible.

(1) ***Proper crop stand and early seedling vigor***:-

Ready and uniform germination of crop seeds and their development into vigorous crop seedling leaves less space for the weeds to grow amongst the crop plants. Uneven and low crop populations and weak crop seedlings, on the contrary, permit thick growth of weeds. A vigorously growing crop aids weed control by weakening the weeds by offering competition.

Important steps in obtaining good germination and optimum stand of crops are (1) selection of most adapted crops and crop varieties, (2) the use of high viability seeds, (3) pre-plant seed and soil treatment with pesticides, dormancy breaking chemicals, and germination boosters, (4) adequate seed rates and (5) proper planting time and method. Despite these practices if some gaps are still seen in the crop rows, these must be filled as soon as possible. Row spacing of crops should be as narrow as agronomic recommendations will allow so that the crops close in early. Unnecessarily deep plantings of crop seeds should be avoided as it results in slow germination, and often, in weak seedling.

(2) ***Selective crop stimulation***:- Selective crop stimulation can be achieved in many ways. To start with, correction of soil condition to favor crop growth by the application of soil amendments like gypsum or lime, as the case may be, is an important step towards favoring crop growth. Addition of farm-yard manure or synthetic soil conditioners to very light or very

heavy soils may be useful in improving crop growth by ameliorating the soil structure and thus, maintaining better air-water relationships.

Application of suitable fertilizers and manures in adequate quantities improves plant growth very much. But when these are applied uniformly to soil, they may benefit the crops and weeds. Therefore to make fertilizers available mainly to the crop, these should be banded or side dressed. Weeds growing 20 cm or more away from the fertilized bands usually fail to make use of even a mobile nutrient like N. Such weeds remain stunted in comparison to the close growing weeds. Foliar application of fertilizer to wide row crops like maize sugarcane, and cotton, also amounts to their selective stimulation.

(3) ***Proper planting method***:- Any planting method that leaves the soil surface rough and dry will discourage early weed growth. For example, in India when winter grains are planted in seedbeds prepared after a pre-sowing irrigation, it leaves the top defers the germination of the weeds. By this time the crop plants are sufficiently grown-up to fight weeds. In variance with this sound practice of planting crops, when a farmer plants his crops in dry soil and irrigates the field soon thereafter, the lands himself into serious weeds problems.

In the summer season, furrow planting of crops is a very useful method of reducing the weed problems. It is so because in this method the irrigation water is restricted initially to the furrows. This leaves the inter-row crop spaces dry where weeds fail to germinate. After the crop seedlings are well established, the fields can be irrigated, uniformly.

In transplanted crops the farmer gets opportunity to prepare a weed free field for the placement of healthy crop seedlings. This gives a definite advantage to the crop over the later germinating weeds.

(4) ***Proper planting time***:- With the availability of photo-insensitive varieties of many crops, manipulation of planting time of crops so as to avoid the first heavy flush of weeds should be easy. For instance, when rainy season crops like maize and cotton are planted about 15 days before the break of monsoon with the help of a pre-sowing irrigation, the crops germinate in weed free environment. And by the time the weeds germinate with the onset of rains, the crop seedlings are well up.

(5) ***Crop rotation*** :- Crop rotation are effective in controlling crop-associated and crop-bound weeds such as *Avena fatua* ‗wildoat' and *Cuscuta* spp. ‗dodder', respectively. Wildoat can be driven away from small grain fields by using pea and gram as break crops for 2 to 3 years. Dodder on the other hand, can be eliminated from Lucerne by turning the land to grain crops for some time.

(6) ***Stale seedbed***:-A stale seedbed is one where 1 to 2 flushes of weeds are destroyed before planting of any crop. As earlier stated, most weed seeds germinate from top 4 to5 cm of surface soil. If a finally prepared seedbed is withheld from planting and it contains adequate moisture in its top 4 to 5 cm of soil, a flush of young weed seedlings will appear on it, in about a week's time. These weed seedlings can be destroyed either with a contact herbicide like spike tooth harrow, trader-packer, spring tooth harrow, corrugated iron land-roller, weeder-mulcher, and sweeps. Depending upon the time available, one or two flushes of weeds can be destroyed in this manner before planting of crops in the stale seedbeds. The main advantage of stale seedbeds is that crops germinate in weed free environment.

(7) ***Smother cropping***: - The smother crops germinate quickly and develop large canopy, capable efficient photosynthesis, in relatively short period. They possess both surface and deep roots. Also called competitive crops, they suppress the weed seedling by excluding light beneath and utilizing large quantities of nutrients from the soil, rapidly.

(8) ***Summer fallowing*** : -Farmers in India, as in many other tropical countries, have used for decades hot months of April, May and June to expose their lands to sun in order to control many soil-borne pests, including weeds. Roots, rhizomes, and tubers of shallow rooted

perennial weeds like Bermuda grass and nut sedge are desiccated when these are brought to surface by tillage and exposed to air temperature of 40 to 45^0 C.

(9) ***Minimum tillage*** :- Deep and frequent tillage may be useful for some reasons, but it serves to (i) bring more of dormant weed seeds and rhizomes to the soil surface, and (ii) preserve, the new ones deep inside the soil for the future. Both these things are undesirable.

(10) ***Lowering area under bunds***:-Soil bunds made in fields for the purpose of irrigation are ideal places for the rapid growth of weeds. Soil dug or scraped for making these carries numerous weed seeds that germinate readily on them soon after the fields are irrigated, and establish into thick weed populations. These weeds form potential source of every year weed seeds on the farm since the application of herbicides and cultivations are usually restricted to the net cropped ground.

(11) ***Flooding and Drainage***: - Flood kills weeds by excluding air from their environment. Some weed species are more susceptible to it than the others. Flooding is a world-wide crop husbandry method of controlling weeds in rice fields. In some parts of Madhya Pradesh (India), deep flooding of fallow fields with rain water is practiced continuously for 2-3 months. After that the water is let out and the winter grains are planted. The practice, locally called ‗Haveli', is considered very effective in controlling weeds, besides conserving moisture. The technique, however, can, be used as a weed suppression measure only in limited situations.

In variance with flooding, drainage is used for controlling aquatic and semi-aquatic weeds in rice fields, canals, and ponds. In rice fields, where both terrestrial and aquatic weeds may be common, a judicious combination of the two can be practiced.

(B) THE PHYSICAL CONTROL OF WEEDS

(1) ***Pre-Plant Tillage Control of Weeds***:-

Pre-plant tillage is usually conducted in two phases, viz., the primary tillage and the secondary tillage. The primary tillage is conducted effectively with either a soil inverting plough or a disc. The secondary tillage, on the contrary, is performed with lighter implements like harrows, cultivators, weeder-mulchers, and corrugated rollers.

(2) ***Post-Plant Tillage***:-

For a long time, besides the control of weeds, at least three more functions were assigned to the post-plant tillage, more popularly called row cultivations. These function are (i) conservation of soil moisture, (ii) enhanced soil aeration, and (iii) mixing of fertilizer and manures with the soil. The development of chemicals to control weeds made it possible to separate the weed control effects of row-tillage from its other effects.

(3) ***Mowing and Cutting***:-

(i) ***Mowing***: Mowing is cutting of a uniform growth of weeds from entire area at the ground level. Its chief purpose is to improve look and accessibility to the area, and in certain cases to prevent multiplication of weed seeds. Also, repeated mowing can weaken the underground parts of perennial weeds.

Mowing is usually practiced in non-crop areas, lawns, and gardens, but it can also prove useful in removing weeds from rows of certain established crops. Common mowing tools and implements are sickle, sword, scythe, machete, lawn mower, and reciprocating type rotary-bar mower. Mowing is effective against only erect, herbaceous type of weeds. It is preferred over tillage control of weeds on land susceptible to erosion since it does not produce any bare land.

(ii) ***Cutting***: In variance with mowing, cutting is topping of the weeds above the ground level. It is most commonly practiced against brushes and trees with the help of axes and saws. In aquatics, under-water weed cutters are used to cut weeds up to 1 m below the water surface. Both cutting and mowing are short-lived in their effects; the topped weeds re-grow soon from

their crown region and underground buds. Therefore, these operations must be repeated often to keep the weeds and grasses low.

(4) ***Dredging and Chaining***: These two physical control methods are used against aquatic weeds growing in shallow ditches. Dredging constitutes mechanical pulling of weeds with their shallow roots and rhizomes covered in mud. In chaining, on the other hand, a very heavy chain is pulled over the bottom of the ditch with the help of two tractors, one moving on either bank of the ditch. The chain fragments the rooted weeds by its rubbing action, and the weed fragments float to the water surface. From here these can be collected down the stream by nets and hooks.

(5) ***Soil Solarisation***:- Soil solarisation, also called solar soil heating, is another method of utilizing solar energy for the desiccation of weeds in fallow fields during the hot summer months. It differs from hot weather tillage control of weeds described earlier in two major aspects (i) It is effective mainly against weeds from seeds. (ii) It usually does not involve any tillage of the field.

(C) Herbicidal control of weeds

Herbicides are chemicals capable of killing or inhibiting the growth of plants. In the last 40 years or so, man has greatly improved upon his weeding efficiency by supplementing the conventional weeding methods with herbicides. It has saved farmers of undue, repeated inter-cultivations and hoeing, and has helped him in obtaining satisfactory weed control where physical methods often fail. Today, we have over 150 herbicides in common use for selective and non-selective weed control in different areas. These chemicals vary greatly in their (a) molecular structures, (b) mobility within plants, (c) selectivity, (d) fate in soils, and (e) response to environment.

Benefits of Herbicides:

1. In monsoon season incessant rainfall may make physical weeding infeasible. Herbicides can be used to ensure freedom of crops from weeds under such a condition. Also, during the early crop growth period when many fields need weeding simultaneously, even in labour-rich countries like India, Pakistan, Bangladeshi Nepal, Nigeria, and Sudan, there is certainly a weeding bottleneck in crop production. The soil applied herbicides can be of great help in these regions in boosting crop production.
2. Herbicides can be employed to control weeds as they emerge from the soil to eliminate weed-crop interference even at a very early stage of crop growth. But by physical methods weeds are removed after they have offered considerable competition to the crops, and rarely at the critical time. Thus, herbicides provide benefits of timely weed control.
3. Herbicides can kill many weeds that survive by mimicry, for example, wildoat (*Avena* spp.) in wheat and barnyard grass (*Echinochloa* spp.) in rice. Weeds that resemble crop plants usually escape physical weeding.
4. Herbicidal control does not dictate strict row spacing. In physical weed control, on the other hand the crop rows have to be sufficiently wide to accommodate weeding implements, else hand weeding and hand-pulling of weeds has to be resorted to.
5. Herbicides bring about longer lasting control of perennial weeds and brushes than is possible with any physical control method. Many modern herbicides can translocate considerably deep in the underground system of weeds and damage them.
6. Herbicides are convenient to use on spiny weeds which cannot be reached manually.
7. Herbicides are safe on erodable lands where tillage may accelerate soil and water erosion. Excessive tillage, in any case, spoils soil structure, reduces organic matter content, and depletes moisture status of the soil.
8. Herbicides kill weeds in situ without permitting their dissemination. Tillage on the other hand, may fragment the vegetative propagules of the weeds and drag them to new sites.

9. Herbicide sprays easily reach the weeds growing in obstructed situations, such as utility-rights-of-way, under fruit trees, and on undulating lands.

Some other benefits of using herbicides include (a) fewer labour problems, (b) greater possibility of farm mechanization, (c) easier crop harvesting and (d) lower cost of farm produce. In dry land agriculture, effective herbicidal control ensures higher water use by crops and less crop failures due to drought.

Limitations of Herbicides:

Like any other method of weed control, herbicides have their own limitations. But with proper precautions these limitations can be overcome, markedly. Important limitations are as follows.

1. In herbicidal control there is no automatic signal to stop a farmer who- may be applying the chemical inaccurately till he sees the results in the crops sprayed or in the rotation crops that follow.
2. Even when herbicides are applied accurately, these may interact with environment to produce unintended results. Herbicide drifts, wash-off, and runoff can cause considerable damage to the neighboring crops, leading to unwarranted quarrels.
3. Depending upon the diversity in faming, a variety of herbicides must be stocked on a farm to control weeds in different fields. On the contrary, for physical control of weeds a farmer has to possess only one or two kinds of weeding implements for his entire farm.
4. Above all, herbicidal control requires considerable skill on the part of the user. He must be able to identify his weeds and possess considerable knowledge about herbicides and their proper usages. Sometimes, an error in the use of herbicides can be very costly.
5. In herbicide treated soils, usually crop failures cannot be made up by planting a different crop of choice. The selection of the replacement crop has to be based on its tolerance to the herbicide already applied.
6. Military use of herbicides is the greatest misfortune of their discovery. In Vietnam, 2, 4, D and 2, 4, 5-T, for example, was used for defoliating forests and crops, leading to miseries to the innocent civilians. In future, the chemical warfare with residual herbicides may be even more devastating, which must be avoided at all costs.

(D) CROP BREEDING FOR WEED CONTROL

Plant breeders, thus far, have engaged themselves in evolving crop varieties tolerant to specific pathogens, insects, nematodes, and even birds. But hardly any attempt has been made to breed crop plants tolerant to competition from weeds. In recent years attention of a group of Asian and African plant breeders has been drawn towards breeding millet varieties tolerant to *Striga* sp.

(E) NON-LIVING MULCHES

Mulching stunts or kills the weeds by cutting light to them. Straw, hay, dry sugarcane leaves, farmyard manure, rice hull, saw dust, and bark dust are natural, partial mulch materials, which can at best stunt the weed growth. Even when these are spread in thickness of 6 to 12 cm, the perennial weeds grow through them easily. Also, the natural mulches tend to harbour insect pests and disease organisms and obstruct farm operations. Synthetic mulches, namely black paper or Polythene film mulches provide stronger mechanical barriers to all kinds of germinating weeds. Black, plastic-coated, craft paper mulches are now preferred on newly-prepared fields to suppress weeds. These are made in rolls of different widths which can be spread on the seedbeds and then crop seedlings can be transplanted through holes made into them. Presently mulching with synthetic materials is costly, so its economic use is limited to certain high value vegetables and ornamentals.

(F) BURNING AND FLAMING

Burning is the cheapest method of eliminating mature, unwanted vegetation from rangelands and non-crop situations like roadsides and ditch banks in dry seasons. Weed seeds that have al- ready

shattered on the ground before flaming will not be killed by it. Burning is limited in its value because it is a potential source of fire hazard. In variance with it, flaming is a momentary exposure of green weeds to as high as 1000^{o} C temperature from flame throwers. Flaming kills plants by coagulating their cell protoplasm. In some western countries, flaming is used for selective control of inter-row weeds in onion, soybean, grain sorghum, castor bean, cotton, sesame, and certain fruit orchards. For selective weed control, flaming must be done when weeds are in their seedling stage and the crop plants are well established. The flame should be directed towards the weeds under hood covers.

Flaming has proved useful in destroying dodder-infested crops of Lucerne. In grasslands, woody shrubs and patches of perennial weeds can be destroyed by spot flaming. Flaming is also helpful in weeding farm ditches and many other difficult non-crop situations. It is believed that repeated light applications of flame to plant shoots can destroy even roots of the perennial weeds. The process is called **searing**.

Integrated weed management

Weed management differs from weed control or weed eradication wherein weeds are kept under check at a level that they do not cause economic loss from the crop. Instead of depending on one method of control, say herbicide or mechanical methods, integration of different methods like sanitation, mechanical methods, biological means and use of herbicides at a lower level keeps the weeds under check at an economic cost. This approach is gaining importance as herbicides at higher levels cause hazards and the labour availability becomes limiting and at times weather conditions do not permit soil manipulation.

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CHAPTER-12

Herbicides resistance and its management

There are three main plant responses to herbicide application. **Susceptibility** is demonstrated when the treated plant dies as a result of a herbicide used at a normal rate. **Tolerance** is the inherent ability of a plant to survive and reproduce after herbicide treatment. This implies that there is no selection or genetic manipulation but that the plant is naturally tolerant- for example, grass tolerance to 2,4-D or carrot tolerance to trifluralin. **Resistance**, as defined by the Weed Science Society of America, is the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type. Resistance may occur naturally or be induced by selection pressure.

Within resistance there are three subcategories used to describe particular types of resistance. **Cross-resistance** occurs when a plant selected for resistance to a specific herbicide is also resistant to other herbicides within a similar chemical group (such as resistant to atrazine and to other s-triazines as well). **Multiple resistance** occurs when a plant is resistant to herbicides that are chemically unrelated and that have different modes of action (such as a well resistant to both sulfonylurea and aryloxyphenoxy propanate herbicides). **Negative cross resistance** occurs when a biotype resistant to a particular herbicide is more susceptible to other classes of herbicides than the susceptible biotype- for instance, an atraxzine-resistant redroot pigweed (*Amaranthus retroflexus*) that is more susceptible to flometuron (cotoran/meturon) that the triazine-susceptible biotype.

Herbicide resistance

Herbicide resistance is the ability of a weed biotype to survive and reproduce after treatment with herbicides that would typically have been lethal. The development of herbicide resistance poses three serious problems:

1. It is very expensive and time consuming to test for and to develop alternative management plans
2. Develop management techniques to continue utilizing current herbicides and protect them against resistance development. Few new active ingredients are being discovered and developed into commercial products due to their high costs of development.
3. Development of herbicide resistance in a biotype limits weed management options and creates economic consequences.

Factors that control development of resistant weeds;

1. Selection Pressure. - If highly effective and applied often, has long soil residual activity, and is the only practice utilized to control a weed species, high selection pressure is placed for resistant biotypes of a weed.

2. Weed biology

a. **Genetic variability**: Some plant species have high genetic variability meaning that many different varieties or biotypes exist under the one species. Cross pollinating species like kochia have greater genetic variability that self-pollinating species. Weeds with higher genetic variability generally develop resistance quicker, since chances are there are more resistant biotypes within a population prior to spraying.

b**. Seed longevity**: Plant species that produce long-lived seed tend to develop resistance more slowly. This is because susceptible seeds from the seedbank germinate over many years adding variation to the population.

3. **Genetics of resistance**: This is regarding the site of action of the herbicide on the plant. There are differences pertaining to the frequency mutations occur at different biological

target sites within plants. Sites that have high frequency of mutation, tend to develop quickly, for example the site of action of ALS inhibitors can develop resistance with 3 or 4 years of continuous use since the target site is highly variable. In contrast, the target site of glyphosate do not mutate as often. Glyphosate resistance does not exist, but it took many years to develop.

Herbicide Resistant Crops

The use of biotechnology to develop crop plants with new resistance to herbicides, notably broad-spectrum herbicides such as glyphosate, has had a significant impact on weed control practices. This will continue as the ability to manipulate herbicide tolerance using these methods expands: More genes for herbicide resistance are being developed and the number of crops that can be genetically modified in this way is increasing. Indeed, it is possible that this approach will change the manner in which herbicides are developed. Rather than identifying a herbicide with selectivity, genes for resistance to specific herbicides (including new ones) may be incorporated into specific crops.

There are three principal requirements for manipulating herbicide resistance in plants through biotechnology:

1. Identification of a gene that can provide resistance to a herbicide
2. Modification of this gene so that it can be expressed in the target crop plant
3. Transfer of the modified gene into the crop plant.

Each of these components has been developed over the last 15 years as our understanding of plant biochemistry, physiology, and molecular biology has increased. The application of genetic engineering to herbicide resistance is the first major commercial success in agricultural biotechnology. However, there is tremendous potential for genetic manipulation of crop plants to impact crop production practices as well as the downstream uses of agricultural products.

Identification of Genes for Herbicide Resistance

Plants use a number of mechanisms to tolerate herbicides, including reduced uptake of the herbicide, increased metabolism, and a target site that is not affected by the herbicide. Conceptually, genes could be identified that would alter any of these steps to provide resistance to a specific herbicide. In practice, the two mechanisms that have been favored for genetic engineering are modification of the target site and metabolism of the herbicide. The **revolutionary** aspect of this new technology is that genes for such traits need not come from the traditional germ plasm resources used by plant breeders. Rather, genes for herbicide resistance may be found in any organism, including microbes. Once identified, these genes can be isolated, modified to function appropriately in a plant, and transferred to the crop.

The strategy used to identify genes for herbicide resistance depends on the nature of the herbicide and its mode of action. An approach that has proven effective in many cases is to identify microbes that either survive in the presence of the herbicide or use the herbicide as a food source. There are a number of advantages to screening for herbicide resistance genes in bacteria:

- Large numbers of bacteria can be tested through simple procedures, such as screening for bacteria that grow on agar medium supplemented with the herbicide.
- Large collections of bacteria can be obtained simply from soil samples or other sources.
- Genes that are responsible for herbicide resistance can be isolated rapidly because bacterial genomes are small and molecular genetic techniques facilitate this process.

Modification of Genes for Expression in Plants

Genes carry two essential pieces of information. **First,** they carry information to produce proteins. The sequence of bases in the DNA is decoded by the cell to direct the synthesis of a specific protein. The machinery of the cell first transcribes the sequence of bases in DNA into a similar sequence of bases in RNA. This is then translated into a sequence of amino acids in the

protein. The DNA code for proteins is essentially the same in all organisms, from bacteria to plants and animals. Consequently, a gene transferred from a bacterium to a plant will encode the same protein if the gene is expressed.

In addition to carrying the code for a specific protein, each gene also carries instructions about where, when, and to what level that gene should be expressed- that is, activated or switched on. These regulatory features are critical for the function of all organisms. The regulatory information is also carried in the sequence of bases in the DNA and is referred to as the **promoter.** The promoter of a gene determines where and when that gene is expressed and whether the protein will be made in abundance or at a low level. However, unlike the codes for proteins, regulatory instructions are not the same from one organism to another. Consequently, genes transferred between organisms will not be expressed unless the promoters are tailored to work in the host into which this gene is being moved. For example, a gene isolated from *Salmonella typhimurium,* a bacterium, will not be expressed in a plant unless the promoter that controls its expression is altered to function in plants.

Genes that are used to provide tolerance to herbicides through biotechnology are therefore comprised of two essential components:

1. A DNA sequence encoding a specific protein that will either metabolize the herbicide or provide a target that is not inhibited by the herbicide
2. A promoter sequence that will direct the expression of this protein in particular tissues of the plant.

The process of gene transfer is commonly referred to as **transformation.** Cells that have taken up a gene by this method, and plants that are regenerated from these cells, are described as transformed or transgenic. The term genetically modified organism (GMO) is also used to describe transgenic organisms, including transformed plants. Genes that are transferred into plants are known as **transgenes**.

The various techniques used to transform plants include a number of common steps:

- A tissue is selected from which fertile plants can be regenerated through tissue culture.
- The desired gene(s) are transferred into as many cells as possible in this target tissue.
- Selection is used to identify transformed cells.
- Plants are regenerated from transformed cells.
- Transgenic plants are analyzed to confirm that the genes have been transferred, are being expressed as expected, and are having the desired effect on the phenotype of the plant.

Transformation of most plants has used either *Agrobacterium tumefaciens* or particle bombardment to move genes into the plant. *Agro bacterium tumefactions* is a soil bacterium that has the unique ability to transfer DNA from the bacterium into plant cells. In nature the bacterium uses this ability to modify plant cells to produce compounds that the bacterium can use for growth. For genetic manipulation of plants, **Agrobacterium** can be used to transfer specific genes into plants without the deleterious effects normally associated with this bacterium. Until recently, Agrobacterium could not be used for transformation of most crop plants. Consequently, other methods were developed to transfer genes into these species, the most widely used being particle bombardment. Metallic particles are coated with the genes (pieces of DNA) to be transferred into the plant and these DNA-coated particles are literally shot into the plant cells. Once inside a cell, the DNA is released from the particle, moves into the nucleus, and incorporates into the genome. Particle bombardment can transfer DNA into essentially any species, as it relies on physical methods to move DNA, unlike the biological system used in Agro bacterium-mediated transformation.

The final step is to confirm that the transgenic is performing as expected. For herbicide tolerance, this involves demonstrating that transgenic plants have tolerance to field applications of the herbicide while maintaining suitable agronomic properties. The transgene must also be stably expressed in all plants and from generation to generation.

The time required to progress from the initial transformation of plant cells to release of a new variety is likely to be at least 5 years. However, once the new herbicide tolerance gene is incorporated into elite breeding material, it can be handled simply as another trait that must be followed during variety development.

Herbicide - Resistant Crops in The Market Or in Development

Herbicide-resistant crops that have been released or are being developed are listed below. As shown, most major crops and several minor crops are being developed for resistance to many widely used herbicides.

The acreage of the major herbicide-resistant crops has shown a tremendous increase since 1996, and world acreage projection suggest that increased production of these crops will continue in the future. Farmers have accepted this new technology with great excitement, especially in the United States, because of its effectiveness, ease of use, and ability to reduce input costs.

Major herbicides for which transgenic herbicide- resistant cultivars are being developed

Herbicide	Herbicide-Resistant Plant Species
Bromoxynil	Cotton, potato, tobacco.
Glyphosate	Sugar beet, corn, cotton, potato, oilseed rape, soybean, tobacco, tomato, winter and spring wheat, barley, rice.
Glufosinate	Alfalfa, sugar beet, corn, barley, peanut, rice, sugarcane, soybean, tomato, wheat, durum wheat, rye.
Sulfonylureas	Corn, cotton, tobacco, tomato.
Imidazolinones	Corn, wheat, rice, sugar beet, sunflower, sugarcane, soybean.
2,4-D	Potato, cotton.
Sethoxydim	Corn.

To prevent and manage existing herbicide resistant biotypes requires an integrative approach.

1. Monitor Results - Scout for resistant biotypes following herbicide applications. If you suspect herbicide resistance, have the field tissue sampled and tested.
2. Integrated Weed Control - Minimize reliance on herbicides. Combine control tools such as mechanical, cultural, and biological with chemical. Monitor weeds and make applications based on actual weed populations and when the infestations exceed economic thresholds.
3. Rotate crop types – Crop rotations allow for a rotation of herbicide types. Don't plant uncompetitive crops two years in a row on a field.
4. Tank Mix herbicides with different modes of action. The tank mix can delay the development of resistant weeds it the components control the same weed with different modes of actions. The chemicals used should have activity against potentially herbicide resistant biotypes.
5. Use herbicides with short residual activity
6. Herbicide Rotation – Herbicides must be rotated. It is important not only to utilize different herbicides, but herbicides with different modes of action. Do not make more than two consecutive herbicide applications to a field using the same herbicide or a herbicide with the same mode of action.
7. Utilize post-harvest weed control - It reduces weed seed production, controls perennials and prevents worse infestations for the following year.
8. Equipment Sanitation - Clean equipment to prevent the spread of herbicide resistant weed seed.

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Theory Notes

Navsari Agricultural University

COLLEGE OF AGRICULTURE, NAVSARI AGRICULTURAL UNIVERSITY, CAMPUS BHARUCH

Agron. 5.6

FARMING SYSTEM AND SUSTAINABLE AGRICULTURE (1+0)

:Course Teacher:

Dr. Swapnil P. Deshmukh

Assistant Professor (Agronomy)

NARP, CoA, NAU,

Bharuch

Farming System and Sustainable Agriculture 1(1+0)

Theory

Farming System-scope, importance, and concept, Types and systems of farming system and factors affecting types of farming, Farming system components and their maintenance, Cropping system and pattern, multiple cropping system, Efficient cropping system and their evaluation, Allied enterprises and their importance, Tools for determining production and efficiencies in cropping and farming system; Sustainable agriculture-problems and its impact on agriculture, indicators of sustainability, adaptation and mitigation, conservation agriculture strategies in agriculture, HEIA, LEIA and LEISA and its techniques for sustainability, Integrated farming system-historical background, objectives and characteristics, components of IFS and its advantages, Site specific development of IFS model for different agro-climatic zones, resource use efficiency and optimization techniques, Resource cycling and flow of energy in different farming system, farming system and environment, Visit of IFS model in different agro-climatic zones of nearby states University/ institutes and farmers field.

Reference books

1. **Principle of Agronomy**
   S. R. Reddy, Kalyani Publication, 5th Ed.2016
2. **Principle of Agronomy**
   T.Y.Reddy & G.H.S.Reddy, Kalyani Publication, 4th Ed.2011
3. **Principles of Crop Production**
   S. R. Reddy, Kalyani Publication, Ed.2012
4. **Farm Sector Development**
   D. D. Gupta, Agrobios (India), Jodhpur Ed. 2011
5. **Cropping system & Farming System**
   S.C.Panda, Agrobios (India), Jodhpur
6. **Principles and Practices of Agronomy**
   P. Balasubramaniyan and SP. Palaniappan
7. **Farming system and sustainable agriculture** (as per new ICAR syllabus)
   S. R. Reddy, Kalyani Publication

Chapter 1: CROPPING SYSTEM

Cropping system:

The term cropping system refers to the crops and crop sequences and the management techniques used on a particular field over a period of years.

Or

The term cropping system refers to the crops and crop sequences in which the crops are cultivated on piece of land over a fixed period and their interaction with farm resources and other farm enterprises.

Cropping system is the most important component of a farming system.

Cropping pattern:

It indicates the yearly sequence and spatial arrangement of crops and fallow in an area. It is for larger area like zone, taluka, district etc.

Basic principles of cropping systems

1. Choose crops that complement each other.
2. Choose crops and a cropping rotation which utilize available resources efficiently.
3. Choose crops and a cropping system that maintain and enhance soil fertility.
4. Choose crops which have a diversity of growth cycles.
5. Choose a diverse species of crops.
6. Strategically plan and modify your cropping system as needed.
7. Monitor the progress.

Benefits of cropping systems

1. Maintain and enhance soil fertility. Some crops are soil exhausting while others help restore soil fertility. However, a diversity of crops will maintain soil fertility and keep production levels high.
2. Enhance crop growth. Crops may provide mutual benefits to each other. For example, reducing lodging, improving winter survival or even acting as windbreaks to improve growth.
3. Minimize spread of disease. The more diverse the species of plants and the longer the period before the soil is reseeded with the same crop, the more likely disease problems will be avoided.
4. Control weeds. Crops planted at different times of the year have different weed species associated with them. Rotating crops helps prevent build up of any one serious weed species.
5. Inhibit pest and insect growth. Changing crops each year to unrelated species can dramatically reduce the population of pests and insects. Crop rotation frequently eliminates their food source and changes the habitat available to them.
6. Use resources more efficiently. Having a diverse group of crops helps to more efficiently use the available resources. Natural resources, such as nutrients, sunlight and water in the soil are evenly shared by plants over the growing period, minimizing the risk

for nutrient deficiencies and drought. Other resources, such as labor, animal draft power and machinery are also utilized more efficiently.

7. Reduce risk for crop failure. Having a diverse group of crops helps prevent total crop failures, as climate weather in one part of the season may not affect all crops equally. It also reduces food security concerns, as well as the amount of money required to finance production.
8. Improve food and financial security. Choosing an appropriate and diverse number of crops will lead to a more regular food production throughout the year. With a lower risk for crop failure, there is a greater reliability on food production and income generation.

Types of cropping systems

Depending on the resources and technology available, different types of cropping systems are adopted on farms. Broadly three types of cropping system are followed

1. Sole cropping

Only a single crop or variety is grown alone in a pure stand at normal density during one farming year.

2. Mono cropping or Monoculture

Mono cropping or monoculture refers to growing of only one crop on same piece of land year after year.

It may be due to climatologically and socio-economic condition or due to specialization of a farmer in growing a particular crop. Under rainfed conditions, groundnut or cotton or sorghum are grown year after year due to limitation of rainfall. In canal irrigate areas, under waterlogged condition; rice crop is grown, as it is not possible to grow any other crop.

Problems of mono cropping

1. The resources like labour, fertilizers, water and machines are not utilized efficiently.
2. The soil health is not cared and nutrients are depleted.
3. There are chances of occurrence of pest and diseases infestation.
4. Natural resources are not fully utilized.

3. Multiple cropping

"Growing two or more crops on the same piece of land in succession within one calendar year is known as multiple cropping" e.g. Rice-Rice-G' nut or Cotton-Wheat etc.

It aims of maximum production per unit area per unit time. It offers multiple use of resource. It is the intensification of cropping in time and space dimensions i.e. more number of crops within a year & more no of crops on the same piece of land at any given period. It includes inter-cropping, mixed cropping, sequence cropping etc.

Advantages of multiple cropping

1. It is a better source of land utilization
2. It improves yield
3. Increase yield per unit of land

4. Costs of input decrease as compared to individual crop growing cost
5. Reduce pest and disease attack
6. Different type of products can be produce at a time
7. It helps to produce a balance diet for a family
8. It helps to maintain the soil fertility
9. It helps to control weeds

Disadvantages of multiple cropping

1. The survival of pests become easy
2. Pests can easily shift from one crop to another crop
3. Problem of weed management
4. Implementation of new technology is difficult etc.

Different types of multiple cropping :

A. Inter cropping

Inter cropping is growing two or more crops simultaneously on the same piece of land with a definite row arrangement.

The main objective of inter-cropping is to utilize the space left between two rows of main crops and to produce more grain per unit area. Inter cropping was originally practiced as an insurance against crop failure under rainfed condition.

e.g.: Groundnut & Tur in 6:1 ratio or sorghum & Tur in 4:2 ratio

Intercropping is further classified as:

Additive Series: Intercrop is introduced in the base crop. It is done by adjusting or changing crop geometry. It is mostly used in India. Eg: maize + mungbean (1+1)

Replacement Series: Both the crops are component crops. It is done by sacrificing certain proportion of population. It is mostly used in western countries. e.g: wheat + mustard (9:1), maize + mungbean (1:3)

Advantages of intercropping:

1. Improvement in yield
2. Improvement in soil property under legume intercropping system
3. Less risk against crop diseases and pests
4. Additional income and higher profit
5. Soil erosion is reduced
6. Stability in production
7. Economic sustainability is maintained

Disadvantages of intercropping:

1. Fertilizer application in one crop may hamper the growth of other crop
2. Improved implements cannot be used efficiently
3. Harvesting is difficult
4. Yield decreases if the crops differ in their competitive abilities

Management of intercropping system

Crops are grown simultaneously. Management practices should, therefore, aim to provide favorable environment to all the components, exploit favorable interactions among the component crops and minimize competition among the components. Prominent interactions in intercropping include:

Light: Intercropping can increase light inception by as much as 30-40 per cent. Proper choice of crops and varieties, adjustment of planting density and pattern are the techniques to reduce competition and increase the tight use efficiency.

Moisture and nutrients: Competition for water and nutrients results in two main types of effects on the less successful or suppressed component. First, the roots of dominated crop may grow less on the sides of aggressive component. Secondly, plants affected by competition for soil factors are likely to have increased root/shoot ratio.

Allelopathy: Some crops may be unsuitable to be grown as intercrops because they may produce and excrete toxins into the soil which are harmful to other components.

Annidation: Refers to complementary interaction which occurs both in space and time.

Varieties: Recommended principles should be followed for realizing the benefits of intercropping.

(a) Varieties of component crops should be less competing with the base crop and the peak nutrient demand period should be different from the base crop.

(b) Difference in duration between the components in intercropping should be a minimum period of 30 days (maize + soybean, sorghum + red gram, *toria* + *gobhi sarson).*

(c) Selection of compatible genotypes of component crops increases the complementarity of intercropping system.

(d) Varieties selected for intercrop should have thin leaves, tolerant to shading and less branching since these crops are, generally, shaded by the base crop.

(e) If the base crop is shorter than intercrop, the intercrop should be compact with erect branching and its early growth should be slow.

(f) Characteristics of base crop should be similar to the sole crop.

Nutrient management

When legumes are associated with cereal crop in intercropping system, a portion of nitrogen requirement of cereal is supplemented by the legume. The amount may be as small as a few kg to 20 kg ha^{-1}. Cereal + legume intercropping, is therefore; mainly advantageous under low fertilizer application. Considering all the factors, it is suggested that the nitrogen dose recommended for base crop as pure crop is sufficient for intercropping system with cereals + legume or legume + legume. With regard to phosphorus and potassium, one-eighth to one-fourth of the recommended dose of intercrop is also added in addition to recommended dose of base crop to meet the extra demand. Basal dose of nitrogen is applied to rows of both components in cereals + legume intercrop system. Top dressing of nitrogen is done only to cereal rows. Phosphorus and potassium are applied as basal dose to both crops.

Water management

Intercropping systems are, generally, recommended for rainfed crops to get stable yield. Total water used in intercropping system is almost the same as for sole crops, but yield is increased. Thus, water-use efficiency of intercropping is higher than sole crops. Component crops differ on their capacity to withstand excess or difficult moisture conditions. However, the irrigation schedule followed for sole crops is suitable even for intercropping system. Scheduling irrigation at IW/CPE ratio of 0.6 to 0.8 or irrigation at one bar soil moisture tension is suitable for most of the system. However, information on this aspect is meager.

Weed management

Weed problem is less in intercropping system as compared to their sole crops. In certain situations, intercrops are used as biological agents to control weeds. Blackgram, greengram, cowpea in sorghum and cowpea in banana reduce weed population and one hand weeding can be avoided by this method. In some intercropping system like maize + groundnut, rice +tapioca, maize + tapioca, weed problem is similar to their sole crops. Growth habit of genotype used in intercropping has a great influence on weed growth. Weeds present in sole crops are different than those present in intercropping system. Though weed problem is less, weed control measures are necessary in intercropping system. But the labour required for weeding is less. Second weeding is not necessary because of crop coverage. Chemical weed control is difficult in intercropping system because the herbicide may be selective to one crop, but non-selective to another.

Pest and disease management

Pests and diseases are believed to be less in inter-cropping system due to crop diversity than in sole crops. Some plant combinations may enhance soil fungistasis and antibiosis through indirect effects on soil organic matter content. Spread of the disease is altered by the presence of different crops. Little leaf of brinjal is less when brinjal is sheltered by maize or sorghum. As the insect carrying virus first attacks maize or sorghum, virus infection is less on brinjal. Non-host plants in mixtures may emit chemicals or odours that affect the pests, thereby protecting host plants.

B. Mixed cropping: Growing two or more crops simultaneously on the same piece of land in a proportion without any row arrangement.

e.g. Wheat and Mustard seeds are mixed together in 2:1 rates and shown broadcast with no spacing maintained between the crops.

No spacing is maintained between the crops it is a common practice in areas where climatic hazards such as flood, drought, frost etc. are frequent and common. Under such circumstances the farmers always fear that their crops will fail. Under mixed cropping, the time of sowing of all the crops is almost the same, however they may

C. Sequential cropping: Growing of crops in sequence

e.g. Double cropping: Growing of 2 crops in a year e.g.: Rice-wheat

Triple cropping: Growing of 3 crops in a year e.g.: Rice-wheat-maize

Quadruple cropping: Growing of 4 crops in a year e.g.: Rice-early potato-Wheat-mung

D. Multistoried cropping: Cultivation of crops of different heights in the same field at the same time.

e.g. Sugarcane + Indian bean or potato or onion, Sorghum+ mung

E. Ratoon cropping: Raising a crop with re-growth coming out of roots or stalks after harvest of the crop.

e.g. sugarcane, tur, fodder sorghum, fodder maize.

This minimizes the cost of production of next crop in terms of land preparation and cost of seed, also the next crop i.e. ratoon crop gets already established root system.

F. Paira/ Utera/ Relay cropping: In this, second crop is sown before the harvest of previous crop in same field.

e.g. 1st crop-Potato 2nd crop-Maize, Lathyrus in rice.

This is done mainly to utilize the conserve moisture in the field after kharif season. It also saves the time and keeps the land under vegetation.

G. Alley cropping: Growing food crops within the rows of tree or plantation crops

e.g. Greengram in alley of glyricidia or subabul.

H. Strip intercropping: Growing alternate rows of erosion resisting and permitting crops along the slope

e.g. Strips of soybean and alfalfa, cowpea and sorghum

Major cropping systems in India

A. Lowland or wetland

- Irrigation or rainfall (> 200 mm per month) extends over 9–10 months
- Rice based cropping systems predominate in lowlands

  e.g. Rice- rice-rice, rice-rice-upland crop or upland crop-rice-rice

  Rice-Rice is the second most dominant cropping system in India

B. Irrigated uplands or garden land

- The systems could be cereal-cereal and cereal-legume, oilseeds or other cash crops
- Rice-Wheat is the most dominant cropping system in India.

  e.g. Potato or mustard can be added to maize-wheat by relay planting either of these in the standing maize and delaying wheat by about 2 months. Short duration green gram or fodder crops can be grown after the harvest of wheat in summer.

C. Rainfed uplands

- Predominantly take the form of intercropping
- Cereal + pigeon pea system (sorghum + pigeon pea), cereal + cotton are popular in India
- Double cropping can be practiced if the monsoon is relatively early.

e.g. sorghum, pearlmillet or a pulse during rainy season followed by sunflower, safflower, chickpea or coriander in post rainy season.

Principles of crop rotation

1. Leguminous crops should be grown before non-leguminous crops because legumes fix atmospheric N into the soil and add organic matter to the soil.
2. Crops with tap roots (deep rooted like cotton) should be followed by those which have fibrous (shallow rooted crops like sorghum or maize) root system. This facilitates proper and uniform use of nutrients from the soil.
3. More exhaustive crops should be followed by less exhaustive crops because crops like potato, sugarcane, maize etc. need more inputs such as better tillage, more fertilizers, greater number of irrigation etc.
4. Selection of crop should be based on need or demand.
5. Crops of same family should not be grown in succession because they act as alternate hosts for insect pests and diseases.
6. The crop selected should also suit to the soil and climatic condition.
7. Selection of crops should be based on the situations such as
   a. On sloppy lands, alternate cropping of erosion permitting and erosion resisting crops should be adopted.
   b. Under rain fed situations crops which can tolerate drought should be selected
   c. In low-lying and flood prone areas crops which can tolerate water stagnation should be selected
   d. In areas where salt affected soils are there, salt tolerant varieties should be grown
8. An ideal crop rotation must provide maximum employment to the farm family and labour, permits farm mechanization to ensure timely operations besides maintaining soil health

Advantages of an ideal crop rotation

(i) The soil fertility is restored by fixing atmospheric N encouraging microbial activity and maintaining physico-chemical properties of the soil.

(ii) Alternate cropping with other crops helps in controlling crop bound weeds.

(iii) Proper utilization of all resources and inputs could be made by following crop rotation.

(iv) The farmer gets a better price for his produce because of its higher demands in the market.

(v) Best utilization of residual moisture, fertilizer and organic residues is made by growing crops of different nature.

(vi) The family needs of feed, food, fuel, fiber, spices; condiments, sugar etc are fulfilled.

TERMS USED IN CROPPING SYSTEMS

1. **Alley cropping:** A fanning system in which arable crops are grown in alleys formed by trees or shrubs, established mainly to hasten soil fertility restoration and enhance soil productivity and for shelter.
2. **Calorie index:** A single productivity index which incorporates caloric equivalents produced by all the crops.
3. **Competition index:** Competition of intercropped species for light, nutrients, water, carbon dioxide and other growth factors.
4. **Complementary effect:** Effect of one component on another which enhance growth and productivity, as compared to competition.
5. **Component crops:** Individual crop species which are a part of the multiple cropping systems.
6. **Cropping index:** The number of crops grown per annum on a given area of land multiplied by hundred.
7. **Double cropping:** Also known as sequential cropping is the practice of planting a second crop immediately following the harvest of a first crop, thus harvesting two crops from the same field in one year. This is a case of multiple cropping, which requires crops that mature quickly enough to allow two harvests in one year.
8. **Mixed intercropping:** Growing two or more crops simultaneously with no distinct row arrangement
9. **Monetary index:** A single productivity index which incorporates monetary value of all the crops in a system.
10. **Multi-story/multi-tier cropping:** It is a system of growing together, crops of different heights at the same time on the same piece of land and thus using land, water and space most efficiently and economically (coconut + pepper + pineapple + grass).
11. **Row intercropping:** Growing two or more crops simultaneously where one or more crops are planted in rows.
12. **Sole cropping:** One crop variety grown in pure stand at normal density.
13. **Spatial arrangement:** The physical or spatial organization of component crops in a multiple cropping system.
14. **Strip cropping:**Growing soil conserving and soil depleting crops in alternate strips running perpendicular to the slope of the land or to the direction of prevailing winds for the purpose of reducing erosion.

Chapter 2: FARMING SYSTEM

What is a system?

A system is defined as a set of components that are interrelated and interact among themselves. A system is a group of interacting components, operating together for a common purpose, capable of reacting as a whole to external forces.

It is unaffected directly by its own outputs and has a specified boundary based on the inclusion of all significant feedbacks.

For example, the human body is a system-it has a boundary (e.g., the skin) enclosing a number of components (heart, lungs) that interact (the heart pumps blood to the lungs) for a common purpose (to maintain and operate the living body).

Ecosystem: Any collection of organisms that interact or have the potential to interact along with the physical environment in which they live, form an ecological system or ecosystem. Ecosystems are not static entities they are dynamic systems with characteristic pattern of energy flow, nutrient cycling and structural change.

Agro-ecosystem: Agro-ecosystems are ecological systems modified by human beings to produce food, fiber or other agricultural products.

Farming system:

Farming system is a mixture of farm enterprises such as crop, livestock, aquaculture, agro forestry and fruit crops to which farm family allocates its resources in order to efficiently manage the existing environment for the attainment of the family goal.

Or

Farming system is a resource management strategy to achieve economic and sustained agricultural production to meet diverse requirements of farm livelihood while preserving resource base and maintaining a high level of environment quality.

Or

Farming system represents an appropriate combination of farm enterprises (cropping systems, horticulture, livestock, fishery, forestry, poultry, etc) and the means available to the farmer to raise them for profitability. It interacts adequately with environment without dislocating the ecological and socioeconomic balance on one hand and attempts to meet the national goals on the other.

Broad categories of farming systems:

1. Irrigated farming system, embracing a broad range of food and cash crop production.
2. Wetland rice-based farming system, dependent upon seasonal rains supplemented by irrigation.
3. Rainfed farming system in humid areas characterized by specific dominant crops or mixed crop-livestock system.
4. Rainfed farming system in steep and highland areas, which are often, mixed crop- livestock system.

5. Rainfed farming system in dry or cold low potential areas, with mixed crop-livestock and pastoral system merging into system with very low current productivity or potential because of extreme aridity or cold.
6. Dualistic (mixed large commercial and small holders) farming system, across a variety of ecologies and with diverse production patterns.
7. Coastal artisanal fishing system, which often incorporate mixed farming elements.

Indigenous farming systems

Shifting cultivation, *taungya* cultivation and *zabo* cultivation are the three major indigenous farm systems in India.

Shifting cultivation

It refers to farming system in north-eastern areas in which land under natural vegetation (usually forests) is cleared by slash and burn method, cropped with common arable crops for a few years and then left unattended when natural vegetation regenerates. Traditionally, the fallow period is 10-20 years but in recent times it is reduced to 2-5 years in many areas. Due to increasing population pressure, the fallow period is drastically reduced and system has degenerated causing serious soil erosion, depleting soil fertility resulting into low productivity. In north-eastern India, many annual and perennial crops with diverse growth habits are being grown.

Taungya cultivation

The Taungya system is like an organized and scientifically managed shifting cultivation. The word is reported to have originated in Myanmar (Burma) and Tauang means hill, ya means cultivation *i.e.,* hill cultivation. It involves cultivation of crops in forests or forest trees in crop fields and was introduced to Chittagong and Bengal areas in colonial India in 1890. Later, it had spread throughout Asia, Africa and Latin America. Essentially, the system consists of growing annual arable crops along with the forestry species during early years of establishment of the forest plantation. The land belongs to forest department or their large scale leases, who allows the subsistence farmers to raise their crops and in turn protect tree saplings. It is not merely temporary use of a piece of land and a poverty level wage, but is a chance to participate equitably in a diversified and sustainable agro-forestry economy.

Zabo cultivation

The Zabo is an indigenous farming system practiced in north-eastern hill regions, particularly in Nagaland. This system refers to combination of forest, agriculture, livestock and fisheries with well-founded soil and water conservation base. Rainwater is collected from the catchment of protected hill tops of above 100 per cent slopes in a pond with seepage control. Silt retention tanks are constructed at several points before the runoff water enters in the pond. Cultivation fully depends on the amount of water stored in the pond. Land is primarily utilized for rice. This system is, generally, practiced in high altitude hill areas, where it is not possible to construct terraces and or irrigation channels across the slope. This is a unique farming system for food production to make livelihood. Zabo means impounding of water. The place of origin of zabo farming system is thought to be the Kikruma village in Phek district of Nagaland.

Scope of farming system

Farming enterprises include crop, livestock, poultry, fish, sericulture etc. A combination of one or more enterprises with cropping when carefully chosen, planned and executed gives greater dividends than a single enterprise, especially for small and marginal farmers. Farm as a unit is to be considered and planned for effective integration of the enterprises to be combined with crop production activity.

Importance of farming system

1. Enhances productivity and profitability
2. Potentiality or sustainability
3. Balanced food production
4. Adoption of new technology
5. Saving energy
6. Meeting fodder crises
7. Solving fuel and timber requirement
8. Provides environmental safety
9. Recycling of farm waste
10. Provides income round the year
11. Helps in employment generation
12. Provides raw materials to agro-industries

Concept of farming system

In farming system, the farm is viewed in a holistic manner. Farming enterprises include crops, dairying, poultry, fishery, sericulture, piggery and tree crops. A combination of one or more enterprises with cropping when carefully chosen, planned and executed, gives greater dividends than a single enterprise, especially for small and marginal farmers. Farm as an unit is to be considered and planned for effective integration of the enterprises to be combined with crop production activity, such that the end-products and wastes of one enterprise are utilized effectively as inputs in other enterprise.

For example the wastes of dairying viz., dung, urine, refuse etc are used in preparation of FYM or compost which serves as an input in cropping system. Likewise the straw obtained from crops (maize, rice, sorghum etc) is used as a fodder for dairy cattle. Further, in sericulture the leaves of mulberry crop as a feeding material for silkworms, grain from maize crop are used as a feed in poultry etc. Sustainability is the objective of the farming system where production process is optimized through efficient utilization of inputs without infringing on the quality of environment with which it interacts on one hand and attempt to meet the national goals on the other.

A farm is a system in that it has inputs, processes and outputs.

Depending on the type of farming e.g. arable/pastoral, commercial/subsistence, the type and amount of inputs, processes and outputs will vary.

Income through arable farming alone is insufficient for bulk of the marginal farmers. The other activities such as dairying, poultry, sericulture, apiculture, fisheries *etc* . assume critical importance in supplementing their farm income.

Input	**Process**	**Output**
Labour	Ploughing	Wheat
Capital	Sowing	Potato
Seeds	Spraying	Milk
Animal	Fertilizer application	Crop waste
Fertilizer	Harvesting	Wool
Pesticide	Grazing	Eggs
	Milking	

Components of farming system

1. Crops, livestock, birds and trees.
2. Cropping systems like monocrop, mixed/ intercrop, multi-tier crops of cereals, legumes (pulses), oilseeds, forage etc.
3. Livestock components may be cows, buffalos, goats, sheeps, poultry and bees.
4. Tree components may include fruit trees, timber, fuel and fodder.

Principles of farming system

1. Minimization of risk
2. Recycling of wastes and residues
3. Integration of two or more enterprises
4. Optimum utilization of all resources
5. Maximum productivity and profitability
6. Ecological balance
7. Generation of employment potential
8. Increased input use efficiency
9. Use of end products from one enterprise as input in other enterprise

Characteristics of farming system

1. Farmer oriented & holistic approach
2. Effective farmer’s participation
3. Unique problem solving system
4. Dynamic system
5. Gender sensitive
6. Responsible to society
7. Environmental sustainability
8. Location specific of technology
9. Diversified farming enterprises to avoid risks due to environmental constraints
10. Provides feedback from farmers

Classification of farming systems

Classified on the basis of	
1. Climate	Tropical, sub-tropical, temperate
2. Stage of development	Shifting cultivation, arable farming, ranching.
3. Components	Crop based, dairy based, poultry based, fish based Or mixed farm.
4. Mode of ownership	Peasant farming, joint farming, co-operative farming, State farming
5. Level of profitability	Subsistence, commercial
6. Irrigation	Wet, dry (garden / rainfed)
7.Degree of mechanization	Mechanized, semi-mechanized, non-mechanized.

Objectives of farming system

1. **Productivity-** Farming system provides an opportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises. Time concept by crop intensification and space concept by building up of vertical dimension through crops and allied enterprises.
2. **Profitability -** The system as a whole provides an opportunity to make use of produce/waste material of one enterprise as an input in another enterprise at low/no cost. Thus by reducing the cost of production the profitability and benefit cost ratio works out to be high. This is the main objective of farming system.
3. **Potentiality –** Soil health, a key factor for sustainability is getting deteriorated and polluted due to faulty agricultural management practices viz., excessive use of inorganic fertilizers, pesticides, herbicides, high intensity irrigation etc. In farming system, organic supplementation through effective use of manures and waste recycling is done, thus providing an opportunity to sustain potentiality of production base for much longer time.
4. **Balanced food-** In farming system, diverse enterprises are involved and they produce different sources of nutrition namely proteins, carbohydrates, fats & minerals etc form the same unit land, which helps in solving the malnutrition problem prevalent among the marginal and sub-marginal farming households.
5. **Environmental safety-** The very nature of farming system is to make use or conserve the byproduct/waste product of one component as input in another component and use of bio-control measures for pest & disease control. These eco-friendly practices bring down the application of huge quantities of fertilizers, pesticides and herbicides, which pollute the soil water and environment to an alarming level. Whereas IFS will greatly reduces environmental pollution.
6. **Income/cash flow round the year-** Unlike conventional single enterprise crop activity where the income is expected only at the time of disposal of economic produce after several months depending upon the duration of the crop, the IFS enables cash flow round the year by way of sale of products from different enterprises viz., eggs from poultry,

milk from dairy, fish from fisheries, silkworm cocoons from sericulture, honey from apiculture etc. This not only enhances the purchasing power of the farmer but also provides an opportunity to invest in improved technologies for enhanced production.

7. **Saving energy-** Availability of fossil fuel has been declining at a rapid rate leading to a situation where in the whole world may suffer for want of fossil fuel by 2030 AD. In farming system, effective recycling of organic wastes to generate energy from biogas plants can mitigate to certain extent this energy crisis.
8. **Meeting fodder crises-** In IFS every inch of land area is effectively utilized. Alley cropping or growing fodder legume along the border or water courses, intensification of cropping including fodder legumes in cropping systems helps to produce the required fodder and greatly relieve the problem of non- availability of fodder to livestock component of the farming system.
9. **Solving timber and fuel crises**
10. **Employment generation**
11. **Scope for establishment of agro- industries**
12. **Enhancement in input use efficiency**

The specific objectives of farming systems are:

1. To identify existing farming system in specific area and assess their relative viability.
2. To formulate farming system models involving main and allied enterprises for different farming situations.
3. To ensure optional utilization and conservation of available resources and effective recycling of farm residues within system.
4. To maintain sustainable production system without harmful resources base of environment.
5. To raise overall profitability of farm household by complementing main allied enterprises with each other.
6. Analysis of existing farming system in terms of resource use efficiency, production and productivity, income, employment & sustainability across different agro-climatic zones.
7. Evaluation and identification of farming system through participatory approach that ensures threshold level of income for the livelihood security.
8. Development and evaluation of synergic effects and their actions associated with different farming systems.
9. Developing appropriate institutional and market linkage including value addition for enhancing sustainability.
10. Imparting training and capacity building of various stakeholders on IFS.

Green revolution

After the green revolution was launched in India, substantial increase in the production of food grains was achieved through the use of improved crop varieties and higher levels of inputs of fertilizers and plant protection chemicals. But it has now been realized that the increase in production was achieved at the cost of soil health and that sustainable production at higher levels is possible only by the proper use of factors, which will help to maintain the fertility of the soil.

In fact, about 60 per cent of our agricultural land currently under cultivation suffers from indiscriminate use of irrigation water and chemical fertilizers. The gravity of environmental degradation resulting from faulty agricultural practices has caused alarm among the concerned farmers, scientists and conservationalists and greater viable and sustainable farming systems have become a necessity. There has been a series of scientists and policy conference on this issue. One such alternative agriculture system which will help to overcome the problems of soil degradation and declining soil fertility is organic farming and ecological agriculture.

Most of the growth in the food production during the green revolution period was attributed to the higher fertilizer use. The growth of the fertilizer industry in India between 1965 and 1983 has been remarkable. Per hectare consumption of NPK increased from 0.6 kg in 1950 to 50 kg by 1987. However, the available data show that the fertilizer consumption was largely confined to irrigated areas which constituted only about 30 per cent of the gross cropped area.
The rise in fertilizer use is anticipated because:

1. N deficiency will continue to be universal in Indian soils.
2. Deficiency of P will be next in the order.
3. K will become limiting in high productive regions.
4. In at least half of the Indian soils, crops would benefit from Zn treatment.
5. S deficiency will limit the productivity in a vast majority of Indian soils.

Impact of green revolution on the environment

The ills of green revolution are stated to be:

1. Reduction in natural fertility of the soil
2. Destruction of soil structure, aeration and water holding capacity
3. Increase in soil salinity problems
4. Increase in pest and disease incidences (Minor pests become Major)
5. Reducing genetic diversity of plant species
6. Pollution with toxic chemicals from the agrochemicals and their production units
7. Endangering the health of the farmers using chemicals and the labours
8. Poisoning the food with highly toxic pesticide residues
9. Cash crops displacing nutritious food crops
10. Chemicals changing the natural taste of food
11. High inputs increasing the cost of production
12. Depleting the fossil fuel resources
13. Depleting the ground water reserves
14. Lowering the drought tolerance of crops

Chapter 3: TOOLS FOR EVALUATION OF CROPPING SYSTEMS

Some of the important indices to evaluate the cropping systems are as below:

Land use efficiency or assessesment of land use:

The main objective is to use available resources effectively. Multiple cropping which include both inter and sequential cropping has the main objective of intensification of cropping with the available resources in a given environment. Several indices have been proposed to compare the efficiencies of different multiple cropping system in turns of land use, and these have been reviewed by Menegay *et al*. 1978.

1. Multiple cropping index or multiple cropping intensity (MCI):

It was proposed by Dalrymple (1971). It is the ratio of total area cropped in a year to the land area available for cultivation and expressed in percentage (sum of area planted to different crops and harvested in a single year divided by total cultivated area times 100).

$$MCI = \frac{\sum_{i}^{n} = 1\ a_i}{A} * 100$$

Where, n is total number of crops, a_i is area occupied by i^{th} crop and A is total land area available for cultivation.

It is similar to cropping intensity.

$$MCI = \frac{a_1 + a_2 + \ldots + a_n}{A} * 100$$

Where $a_1 + a_2 + \ldots + a_n$ is the gross cropped area and A the net cultivated area.

2. Crop intensity index (CII):

Crop intensity index assesses farmers actual land use in area and time relationship for each crop or group of crops compared to the total available land area and time, including land that is temporarily available for cultivation. It is calculated by summing the product of area and duration of each crop divided by the product of farmers total available cultivated land area and time periods plus the sum of the temporarily available land area with the time of these land areas actually put into use (Menegay *et al.* 1978). The basic concept of CLUI and CII are similar. However, the latter offers more flexibility when combined with appropriate sampling procedure for determining and evaluating vegetable production and cropping pattern data.

$$CII = \frac{\sum_{i=1}^{Nc} a_i\ t_i}{\sum_{j=1}^{M} A_j\ T_j}$$

Where, Nc = total number of crops grown by a farmer during the time period T; ai = area occupied by i^{th} crop (months that the crop i occupied an area a_i); t_i , duration occupied by i^{th} crop (months that crops occupied area a_i); T = time period under study (usually one year), A_j= Total cultivated land area available with the farmer for use during the entire time period T; M= total number of fields temporarily available to the farmer for cropping during time period T_j=1, 2, 3…….. M, A_j=land area of j^{th} field and T_j= time period when A_j is available.

When, CII = 1 means that area or land resources have been fully utilized and less than 1 indicates under utilization of resources. CII and LER are used to assess the efficient cropping zone. **Cropping intensity/intensity of cropping (CI)** indicates the number of times a field is grown with crops in a year. It is calculated by dividing gross cropped area with net area available in the farm, region or country multiplied by 100.

$$CI= \frac{\text{Gross cropped area}}{\text{Net sown area}} * 100 = \frac{\text{Area under } kharif + rabi + zaid \text{ crops}}{\text{Net sown area}} * 100$$

When long duration crop is grown, crop remains for a longer time in field. This is the drawback of CI. So time is not considered. Thus, when long duration crops like sugarcane and cotton are grown, the cropping intensity will be low.

3. Land equivalent ratio (LER):

This is the most frequently used efficient indicator. LER can be defined as the relative land area under sole crop that would be required to produce the equivalent yield under a mixed or an intercropping system at the same level of management.

$$LER= La + Lb = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

Where, La and Lb are LER of crop a and crop b, respectively; Yab = yield of crop an in intercropping, Yba = yield of crop b in intercropping, Yaa = yield of crop an in pure stand and Ybb = yield of crop b in pure stand.

LER of more than 1 indicates yield advantage, equal to 1 indicates no grain or no gain or no loss and less than 1 indicates yield loss. It can be used both for replacement and additives series of intercropping. LER is the summation of ratios of yields of intercrop to the yield of sole crop.

LER gives a better picture of the competitive abilities of the component crops. It also gives actual yield advantage of intercropping. In other words LER is the measure of production efficiency of different system by convening the production in terms of land acreage. LER gives an accurate assessment of the biological efficiency of intercropping.

Example: Let the yields of groundnut and Sesame grown, as pure crops are 1,200 and 1,000 kg/ha, respectively. Let yields of these cops when grown, as intercrop be 1,000 and 600 kg/ha, respectively. The land equivalent ratio of groundnut + Sesame intercropping system is

$$\text{LER of Groundnut} = \frac{\text{Yield of intercrop}}{\text{Yield of sole crop}} = \frac{1000}{1200}$$

$$\text{LER of sesame} = \frac{\text{Yield of intercrop}}{\text{Yield of sole crop}} = \frac{600}{1000}$$

$$\text{LER of system} = \frac{1000}{1200} + \frac{600}{1000} = 1.43$$

LER of 143 indicates that a 43 percent yields advantage is obtained when grown as intercrop compared to growing as sole crops. In other words the sole crops have to be grown in 1.43 ha to get the same yields level that is obtained from 1.00 ha of intercropping.

4. Relative yields total (RYT):

Oldest established measures of the yield advantage of crop mixture.

The mixture yields of a component crop expressed as a portion of its yields as a sole crop from the same replacement series is the relative yield of crop and sum of the relative yields of component crop is called Relative yields total (RYT). Or When LER is compared at uniform overall plant density of sole and intercrops then it is known as RYT. In RYT yield advantages is to measure not only unit area, but also on unit population. This is mainly used for replacement series.

$$\text{RYT} = \frac{\text{Yab}}{\text{Yaa}} + \frac{\text{Yba}}{\text{Ybb}}$$

Where, Yaa = yields of component a as sole crop Ybb = yields of component b is a sole crop Yab = yields of component a as intercrop in b Yba = Yield of component b as intercrop in a.

Example: In pasture mixture, Stylo and anjan grown in 1:1 ratio with 50% sole crop population of both crops. In I/C, mixture yield (50%) for Stylo and anjan is 6 and 4 tons/ha of fodder, respectively. The yield of these crops in sole stand with 100% plant population is 10 and 8 ha of green fodder, respectively.

RYT = 12+8/10+8 = 20/18 = 1.11.

So, RYT 1.11 indicates 11% extra fodder yields obtained by mixture.

Two crops yields in the intercrop mixture are MA and MB and the yield of crops grown as pure crop are SA and SB then the combined index is

$$\text{L} = \frac{\text{MA}}{\text{SA}} + \frac{\text{MB}}{\text{SB}}$$

The intercrop embodied in LER is that L represents the land required for sole crops to reduce yields achieved in the intercropping mixture. A value of L greater than 1 indicates overall biological advantages of intercropping. The two component of total index LA and LB represent the efficiency of yields production of each crop when grow in mixture, relative to crop performance.

5. Relative crowding coefficient (K or RCC):

It was proposed by de Wit (1960). It is used in replacement series of intercropping. It indicates whether a species or crop when grown in mixed population has produced more or less yield than expected in pure stand. In 50 : 50 mixture relative crowding coefficient can be defined as

$$Kab = \frac{\text{Mixture yield of a}}{\text{Pure yield of a} - \text{mixture yield of a}} = \frac{Yab}{Yaa - Yab}$$

But when population differ from 50: 50 then,

$$Kab = \frac{Yab * Zba}{(Yaa - Yab)\, Zab}$$

Where, K = coefficient of each crop species
Yaa = Yield of pure stand of a
Ybb = Yield of pure stand of b
Yab = Mixture yield of a in combination with b
Yba = Mixture yield of b in combination with a
Zab = Sown proportion of a in mixture with b
Zba = Sown proportion of b in mixture with a
Kab = Values indicate the following conclusions:
K>1 = there is yield disadvantage
K= 1 = there is no difference
K< 1 = there is yield advantage in mixing

Crowding coefficient and LER give the yield advantage but only LER gives the magnitude of advantage. Therefore, LER is preferred to assess the competition effect and yield advantage in intercropping situations.

6. Crop equivalent yield (CEY):

Many types of crops/cultivars are included in a multiple cropping sequences. It is very difficult to compare the economic produce of one crop to another. To cite an example, yield of rice cannot be compared with the yield of grain cereals or pulse crops and so on. In such situations, comparisons can be made based on economic returns (gross or net return). The yield of protein and carbohydrate equivalent can also be calculated for valid comparison. Efforts have

also been made to convert the yields of different crops into equivalent yield of any one crop such as wheat equivalent yield.

Crop equivalent yields (CEY): The yields of different intercrops/crops are converted into equivalent yield of any one crop based on price of the produce.

$$\text{CEY (kg/ha)} = \text{Cy} + \text{C1y} * \frac{\text{Pc1}}{\text{Pc}} + \text{C2y} * \frac{\text{Pc2}}{\text{Pc}} + - - -$$

or

$$\text{Crop Equivalent Yield (kg/ha)} = \text{Yield (main crop)} + \frac{\text{Yield (intercrop) x Price (intercrop)}}{\text{Price (maincrop)}}$$

CEY is the crop equivalent yield; Cy is the yield of the main crop, the yield of other crops converted to its equivalent and Pc is its respective price; C1y, C2y ……. are yields of intercrops/other crops which are to be converted to equivalent of main crop yield and Pc1 and Pc2 …….. are their respective prices.

Economic viability

CEY, LER, RYT etc. give biological suitability of cropping system to an area. At the same time, cropping system should be economically viable and profitable. Following terms can be used to evaluate profitability of cropping system.

1. Gross return:

The total monetary returns of the economic produce such as grain, tuber, bulb, fruit, etc. and byproducts *viz;* straw, fodder, fuel etc. obtained from the crops included in the system are calculated based on the local market prices. The total return is expressed in terms of unit area, usually one hectare. The main draw back in this calculation is that market price of the produce is higher than that actually obtained by the farmer. Generally gross return calculated is somewhat inflated compared to the actual receipt obtained by the farmer.

2. Net return or net profit:

This is worked out by subtracting the total cost of cultivation from the returns. This value gives the actual profit obtained by the farmer. In this type of calculation only the variable costs are considered. Fixed costs such as rent for the land, land revenue, interest on capital etc. are not included. For a realistic estimate, however, fixed costs should also be included.

3. Return per rupee invested:

This is also called benefit-cost-ratio or input- output ratio.

$$\text{Return per rupee invested} = \frac{\text{Gross return}}{\text{Cost of cultivation}}$$

This index provides an estimate of the benefit derived and expenditure incurred by the farmer in adopting a particular cropping system. Anything above the value of 2.0 (meaning that the farmer can get RS.2 as return for every rupee invested) can be considered worthwhile.

4. Per day return:

This is called as income per day and can be obtained by dividing the net return by number of cropping period (days).

$$\text{Per day return} = \frac{\text{Net return}}{\text{Cropping period (days)}}$$

This gives the efficiency of the cropping system in terms of monetary value. If the system is stretched over one year, the denominator can be replaced by 365 days and per day for the whole year can be calculated.

No single index is capable of giving good comparison of different cropping systems. So a number of indices are used together to assess the economic viability of the system.

Fertilizer use efficiency (FUE)

The FUE is the output of any crop per unit of the nutrient applied under a specified set of soil and climatic conditions. The NUE/FUE can be expressed in several ways:

-*Partial factor productivity* (PFP, kg crop yield per kg input applied).

-*Agronomic efficiency* (AE, kg crop yield increase per kg nutrient applied).

-*Apparent recovery efficiency* (ARE, kg nutrient taken up per kg nutrient applied).

-*Physiological efficiency* (PE, kg yield increase per kg nutrient taken up).

-*Crop removal efficiency* (removal of nutrient in harvested crop as per cent of nutrient applied) is also commonly used to explain nutrient efficiency.

Water use efficiency

Crop water use efficiency: Crop water use efficiency is a ratio between marketable crop yield and water used by the crop in evapotranspiration.

c

$$\text{WUE (kg ha-mm}^{-1}) = \frac{Y}{ETc}$$

where,

WUE = Water use efficiency (kg ha-mm^{-1})

Y = Marketable crop yield (kg ha^{-1})

ET_C = Crop evapotranspiration (mm).

Field water use efficiency: Field water use efficiency is a ratio between marketable crop yield and field water supply which includes water used by the plant in metabolic activities, ET and deep percolation losses.

$$\text{FWUE (kg ha-mm}^{-1}) = \frac{\mathbf{Y}}{\mathbf{WR}}$$

where,

FWUE = Field water use efficiency (kg ha-mm^{-1}).

Y = Crop yield in kg ha^{-1}.

WR = Water requirement

Table 3.1 Water use efficiency of selected crops

Crop	Water requirement (mm)	Grain yield (kg ha^{-1})	WUE (kg ha-mm^{-1})
Rice	1200	4500	3.7
Sorghum	500	4500	9.0
Pearlmillet	500	4000	8.0
Maize	625	5000	8.0
Groundnut	506	4616	9.2
Wheat	280	3534	12.6
Fingermillet	310	4137	13.7

Growing marginalization and fragmentation of land holdings coupled with rising incidence of informal tenancies and poor rural infrastructure such as road, electricity, markets and education affect factor productivity. Availability of good quality irrigation water coupled with flexibility of irrigation and drainage system and appropriate methods of application as well as pricing of irrigation water is crucial for sustainable use of land and water resources.

In one sense, efficiency of a firm is its success in producing as large an amount of output as possible from given sets of inputs. Maximum efficiency of a firm is attained when it becomes impossible to reshuffle a given resource combination without decreasing the total output.

Chapter 4: SUSTAINABLE AGRICULTURE

Paul Hawken (1993) advised: "Leave the world better than you found it, take no more than you need, try not to harm life or the environment, make amends if you do.

"The first rule of sustainability is to align with natural forces or at least not try to defy them".

The word "sustain," from the Latin *sustinere* (*sus*-, from below and *tenere.* to hold), to keep in existence or maintain, implies long-term support or permanence. As it pertains to agriculture, sustainable describes farming systems that are "capable of maintaining their productivity and usefulness to society indefinitely. Such system... must be resource-conserving, socially supportive, commercially competitive and environmentally sound.

The *concept of sustainable agriculture* set out by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) states "sustainable agriculture is the successful management of resources for agriculture to satisfy the changing human needs, while maintaining or enhancing the quality of environment and conserving natural resources".

Modern definition: Sustainable agriculture is the use of farming systems and practices which maintain or enhance

1.The economic viability of agricultural production;

2.The natural resource base; and

3.Other ecosystems which are influenced by agricultural activities.

This definition can be supplemented by some fundamental principles of sustainable agriculture:

1. That farm productivity is enhanced over the long term;
2. That adverse impacts on the natural resource base and associated ecosystems are ameliorated, minimized or avoided;
3. That residues resulting from the use of chemicals in agriculture are minimised;
4. That net social benefit (in both monetary and non-monetary terms) from agriculture is maximized; and
5. That farming systems are sufficiently flexible to manage risks associated with the vagaries of climate and markets.

The United States Department of Agriculture defined *'sustainable agriculture'* as a management-system for renewable natural resources that provides food, income and livelihood for present and future economic productivity and ecosystem services of these resources.

Sustainable agriculture is a farm system that mimics as closely as possible the complexity of a healthy and natural ecosystem. It integrates three main goals.

1. Environmental health.
2. Economic efficiency
3. Social- economic equity (community)

Environmental health

Ecological sustainability is associated with genetic resource base and bio-diversity. Increase in diversity at genetics, species and ecosystem level forms the backbone of a sustainable ecology. Several possible solutions to the environmental problems created by capital and technology-intensive farming system have been proposed and research is currently in progress to evaluate alternative system. Main focus lies on the reduction or elimination of agro-chemical inputs through changes in management to assure adequate plant nutrition, plant protection through nutrient sources and integrated pest management and efficient use of energy and water.

Economic efficiency

In an economic contest, the farm must generate revenue, not always in terms of cash, but in terms of kind also. Farmers make decisions in risky, continuously changing environment and the consequences of their decisions are generally not known when the decisions are made. Variability of yields and prices are major sources of risk in agriculture. Changes in technology, legal and social concerns and the human factor itself also contribute to risky environment for the

farmers. Excessive dependency on external inputs maximizes the risk of profit reduction. In order to stabilize the farm economics, the farm should be made self sufficient, there should be parity in income distribution and finally the resilience of agricultural system should be increased.

Community

An ideal farming system will surely meet nutritional and livelihood security of the farmers and sustainability decreases the market dependency. It should have equitable access to common property resources. A farm can be said to be socially just only when it satisfy all the following options:

- Whether the farm is getting fare share of price.
- Whether it is sufficient to maintain a family well-being.
- Whether he get enough remuneration to purchase his food.
- Whether the minimum wage requirement is attained.

Sustainable agriculture means, an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- Satisfy human food and fiber needs;
- Enhance environmental quality and the natural resource based upon which the agricultural economy depends;
- Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- Sustain the economic viability of farm operations;
- Enhance the quality of life for farmers and society as a whole.

Advantages

1. Production cost is low
2. Overall risk of the farmer is reduced
3. Pollution of water is avoided
4. Very little or no pesticide residue is ensured
5. Ensures both short and long term profitability

Disadvantage

Since sustainable agriculture uses least quantum of inputs, naturally the output (yield) may also be less.

Basic features and concepts of sustainable systems

1. Need to maintain or improve soil quality and fertility. This is often attained by increasing the organic matter content of the soil, and by minimizing losses from soil erosion.
2. Production programs are designed to improve the efficiency of resource utilization. This will result in the most cost-effective use of water, fertilizers, and pesticides.
3. An attempt is made to improve internal nutrient cycles on the farm, which will reduce the dependence on external fertilizers.

4. Efforts are made to improve biological diversity on the farm. This will result in improved natural suppression of pests, and may also help to improve internal nutrient cycling within the farm.
5. Farm management and marketing programs are designed to minimize overhead costs and to increase returns, often by following alternative marketing schemes.

Problems and impact on agriculture

Agriculture has changed dramatically, especially since the end of World War II. Food and fiber productivity soared due to new technologies, mechanization, increased chemical use, specialization and government policies that favoured maximizing production. Although, these changes have had many positive effects and reduced many risks in farming, there have also been significant costs. Prominent among these are topsoil depletion, ground water contamination, decline of family farms, continued neglect of the living and working conditions for farm labourers, increasing costs of production and the disintegration of economic and social conditions in rural communities. Problems of agriculture can be listed as under:

1. Decline in agricultural growth rate
2. Decline in factor productivity
3. Static or decline in food production
4. Increasing malnutrition
5. Shrinkage in net cultivated area
6. Increasing environmental pollution
7. Depleting groundwater table
8. Increasing cost of production
9. Low farm income
10. Increasing unemployment

As a result, agricultural productivity has been witnessing stagnation in recent years. Besides, issues such as competing demand for water in the context of changing demographics and its various end uses further aggravates the degree of risks in the agriculture sector. These have considerable implications for food and livelihood security and as agriculture production being risk prone, may lead to migration from rural to urban and sub urban areas.

Indian agriculture now faces the challenge of ensuring food security amidst constraints such as stagnating net sown area, deterioration of land quality, reduction in per capita land availability etc.

The challenges are:

(i) Need for more food: Around 310 M t of food grains in 2050
(ii) Stagnating net sown area: 140 ± 2 M ha since 1970
(iii) Land share under fallow: 38 per cent increase since 1951
(iv) Per capita land availability: From 0.91 ha in 1951 to 0.32 ha in 2001 and to 0.19 ha is projected by 2050
(v) Per capita net sown area: 0.33 ha in 1951 to 0.14 ha in 2001

Fostering rapid, sustainable and broad-based growth in agriculture is therefore, a key priority keeping in mind the overall socio-economic development trajectory of the country, especially in the light of existing vulnerabilities that relate to a shrinking land resource base, additional stresses arising from the non-agricultural sector and issues emerging due to changing climate. This necessitates a strategic approach with a renewed vision and redefined focus.

A growing movement has emerged during the past three decades to question the role of the agricultural establishment in promoting practices that contribute to these social problems. Today, this movement for sustainable agriculture is garnering increasing support and acceptance within mainstream agriculture. Not only does sustainable agriculture address many environmental and social concerns, but it offers innovative and economically viable opportunities for growers, labourers, consumers, policymakers and many others in the entire food system.

Indicators of agricultural sustainability

These help us to identify, quantify and evaluate the effect of agriculture. We will be able to see the consequences of our policies on progress towards sustainability. Our future programmes and initiatives, as well as those of others, will be more easily and better targeted.

This set of indicators provides a means of measuring the economic social and environmental impacts of agriculture and to help assess the effectiveness of policies and the sustainability of the sector.

In order to be able to make a balanced assessment of agriculture's progress towards sustainability, social, environmental and economic factors must be examined. Tins calls for indicators that are cross-linked as well as representative of the issues most relevant to agriculture. The trends revealed by individual indicators need careful interpretation before conclusions can be drawn on the progress towards sustainability of the sector as a whole.

Indicators are able to show positive progress towards sustainability. For example, use of environmentally friendly fanning system has been rising. By combining indicators with agricultural productivity and energy use, we can see that energy efficiency has been rising. But other indicators show adverse movement. The numbers of certain species of farmland birds, for example, are in decline. Some of the indicators included in this set are not yet fully developed as they are based on existing data. In time, however, they should provide a better reflection of the trends towards a more sustainable agriculture sector.

Indicators are a composite set of attributes or measures that embody a particular aspect of agriculture. Indicators are quantified information, which help to explain how things are changing over time. Sustainability indicators look at economic, social and environmental information in an integrated manner. Many professionals agree that at least three criteria should guide the development of sustainability indicators:

Table 4.1: Indicators of key natural resources in rainfed cropping system

Sr. No.	Indicators	Management aspects
1	Nutrient balance	Organic matter—rate of change Nitrogen cycling—especially when using grain legumes in rotation with cereals. Monitoring status of phosphorus, sulphur and potassium Micronutrients.
2	Erosion	Vegetation cover—includes trees as well as stubble. Soil surface cover—stubble retained (30% sufficient to prevent wind and water erosion). Stream bank. Sheet and gully erosion
3	Productivity, yield and quality	Water use efficiency—*i.e.*, actual versus potential (in some areas the potential is much less than the actual) (biomass/grain yield/net return), recharge (dryland salinity and nutrient leaching). Pasture composition—legume and perennial. i Matched animal versus pasture production—appropriate enterprise selection/capability Maintenance of genetic base/improvement
4	Soil structure	Infiltration. Permeability/water storage. Stability. Water logging Compaction
5	pH	Change, Toxicity deficiency, Indicator plants
6	Energy effi.	Energy input vis-à-vis energy output of the whole agricultural system
7	Biological factors	Soil macro/micro flora and fauna, animal health, plant health (root growth and others) pests (animals and plants)
8	Farm manag. skills	Understanding a good indicator would be the understanding of the farmers of their own technical system
9	Precipitation	Performance of rainfall in a year as % of normal and its coefficient of variation Distribution of area based on rainfall amount (dry: 0-750mm,, medium: 750-1150 and 1150-2000mm, assured: > 2000mm) Categorization of the amount of rainfall (excess: =20% or more, normal: =10% to -10%, deficient: 20% to -59%, scanty: -60% or less) Number of districts having mean annual rainfall of 750-1250 mm and moisture availability period for at least 150 days. Area affected due to drought (slight, moderate or calamitous)

SUSTAINABLE AGRICULTURE RELATED TERMS

Alternative farming/alternative agriculture: These are essentially synonymous terms encompassing a vast array of practices and enterprises, all of which are considered different from prevailing or conventional agricultural activities. They include:

a. Non-traditional crops, livestock and other farm products.
b. Service, recreation, tourism, food processing, forest/woodlot and other enterprises based on farm and natural resources (ancillary enterprises).
c. Unconventional production system such as organic farming or aquaculture or direct marketing and other entrepreneurial marketing strategies.

Best management practices (BMPs): They include such practices as cover crops, green manure crops and strip cropping to control erosion along with soil testing and timing of chemical applications (similar to IPM) to prevent the loss of nutrients and pesticides.

Bio-diversity: It is the sum total of all the plants, animals, fungi and micro-organisms in the world or in a particular area; all of their individual variation and all the interactions between them."

Agro-bio-diversity: It is a fundamental feature of farming system around the world. It encompasses many types of biological resources tied to agriculture, including:

Bio-dynamic agriculture/Bio-dynamic farming: Specific practices and preparations that enable the farmers or gardeners to work in concert with the parameters.

Biological farming/Ecological farming: It is a system of crop production in which the producer tries to minimize the use of chemicals for control of crop pests.

Carbon sequestration: It is the process through which agricultural and forestry practices remove carbon dioxide (CO_2) from the atmosphere. The term 'sinks is also used to describe agricultural and forestry lands that absorb CO_2, the most important global warming gas emitted by human activities. Agricultural and forestry practices can also release CO_2 and other greenhouse gases to the atmosphere. Sequestration activities can help prevent global climate change by enhancing carbon storage in trees and soils, preserving existing tree and soil carbon and by reducing emissions of $C0_2$, methane (CH_4) and nitrous oxide (N_20)."

Carrying capacity: It is the theoretical equilibrium population size at which a particular population in a particular environment will stabilize when its supply of resources remains constant.

Conservation buffer strips: Conservation buffer strips are areas or strips of land maintained in permanent vegetation, designed to intercept pollutants and erosion. Placed around fields, they can enhance wildlife habitat, improve water quality and enrich aesthetics on farmlands. Various types of buffers include contour buffer strips, filter strips, riparian forest buffers, field borders, windbreaks, shelterbelts, hedgerows, grassed waterways, and alley cropping.

Ecological footprint (EF): Term has been introduced by William Rees in 1992. It is a measure of how much land and water is needed to produce the resources we consume and to

dispose of the waste we produce.

Carbon footprint: Representations of the effect human activities have on the climate in terms of total amount of greenhouse gases produced.

Good agricultural practices (GAP): Broadly defined, a GAP approach aims at applying available knowledge to addressing environmental, economic and social sustainability dimensions for on-farm production and post-production processes, resulting in safe and quality food and non-food agricultural products.

Natural farming: Natural farming reflects the experiences and philosophy of Japanese farmer Masanobu Fukuoka. It is a farming method which involves no tillage, no fertilizer, no pesticides, no weeding, no pruning and remarkably little labours.

Permaculture: A contraction of "permanent agriculture," the word "permaculture" was coined by Australian Bill Mollison in the late 1970s. One of the many alternative agriculture system described as sustainable, permaculture is unique in its emphasis on design; that is, the location of each element in a landscape and the evolution of landscape over time.

Precision farming/agriculture: Precision agriculture is a management strategy that employs detailed, site-specific information to precisely managed production inputs. This concept is sometimes called precision agriculture, prescription farming or site-specific management. The idea is to know the soil and crop characteristics unique to each part of the field and to optimize the production inputs within small portions of the field. The philosophy behind precision agriculture is that production inputs (seed fertilizer, chemicals etc.) should be applied only as needed and where needed for the most economic production.

Regenerative agriculture: Robert Rodale coined this term. Enhanced regeneration of renewable resources which is essential to the achievement of a sustainable form of agriculture.

Chapter 5: CONSERVATION AGRICULTURE STRATEGIES IN AGRICULTURE

Conservation agriculture is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. It is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with or disrupt the biological processes. It is characterized by three principles which are linked to each other, namely:

1. Continuous minimum mechanical soil disturbance
2. Permanent organic soil cover
3. Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops

Definition

It is the collective umbrella term commonly given to no tillage, direct-drilling, minimum tillage and/or ridge tillage, to denote that the specific practice has a conservation goal of some nature. Usually, the retention of 30 per cent surface cover by residues characterizes the lower limit of classification of conservation tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil-water, soil structure and nutrients. Thus, residue levels alone do not adequately describe all conservation tillage practices.

This has led to confusion among the agricultural scientists and more importantly, the farming community. To add to the confusion, the term 'conservation agriculture' has recently been introduced and its goals defined by FAO.

Conservation agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. It can also be referred to as resource efficient or resource effective agriculture.

According to FAO, it is a set of practices that leave crop residues on the surface which increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion. However, it still depends on tillage as the structure forming element in the soil. Never the less, conservation tillage practices such as zero tillage practices can be transition steps towards conservation agriculture.

Conservation agriculture is defined as minimal soil disturbance (no-till) and permanent soil cover (mulch) combined with rotations, is a recent agricultural management system that is gaining popularity in many parts of the world (FAO 2006).

Appropriate definition appears to be "A sustainable agriculture production system comprising a set of farming practices adapted to the requirements of crops and local condition of each region, whose farming and soil management techniques protect the soil from erosion and degradation, improve its quality and bio-diversity and contribute to the preservation of the natural resources, water and air, while optimizing yield".

Table:5.1 characteristic features of conventional & conservation agricultural system

Sr. No.	Conventional agriculture	Conservation Agriculture
1	Cultivating land, using science and technology to dominate nature	Least interference with natural processes
2	Excessive mechanical tillage and soil erosion	No-till or drastically reduced tillage (biological tillage)
3	High wind and soil erosion	Low wind and soil erosion
4	Residue burning or removal (bare surface)	Surface retention of residues (permanently covered)
5	Water infiltration is low	Infiltration rate of water is high

6	Use of *ex-situ* FYM/composts	Use of *in-situ* organics/composts
7	Green manuring (incorporated)	Brown manuring/cover crops (surface retention)
8	Kills established weeds, but stimulates more weed seeds to germinate	Weeds are a problem in the early stages of adoption but decrease with time
9	Free-wheeling of farm machinery, increased soil compaction	Controlled traffic, compaction in tramline, no compaction in crop area
10	Monocropping/culture, less efficient	Diversified and more efficient rotations
11	Heavy reliance on manual labor, uncertainty of operations	Mechanized operations, ensure timeliness of operations
12	Poor adaptation to stresses, yield losses greater under stress conditions	More resilience to stresses, yield losses are less under stress conditions
13	Productivity gains in long-run are in declining order	Productivity gains in long-run are in incremental order

Principles of conservation agriculture

The main principles of conservation agriculture are: conservation agriculture system utilize soils for the production of crops with aim of reducing excessive mixing of the soil and minimizing crop residues on the soil surface in order too minimize damage to the environment. By doing this conservation agriculture will:

1. Provide and maintain an optimum environment of the root zone to maximum possible depth. Roots are able to function effectively and without restriction to capture high amount of plant nutrients and water.
2. Ensure that water enters the soil so that:
    - Plants never or for the shortest time possible, suffer water stress that will limit the expression of their potential growth.
    - Residual water passes down to ground water and stream flow, not over the surface as runoff.
3. Favour beneficial biological activity in the soil in order to:
    - Maintain and rebuild soil architecture.
    - Compete with potential in-soil pathogens.
    - Contribute to soil organic matter and various grades of humus.
    - Contribute to capture, retention, chelation and slow release of nutrients.
4. Avoid physical or chemical damage to roots that disrupts their effective functioning.

Three principles of conservation agriculture include:

1. Direct planting of crop seeds.
2. Permanent soil cover, especially by crop residues and cover crops.
3. Crop rotation.

Direct seeding or planting

Direct seeding involves growing crops without mechanical seedbed preparation and with minimal soil disturbances since the harvest of the previous crop. The term direct seeding is

understood in conservation agriculture system as synonymous with no-till fanning, zero-tillage, no-tillage, direct drilling etc. Planting refers to the precise placing of large seeds (maize and beans); whereas seeding usually refers to a continuous flow of seed as in the case of small cereals (wheat and barley). Equipment penetrates the soil cover, opens a seeding slot and places the seed into that slot. Size of the seed slot and the associated movement of soil are to be kept at the absolute minimum possible. Ideally, the seed slot is completely covered by mulch again after seeding and no loose soil should be visible on the surface.

Land preparation for seeding or planting under no-tillage involves slashing or rolling the weeds, previous crop residues or cover crops or spraying herbicides for weed control and seeding directly through the mulch. Crop residues are retained either completely or to a suitable amount to guarantee the complete soil cover and fertilizer and amendments are either broadcast on the soil surface or applied during seeding.

Permanent soil cover

A permanent soil cover is important to:

- Protect the soil against the deleterious effects of exposure to rain and sun.
- Provide micro and macro-organisms in the soil with a constant supply of "food".
- Alter the microclimate in the soil for optimal growth and development of soil organisms, including plant roots.

Cover crops need to be managed before planting the main crop. This can be done manually or with animal or tractor power. The important point is that the soil is always kept covered (FAO 2006).

The effect of soil cover includes:

1. Improved infiltration and retention of soil moisture resulting in less severe, less prolonged crop-water stress and increased availability of plant nutrients.
2. Source of food and habitat for diverse soil life: creation of channels for air and water, biological tillage and substrate for biological activity through the recycling of organic matter and plant nutrients.
3. Increased humus formation.
4. Reduction of impact of raindrops on soil surface resulting in reduced crusting and surface sealing.
5. Consequential reduction of runoff and erosion.
6. Soil regeneration is higher than soil degradation.
7. Mitigation of temperature variations on and in the soil.
8. Better conditions for the development of roots and seedling growth.

Means and practices include:

1. Use of appropriate/improved seeds for high yields as well as high residue production and good root development.
2. Integrated management and reduced competition with livestock or other uses
3. Use of various cover crops, especially multipurpose crops, like nitrogen fixing, soil-porosity-restoring, pest repellent etc.

4. Optimization of crop rotations in spatial, timing and economic terms.
5. Targeted use of herbicides for controlling cover crop and weed development.

Crop Rotation

Rotation of crops is not only necessary to offer a diverse "diet" to the soil micro-organisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients. Nutrients that have been leached to deeper layers and that are no longer available for the commercial crop can be "recycled" by the crops in rotation. This way the rotation crops function as biological pumps.

Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna, as the roots excrete different organic substances that attract different types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant available nutrients. Crop rotation also has an important phytosanitary function as it prevents the carryover of crop-specific pests and diseases from one crop to the next via crop residues.

Effect of crop rotation include:

1. Higher diversity in plant production and thus in human and livestock nutrition.
2. Reduction and reduced risk of pest and weed infestations.
3. Greater distribution of channels or bio-pores created by diverse roots (various forms, sizes and depths).
4. Better distribution of water and nutrients through the soil profile.
5. Exploration for nutrients and water of diverse strata of the soil profile by roots ofMany different plant species resulting in a greater use of the available nutrients and water.
6. Increased nitrogen fixation through certain plant-soil biota symbionts and improved balance of N/P/K from both organic and mineral sources.

Means and practices include:

1. Design and implementation of crop rotations according to the various objectives: food and fodder production (grain, leaf, stalks), residue production, pest and weed control, nutrient uptake and biological subsurface mixing/cultivation etc.
2. Use of appropriate/improved seeds for high yields as well as high residue production of above-ground and below-ground parts, given the soil and climate conditions.

Advantages of conservation agriculture

To be widely adopted, all new technology needs to have benefits and advantages that attract a broad group of farmers who understand the differences between what they are doing and what they need. In the case of conservation agriculture, advantages can be grouped as:

(i) Economic benefits: These improve production efficiency

(ii) Agronomic benefits :These improve soil productivity

(iii) Environmental and social benefits: These protect the soil and make agriculture more sustainable.

(i) Economic Benefits

Three major economic benefits can result from CA adoption:

1. Time saving and thus reduction in labour requirement.
2. Reduction of costs (fuel, machinery operating costs and maintenance, as well as a reduced labour cost).
3. Higher efficiency in the sense of more output for a lower input.

The positive impact of conservation agriculture on the distribution of labour during the production cycle and even more important, the reduction in labour requirement are the main reasons for farmers in Latin America to adopt conservation agriculture, especially for fanners who rely fully on family labour. Manual labour for soil preparation is back-breaking and unnecessary. Should the supply of labour be reduced, through sickness or migration, then the system can quickly become unsustainable.

(ii) Agronomic Benefits

Adopting conservation agriculture leads to improvement of soil productivity:

1. Organic matter increase.
2. In-soil water conservation.
3. Improvement of soil structure and thus rooting zone.

Constant addition of crop residues leads to an increase in the organic matter content of the soil. In the beginning this is limited to the top layer of the soil, but with time this will extend to deeper soil layers. Organic matter plays an important role in the soil: fertilizer use efficiency, water holding capacity, soil aggregation, rooting environment and nutrient retention, all depend on organic matter.

(iii) Environmental Benefits

1. Reduction in soil erosion and thus of road, dam and hydroelectric power plant maintenance costs.
2. Improvement of water quality.
3. Improvement of air quality.
4. Bio-diversity increase.
5. Carbon sequestration.

Limitations of conservation agriculture

Most important limitation in all areas where conservation agriculture is practiced is the initial lack of knowledge. There is no blueprint available for conservation agriculture, as all agro-ecosystem are different. Particularly important gap is the frequent dearth of information on locally adapted cover crops that produce high amounts of biomass under the prevailing conditions. The success or failure of conservation agriculture depends greatly on the flexibility and creativity of the practitioners and extension and research services of a region. Trial and error, both by official institutes and the farmers themselves, is often the only reliable source of information.

However, as conservation agriculture is gaining momentum rapidly in certain regions there now exist new networks of farmers organizations and groups of interested people who exchange information and experiences on cover crops, tools and equipment and other techniques used in conservation agriculture.

Initial nervousness about switching from plough-based farming to CA can be ameliorated by forming farmer groups to exchange ideas and gain knowledge from more experienced practitioners.

As conservation agriculture partly relies on the use of herbicides, at least during the initial stage of adoption, some people worry that adoption of conservation agriculture will increase herbicide use and that in turn will lead to increased contamination of water by herbicides. In fact, experience has shown that herbicide use tends to decline over time as the soil cover practices prevent weed emergence.

Reductions in leaching of pesticides under conservation agriculture might be caused by greater microbial activity degrading pesticides faster or to greater organic matter adsorbing the pesticides.

2.5.4 Constraints for adopting conservation agriculture

A mental change of farmers, technicians, extensionists and researchers away from soil degrading tillage operations towards sustainable production system like no tillage is necessary to obtain changes in attitudes of farmers however, noted that probably the most important factor in the adoption of CA is overcoming the bias or mindset about tillage. It is argued that convincing the farmers that successful cultivation is possible even with reduced tillage or without tillage is a major hurdle in promoting CA on a large scale. In many cases, it may be difficult to convince the farmers of potential benefits of CA beyond its potential to reduce production costs, mainly by tillage reductions. CA is now, considered a route to sustainable agriculture. Spread of conservation agriculture, therefore, will call for scientific research linked with development efforts. The following are a few important constraints which impede broad scale adoption:

(1) Lack of appropriate seeders especially for small and medium scale farmers: Although significant efforts have been made in developing and promoting machinery for seeding wheat in no till system, successful adoption will call for accelerated effort in developing, standardizing and promoting quality machinery aimed at a range of crop and cropping sequences. These would include the development of permanent bed and furrow planting system and harvest operations to manage crop residues.

(2) Wide spread use of crop residues for livestock feed and fuel: Especially under rainfed situations, farmers face a scarcity of crop residues due to less biomass production of different crops. There is competition between conservation agriculture practice and livestock feeding for crop residue. This is a major constraint for promotion of conservation agriculture under rainfed situations.

(3) Burning of crop residues: For timely sowing of the next crop and without machinery for sowing under conservation agriculture system, fanners prefer to sow the crop in time by burning the residue. This has become a common feature in the rice-wheat system in north India. This creates environmental problems for the region.

(4) Lack of knowledge about the potential of conservation agriculture *to agriculture leaders, extension agents and farmers:* This implies that the whole range of practices in conservation agriculture, including planting and harvesting, water and nutrient management, diseases and

pest control etc need to be evolved, evaluated and matched in thecontext of new system.

(5) Skilled and scientific manpower: Managing conservation agriculture system, will call for enhanced capacity of scientists to address problems from a system perspective and to be able to work in close partnerships with farmers and other stakeholders. Strengthened knowledge and information sharing mechanisms are needed.

Conservation Agriculture vs Conservation Tillage

Conservation agriculture is largely the product of the collective efforts of a number of previous agricultural movements, including no-till agriculture, agro-forestry, green manures/ cover crops, direct planting/seeding and conservation tillage among many others. Yet, conservation agriculture is distinct from each of these so-called agricultural packages, even as it draws upon many of their core principles. This is because conservation agriculture uses many of the available technologies in unison, resulting in something many believe to be much greater than the sum of its parts. The following terms are often confused with conservation agriculture:

No-Till (NT)/ Zero-Till (ZT)

The NT and ZT are technical components used in conservation agriculture that simplyinvolve the absence of tillage/ploughing operations on the soil. Crops are planted directly into a seedbed not tilled after harvesting the previous crop. Not everyone utilizing no-till technologies adopts other important components of conservation agriculture. One major difference is that NT or ZT do not necessarily leave residue mulch. Some recent research data suggests this is vital, since without the residue mulch many of the benefits of conservation agriculture are lost or decreased in value.

Conservation Tillage/ Minimum Tillage/ Reduced Tillage

These are tillage operations that leave at least 30 per cent of the soil surface covered by plant residues in order to increase water infiltration and cut down on soil erosion and runoff. Conservation tillage is an intermediate form of conservation agriculture since it keeps some soil cover as residue from the previous crop. But some tillage is usually done. It developed as a management system after the “Dust Bowl” of the 1930’s in the Mid-West areas of the USA. It was found to reduce erosion by protecting the soil surface from wind and rain.

Organic Farming

Organic agriculture does not permit the use of synthetic chemicals to produce plant and animal products, relying instead on the management of soil organic matter and biological processes. In some parts of the world, farms must be inspected and certified before their food products can be sold as organic, indicating that no synthetic chemicals were used in producing them. But organic farming uses the principles of conservation agriculture to some extent and one objective similar to conservation agriculture is to maintain and improve soil health. Unlike organic farming, conservation agriculture does allow farmers to apply synthetic chemical fertilizers, fungicides, pesticides and herbicides. Many farmers rely on using these to control weed and pest problems, particularly during the early transition years. As soil physical, chemical

and biological health improves over time; the use of agrichemicals can be significantly reduced or, in some cases, phased out entirely.

Chapter 6: HEIA and LEISA

High external input agriculture (HEIA)

High external input Agriculture (HEIA) are technologies that utilize high external inputs such as inorganic or chemical fertilizers to increase nutrient depletion from the soil, pesticides to control pests and diseases, herbicides to control weeds and irrigation facilities for water management in the farms. These technologies are often beyond the financial reach of the small - holder farmers.

Advantages of high external input agriculture (HEIA)

1. Agricultural Production could be rapidly increased to meet the demand for food for the increasing population.
2. As a result of availability of adequate food stuffs many problems related to diseases caused by mal-nutrition and deficiency were prevented or reduced.
3. New improved varieties gave yields within a short period of time.
4. Mechanization solves the problem of labour shortage.
5. Income and profit margins of the products were increased.
6. Productivity of land increased.
7. Increased market facilities for production.

Disadvantages of HEIA

1. Collapse of environmental balance due to lack of biodiversity by planting a few cash crops.
2. Increase in soil erosion due to constant furrowing by machinery.
3. Dependence on imported machinery, chemical fertilizer, pesticides, hybrid seeds and other inputs.
4. Extensive use of pesticides disturbed the natural mechanism of controlling pest and diseases as the artificial pesticides kill both pests and their natural enemies.
5. Use of artificial agro-chemicals adversely affected the soil pH, cation exchange capacity, soil structure, soil texture and soil organisms. Consequently the microbial activities of the soil tend to reduce forming dead soil.

Low-external input sustainable agriculture (LEISA)

"Low-External Input Sustainable Agriculture (LEISA) is a series of practices which serve to reinforce ecological principles that are in line with local ecosystems".

Practices such as recycling of plant nutrients (nitrogen and others), minimizing crop losses due to insects and pests, and securing favorable soil conditions for plant growth are just the tip of the hat.

An integral component of LEISA is in ensuring that this environmental awareness remains connected to the daily lives, needs and concerns of farmers who rely on these ecosystems for their livelihoods.

The LEISA relies mostly on the inputs from the local farm, village or region and deliberate action is taken to ensure sustainability.

The principles are:

1. Securing favorable soil conditions for plant growth particularly managing organic matter and enhancing soil life.
2. Optimizing the nutrient availability and balancing the nutrient flow, particularly by means of nitrogen fixation, nutrient acquisition and complementary use of external fertilizers.
3. Minimizing the losses due to plant and animal pests by means of prevention and safety treatment.
4. Minimizing losses due to flows of solar radiation, air, water by way of microclimate management, water management and erosion control.

Characteristics of HEIA and LEISA

Sl. No.	HEIA	LEISA
1	The farming pattern depends heavily on external and chemical inputs.	LEIA relies on the optimal use of natural processes.
2	The focus is mainly on maximizing yields coupled with increasing specialization of production	The focus is on the sustainability of farming system
3	There is a great damage to the environment	Environmentally sound and that have the potential to contribute to the long-term sustainability of agriculture.
4	The continuing drop in prices of farm produce and the rising costs of agricultural inputs have made farming increasingly unprofitable	Greater emphasis is on the long-term nourishment and balance between the profit and livelihood.
5	HEIA depends on the higher production and profit, without consideration of the local needs and local market	LEISA depend largely on local agro-ecological conditions and on local socio-economic circumstances, as well as on farmers' individual needs and aspirations.
6	Primarily one or two commodity driven development, lack of diversity	One way of LEIA is to diversification of farms; with a range of crops and/or

	in the farming practices; as a result, there is greater risk of failure and price fluctuation. The number of products and commodities are very minimum.	animals, farmers will suffer less from price fluctuations or drops in yield of single crops. Maintaining diversity will also provide a farm family with a range of products to eat or sell throughout a large part of the year.
7	Under HEIA system, soil quality deteriorates, and there is resurgence of pests, lack of resilience in the soil-plant system	LEIA maintains a healthy soil, recycling nutrients on the farm, and utilizing approaches such as integrated pest management (IPM).
8	In HEIA, there is lack of use of indigenous technologies.	Best bet technologies, for example, soil and water conservation (terraces, ditches, and vegetation strips on sloping land), better timing of operations, improved crop spacing and densities, manure or compost and water application based on local conditions.

Chapter 7: INTEGRATED FARMING SYSTEM

History:

All over the world, during the last four decades, grain yields went up at spectacular rates during the green revolution and individual levels of production in animals followed similar trend. Ensuring food security for the fast growing global population is a mammoth challenge for the present agricultural production system. Shrinking average farm size in India and financial constraints for higher investment in agriculture due to 80 per cent farm families belonging to small and marginal farmer categories further heighten the challenge. For securing food and nutrition security for sizable population, productivity enhancement may provide a vital solution. This involves adoption of scientific agronomic practices and technologies which promise an augmentation of the productive capacity of traditional agricultural system. Agronomic practices such as the liberal use of inorganic pesticides and fertilizers during the twentieth century enhanced productivity significantly but undesirable environmental degradation accompanied by increased operational costs in agriculture raised concerns about economic feasibility and sustainability. Unsustainable farming leads to environmental pollution and threatens the livelihood of millions of small farm holders. Strengthening agricultural production systems for greater sustainability and higher economic returns is a vital process for increasing income and food and nutrition security in developing countries.

Therefore, integrated farming system (IFS) is a multidisciplinary whole farm approach and appears effective in solving the problems of small and marginal farmers. The approach aims

at increasing income and employment from small-holding by integrating various farm enterprises and recycling crop residues and by products within the farm itself. Farmers need to be assured of regular income for living at least above poverty line. Progress in production or steady growth in output is necessary to face the challenges posed by present economic, political and technological environment. In this context, farming system approach is one of the important solutions to face this particular situation as in this approach different enterprises can be carefully undertaken and the location specific system are developed based on available resources which will result in sustainable development.

Objectives:

Sustainability is the objective utilization of inputs without impairing the quality of environment with which it interacts. Therefore, it is clear that farming system is a process in which sustainability of production is the objective.

The overall objective is to evolve technically feasible and economically viable farming system models by integrating cropping with allied enterprises for irrigated, rainfed, hilly and coastal areas with a view to generate income and employment from the farm.

Integrated Farming as a farming system where high quality food, feed, fibre and renewable energy are produced by using resources such as soil, water, air and nature as well as regulating factors to farm sustainably and with as little polluting inputs as possible.

At present, the farmers concentrate mainly on crop production which is subjected to a high degree of uncertainty in income and employment to the farmers. In this contest, it is imperative to evolve suitable strategy for augmenting the income of a farm.

Integration of various agricultural enterprises *viz.*, cropping, animal husbandry, fishery, forestry *etc.* have great potentialities in the agricultural economy. These enterprises not only supplement the income of the farmers but also help in increasing the family labour employment.

1. The integrated farming system approach introduces a change in the farming techniques for maximum production in the cropping pattern and takes care of optimal utilization of resources.
2. The farm wastes are better recycled for productive purposes in the integrated system.
3. A judicious mix of agricultural enterprises like dairy, poultry, piggery, fishery, sericulture *etc.* suited to the given agro-climatic conditions and socio-economic status of the farmers would bring prosperity in the farming.

The growth rate of agriculture in the recent past is very slow in spite of the rapid economic growth in India. According to the Economic Survey of India, 2008, the growth rate of food grain production decelerated to 1.2% during 1990-2007, lower than the population growth of 1.9%. It is projected that in our country population will touch 1370 million by 2030 and to 1600 million by 2050. To meet the demand, we have to produce 289 and 349 MT of food grains during the respective periods. The current scenario in the country indicates that area under

cultivation may further dwindle and more than 20% of current cultivable area will be converted for non-agricultural purposes by 2030.

The operational farm holding in India is declining and over 85 million out of 105 million are below the size of 1 ha. Due to ever increasing population and decline in per capita availability of land in the country, practically there is no scope for horizontal expansion of land for agriculture. Only vertical expansion is possible by integrating farming components requiring lesser space and time and ensuring reasonable returns to farm families. The Integrated farming system (IFS) therefore assumes greater importance for sound management of farm resources to enhance the farm productivity and reduce the environmental degradation, improve the quality of life of resource poor farmers and maintain sustainability. In order to sustain a positive growth rate in agriculture, a holistic approach is the need of the hour.

Integrated farming system approach is not only a reliable way of obtaining fairly high productivity with considerable scope for resource recycling, but also concept of ecological soundness leading to sustainable agriculture. With increasing energy crisis due to shrinking of non-renewable fossil-fuel based sources, the fertilizer nutrient cost has increased steeply and with gradual withdrawal of fertilizer subsidy. It is expected to have further hike in the cost of fertilizers. This will leave the farmers with no option but to fully explore the potential alternate sources of plant nutrients at least for the partial substitution of the fertilizer nutrients for individual crops and in the cropping systems.

During XII plan period the ICAR-Project Directorate for Farming Systems Research (ICAR-PDFSR) officially renamed as Indian Institute of Farming Systems Research (IIFSR) and it established with focus on farming systems research after re-naming the Project Directorate for Cropping Systems Research (PDCSR) which became operational during 2009.

Objectives of integrated farming system:

1. Maximization of yield of all component enterprises to provide steady and stable income at higher levels.
2. Rejuvenation/amelioration of system's productivity and achieve agro-ecological equilibrium.
3. Control the buildup of insect-pests, diseases and weed population through natural cropping system management and keep them at low level of intensity.
4. Reducing the use of chemical fertilizers and other harmful agro-chemicals and pesticides to provide pollution free, healthy produce and environment to the society at large.

Advantages of Integrated farming system

1. It improves space utilization and increase productivity per unit area.
2. It provides diversified products.
3. Improves soil fertility and soil physical structure from appropriate crop rotation and using cover crop and organic compost.
4. Reduce weeds, insect pests and diseases from appropriate crop rotation.
5. Utilization of crop residues and livestock wastes.
6. Less reliance to outside inputs – fertilizers, agrochemicals, feeds, energy, *etc.*

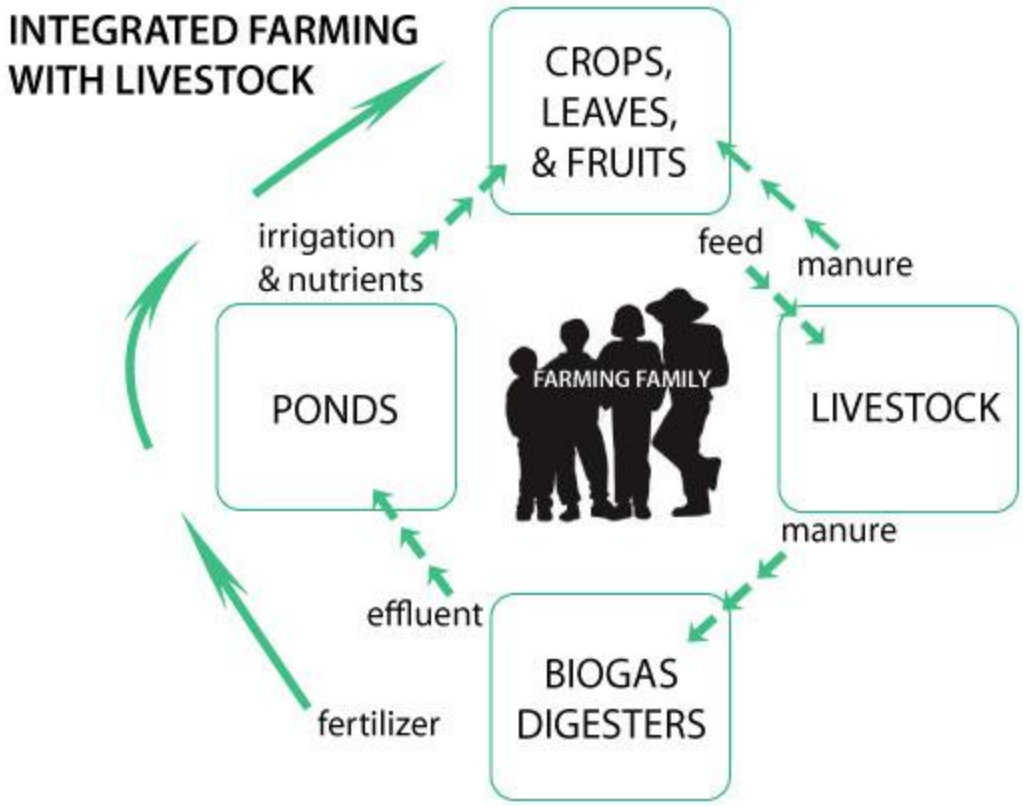
7. Higher net returns to land and labour resources of the farming family.
8. Regular stable income through the products like egg, milk, mushroom, vegetables, honey and silkworm cocoons from the linked activities in integrated farming.
9. Reduced production cost of components through input recycling from the byproducts of allied enterprises.
10. Integration of allied activities will result in the availability of nutritious food enriched with protein, carbohydrate, fat, minerals and vitamins.

List of the components/enterprises in integrated farming system

Agriculture	Mushroom cultivation	Seed Production	Sheep/goat rearing
Horticulture	Sericulture	Vermiculture	Piggery
Forestry	Azolla farming	Pigeon rearing	Rabbitory
Dairy	Kitchen gardening	Apiary	Value addition
Fish farming	Fodder production	Poultry	

Elements of integrated farming system

Watershed	Farm ponds	Bio-pesticides & Bio-fertilizers
Plant products as pesticides	Bio-gas	Solar energy
Compost making	Green manuring	Rain water harvesting



Allied enterprises and their maintenance

1. Crop production

Crop production is an integral part of farm activities in the country. The cropping system should provide enough food for the family, fodder to the cattle and generate sufficient cash for domestic and cultivation expenses. These objectives could be achieved by adopting intensive cropping.

Detailed to this is discussed earlier in cropping systems.

2. Dairy farming

Dairy farming is an important source of income to farmers. Besides producing milk and/or draft power, the dairy animals are also good source of farm yard manure, which is good source of organic matter for improving soil fertility. The farm byproducts in turn are gainfully utilized for feeding the animals.

(a) Cattle Rearing:

Cattle's rearing in India is carried out under a variety of adverse climatic and environmental conditions. The cattle are broadly classified into three groups.

(i) Draft breeds: The bullocks of these breeds are good draft animals, but the cows are poor milkers, e.g. Khillari, Nagore, Hallikar,, Mali.

(ii) Dairy breeds: The cows are high milk yielders, but the bullocks are of poor draft quality, e.g., Sahiwal, Red Sindhi, Gir.

(iii) Dual purpose: The cows are fairly good milkers and the bullocks are with good draft work capacity, e.g., Tharparkar, Hariana, Ongole, Kankrej and Deoni.

Exotic breeds: The exotic breeds are high milk yielder e.g., Jersey, Holstein-Friesian, Aryshire, Brown Swiss and Guernsey.

Some brief information about the cow breeds:

Sahiwal: Originated in Montgomery region of undivided India. Best indigenous dairy breed. Reddish dun or pale red in colour, sometimes flashed with white patches. Heavy breed with symmetrical body having loose skin. The average milk yield of this breed is between 1400 and 2500 kgs per lactation.

Red Sindhi: Originated in Karachi and Hyderabad (Pakistan) regions of undivided India and also reared in certain organized farms in our country. Colour is red with shades varying from dark red to light, strips of white. Milk yield ranges from 1250 to 1800 kgs per lactation. Bullocks despite lethargic and slow can be used for road and field work.

Gir: Originated in Gir forests of South Kathiawar in Gujarat also found in Maharashtra and adjacent Rajasthan. Basic colours of skin are white with dark red or chocolate-brown patches or sometimes black or purely red. Horns are peculiarly curved, giving a 'half moon' appearance. Milk yield ranges from 1200-1800 kgs per lactation. his bread is known for its hardiness and disease resistance

Hallikar: Originated from the former princely state of Karnataka. The colour is grey or dark grey. The breed is best known for its draught capacity and especially for its trotting ability.

Khillari: Originated from Sholapur districts of Maharashtra. Long horns turn forwards in a peculiar fashion. The horns are generally black, sometimes pinkish. Bullocks are fast and powerful.

Kangayam: Originated in Kangayam, Dharapuram and Coimbatore district of Tamil Nadu. The eyes are dark and prominent with black rings around them.

Tharparkar: Originated in Tharparkar district (Pakistan) of undivided India and also found in Rajasthan. Also known as White Sindhi, Gray Sindhi and Thari. The bullocks are quite suitable for ploughing and casting and the cows yield 1800 to 2600 kgs of milk per lactation.

Hariana: It was originated from Rohtak, Hisar, Jind and Gurgaon districts of Haryana and also popular in Punjab, UP and parts of MP. Horns are small. The bullocks are powerful work animals. Hariana cows are fair milkers yielding 600 to 800 kg of milk per lactation.

Kankrej: Originated from Southeast Rann of Kutch of Gujarat and adjoining Rajasthan (Barmer and Jodhpur district). Colour of the animal varies from silver-grey to iron-grey or steel black. The gait of Kankrej is peculiar called as 1 ¼ paces (sawai chal). Kankrej is valued

for fast, powerful, draught cattle. Useful in ploughing and carting. The cows are good milkers, yielding about 1400 kgs per lactation.

Ongole: Home tract is Ongole taluka in Guntur district of Andhra Pradesh. Large muscular breed with a well developed hump. Suitable for heavy draught work. Average milk yield is 1000 kgs per lactation.

Deoni: Originated in Western Andra Pradesh, Marathwada region of Maharashtra state and adjoining part of Karnataka. Body colour is usually spotted black and white. Milk yield ranges from 636 to 1230 kgs per lactation. Bullocks are suitable for heavy cultivation

Exotic Breeds

Jersey: Originated from Jersey Island, U.K. The typical colour of Jersey cattle is reddish fawn. Economical producers of milk with 4.5% fat. Average milk yield is 4500 kgs per lactation.

Holstein Friesian: Originated from the northern parts of Netherlands especially in the province of Friesland. Largest dairy breed and ruggedly built is shape and possess large udder. Breeds have typical marking of black and white that make them easily distinguishable. The average milk production of cow is 6000 to 7000 kgs per lactation.

Brown Swiss: Origin Switzerland. Average milk yield is 5000 kgs per lactation. The Karan Swiss is the excellent crossbred cattle obtained by crossing this breed with Sahiwal cattle at NDRI, Karnal.

Red Dane: Orginated in Denmark. Lactation yield varies from 3000 to 4000 kg

Ayrshire: Origin is Ayrshire in Scotland. This one is considered as most beautiful dairy breed. These are very active animals but hard to manage.

(b) Buffaloes:

Important dairy breeds of buffalo are Murrah, Nili Ravi (which has its home tract in Pakistan), Mehsana, Surti, Zafarabadi, Godavari and Bhadawari. Of these Godavari has been evolved through crossing local buffaloes in coastal regions of Andhra Pradesh with Murrah.

Murrah: Most important breed of buffaloes. Origin is Rohtak, Hisar and Sind of Haryana, Nabha and Patiala districts of Punjab and southern parts of Delhi state. Most efficient milk and butter fat producers in India. Butter fat content is 7.83%. Average lactation yield is varying from 1500 to 2500 kgs per lactation.

Surti: Origin is Kaira and Baroda district of Gujarat. The peculiarity of the breed is two white collars, one round the jaw and the other at the brisket region. The milk yield ranges from 1000 to 1300 kgs per lactation. The peculiarity of this breed is very high fat percentage in milk (8-12 %)

Jaffrabadi: Gir forests, Kutch and Jamnagar districts of Gujarat. This is the heaviest Indian breed of buffalo. The average milk yield is 1000 to 1200 kgs per lactation. These animals are

mostly maintained by traditional breeders called *Maldharis*, who are nomads. The bullocks are heavy and used for ploughing and carting.

Mehsana: Mehsana, Sabarkanda and Banaskanta districts in Gujarat and adjoining Maharashtra state. The breed is evolved out of crossbreeding between the Surti and the Murrah. Body is longer than Murrah but limbs are lighter. The horns are less curved than in Murrah and are irregular. Bullocks are good for heavy work. The milk yield is 1200-1500 kgs per lactation.

3. Goat and sheep rearing

(I) Goat rearing:

- In India, Goat is mainly reared for meat, milk, hair and skin.
- Goat meat is the preferred meat in the country.
- A goat on hoof (live goat) fetches a better price than a sheep on hoof.

Goat Breeds

- Milk & Meat – Jamnapari, Osmanabadi, Barbari , Beetal
- Meat and skin – Black Bengal, Kanni adu
- Meat, skin and milk – Barvari, Malabari (Tellicherry), Sirohi, Surti
- Meat, hair and skin – Gaddi, Kutchi, Marwari

- **Jamnapari** : is the most popular breed for commercial goat farming in India. It is mostly found in Uttar Pradesh. This goat is reared mainly for milk.
- **Boer Goat:** breed was developed in South Africa and it is the most popular breed in the world for meat.
- **Surti :** Surti Goat is one of the best breed in India for dairy. This breed is very small and is native of Surat in Gujarat. They are most economical to the rear. Surti female goats are bigger than male goats.

(II) Sheep rearing:

- Sheep are well adapted to many areas.
- They are excellent gleaners and make use of much of the waste feed.
- They consume large quantities of roughage, converting a relatively cheap food into a good cash product.
- Housing need not be elaborate or expensive.
- However, to protect the flock from predatory animals, the height of the fencing should be raised to two meters.

Breeds of Indian Sheep:

- Karanah, Bhakarwal, Bikaneri, Marwari, Kutchi, Kathiawari, Deccani, Nellore, Bellary etc.

4. Piggery

Pigs are maintained for the production of pork.

Breeds:

Imported breeds of Large White Yorkshire and Landrace are being used widely.

Yorkshire is the most extensively used exotic breed in India. It is a prolific breed having good carcass quality, growth rate and feed conversion ability.

5. Poultry

Poultry is one of the fastest growing food industries in the world. Poultry meat accounts for about 27% of the total meat consumed worldwide and its consumption is growing at an average of 5% annually. Poultry industry in India is relatively a new agricultural industry.

Breeds:

Specific poultry stocks for egg and broiler production are available. A majority of the stocks used for egg production are crosses involving the strains or inbred lines of white Leghorn. To a limited extent, other breeds like Rhode Island Red, California Grey and Australop are used.

Cage system:

The cage system of rearing birds has been considered as a super intensive system providing floor area of 450-525 sq.cm. (0.6-0.75 sq.feet) per bird.

Advantages

1. Greater number of birds is reared per unit of area
2. Facilitates correct maintenance of records
3. Helps in identifying poor producers and prompt culling
4. Control of vices of poultry cannibalism and egg eating
5. It helps in production of clean eggs
6. Removal of stress factors
7. Easy control of parasitic disease like coccidiosis and worm infestation
8. Prompt steps to control feed wastage.
9. The cage method of housing is ideal for the area of moderated climate conditions where the day temperature in summer does not high and temperature does not fall too low.
10. Egg production of caged layer was reported to be more than those kept in deep litter system.
11. Feed efficiency and egg weight were better in caged birds than the laying flock under deep litter system

Disadvantages

1. Difficulties in ensuring proper ventilation to birds especially in summer season and under very high densed conditions.
2. Incidence of leg problem, cage layer fatigue, fatty liver syndrome, flies and obnoxious gases in the house will be on increases
3. Hysteriosis of chicks

Deep litter system: Deep litter system is commonly used in all over the world.

Advantages:

1. It is an economical
2. Hygienic, comfortable and safe to birds
3. Built up litter supplies vitamin B12 and Riboflavin to the birds
4. Controls diseases and vices
5. It increases the efficiency of production
6. Materials such as paddy husks saw dust, dried leaf, chopped straw and groundnut kernels depending upon the availability can be used as litter materials

Disadvantages

1. The deep litter system should always keep dry.
2. Only right numbers of birds should be housed
3. The house should be well ventilated
4. The litter should be stirred at least once in a week-wet litter if any should be replaced immediately with new dry litter and birds must be fed a balanced ratio.
5. The time starting deep litter system should be in the dry period of the year as it allows sufficient time (At least two months) for bacterial action.
6. Placing of water should be given due attention to keep litter dry.

6. Duck rearing

Ducks account for about 7% of the poultry population in India.

Breeds:

The important Indian breeds are Sylhet Mete and Nageswari, which are mostly found in the Eastern region of the country. Their annual production of 150 eggs/bird/year. Khaki Campbell and Indian Runner are the most popular breeds for egg laying.

Housing:

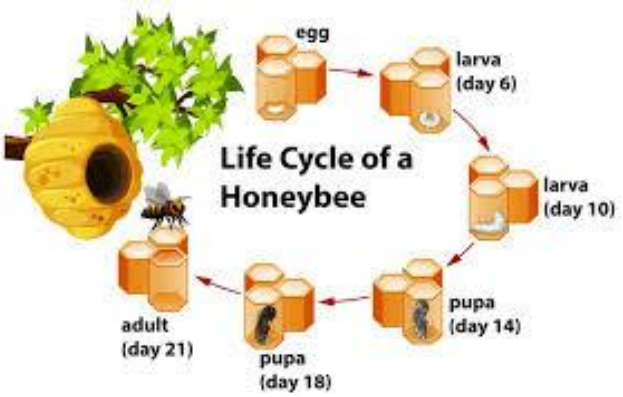
Ducks prefer to stay outside day and night even during winter or rains. In mild climate, it is possible to raise ducks without artificial shelter.

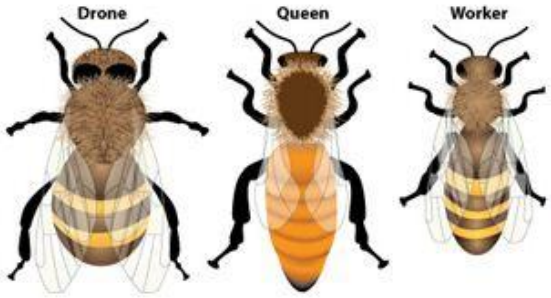
7. Apiculture

Apiculture is the science and culture of honeybees and their management. Apiculture is a subsidiary occupation and it is a additional source of income for farm families. It requires low investments and so can be taken up by small, marginal and landless farmers and educated unemployed youth. Honey is a sweet viscous fluid produced by honeybees mainly from the nectar of the flowers. Honey should have good quality to meet the national and international standards. Qualities such as aroma, colour, consistency and floral sources are important.

Species:

There are two bee species, which are most commonly grown in India. They are *Apis cerana indica* and *A. mellifera*, are complementary to each other but have different adaptations. *A. cerana* is known as Indian bees, while *A mellifera* is known as European/western bee.





Management:

The beekeeper should be familiar with the source of nectar and pollen within his locality. Bee flora species are specific to different areas and have micro regional habitats. Under subtropical climates of India, nectar and pollen sources are available for most part of the year, but continuous succession throughout the year is lacking in some localities. Flowers of large number of plants species are visited by honeybees for nectar and pollen. The most important sources of nectar and pollen are maize, mustard, sunflower and palm, litchi, pongamia, coconut, sesamum *etc.*

Honey collection: Honey is a sweet viscous fluid produced by honeybees mainly from the nectar of the flowers. Honey should have good quality to meet the national and international standards. Qualities such as aroma, colour, consistency and floral sources are important. Proper honey straining and processing are needed to improve the quality of the produce. Honey varies in the proportion of its constituents owing to the differences in the nectar produced by different plants. The nectar collected by bees is processed and placed in comb cells for ripening. During the ripening, sucrose is converted into glucose and fructose by an enzyme called invertase, which is added to it by the bees. Honey is an excellent energy food with an average of about 3500 calories per kg. It is directly absorbed into the human blood stream, requiring no digestion.

8. Fishery

Ponds serve various useful purposes, viz., domestic requirement of water, supplementary irrigation source to adjoining crop fields and pisciculture.

Species of fish:

Catla, Rohu, Calbasu Mrigal, Common carp, Silver carp, Grass carp

Management:

For higher productivity fish are to be provided with supplementary feeding with rice bran and oilseed cakes.

9. Sericulture

Sericulture is defined as a practice of combining mulberry cultivation, silkworm rearing and silk reeling. Sericulture is a recognized practice in India. India occupies second position among silk producing countries in the world, next to China.

Moriculture: Cultivation of mulberry plants is called as 'Moriculture'. There are about 20 species of mulberry, of which four are commonly cultivated. They are *Morus alba, M. indica, M. serrata* and *M. latifolia*.

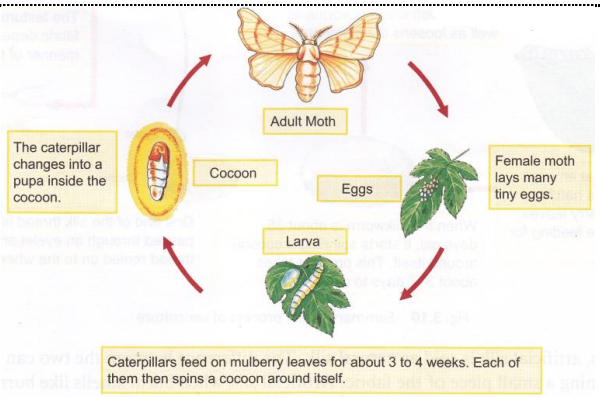
Silk worm rearing:

There are four types of silk worm viz.

(i) Mulberry silk worm – *Bombyx mori* (ii) Eri silk worm – *Philosamia ricini*

(iii) Tassar silk worm – *Antheraea mylitta* (iv) Muga silk worm

Green HDPE Plastic Netrika or Plastic Chandrika HDPE Sericulture Net



Life cycle

Larva

Eggs

Moth

All stages of life cycle

Cocoon

Mullberry plant

Processing

Silk

10. Mushroom cultivation

Mushroom is an edible fungus with great diversity in shape, size and colour. Essentially mushroom is a vegetable that is cultivated in protected farms in a highly sanitized atmosphere. Just like other vegetables, mushroom contains 90% moisture with high in quality protein.

Species*:* There are three types of mushrooms popularly cultivated in India.

(i) Oyster mushroom – *Pleurotus sp*.

(ii) Paddy straw mushroom – *Volvariella volvacea*

(iii) White bottom mushroom – *Agaricus bisporus*

Method of production

(i) Oyster mushroom : Take fresh paddy straw and cut into small pieces of 3-5 cm length. Soak them in water for 4-6 hours and then boil for half an hour. Drain the water and dry the straw in shade till it is neither too dry nor wet. Take polythene bags of 60 x 30 cm size and make two holes of one cm diameter in the center of the bag such that they face opposite sides. Tie the bottom of the bag with a thread to make a flat bottom. Fill the bag with paddy straw to 10 cm height. Then inoculate with the spawn. Likewise prepare 4-5 layers of straw and spawn alternatively. The last layer ends up in straw of 10 cm height. Keep this in a spawn running room maintained at a temperature of about 22-28 ^{o}C and with RH 85-90%. After 15-20 days when the spawn running is completed, cut open the polythene bag and take it to cropping room and allow it to grow for 7 days and harvest the mushroom. Mushroom yield is around 0.5-1.0 kg/bag.

(ii) Paddy straw mushroom : Cut the straw into long pieces of 60-90 cm and soak in water for 12 hours and sterilize 15 minutes. Arrange the straw in bundles. Lay the moistened straw bundles on the slightly raised concrete floor or on wooden platform in layers of four bundles width. Spawn or seed the beds simultaneously in each layer either by broadcasting or placing the grain spawn at different spots. Sprinkle grain dhal over each layer on the spawn. Don't spawn below the topmost layer. Maintain it at 30-35 ^{o}C. Harvesting is ready after 25-30 days. Yield is around 1-1.5 kg/bed.

(iii) Button mushroom: It requires a complex method of preparing compost, which is used as a substrate for mushroom production. Spawning is done by three methods, *viz.*, surface spawning, layer spawning and trough spawning. Fill the trays with compost and do spawning. After spawning, compost is pressed hard to make it compact. The trays are arranged in the cropping room in tiers and cover with newspaper sheet sprayed with 2% formalin. The temperature of 20- 25 ^{o}C and RH of 90-95% should be maintained. After spawn running is completed in 15-20 days and do casing. Pin heads appear within 10-15 days after casing. Cropping continues for 60-75 days. Mushrooms can be harvested at button stage. Yield ranges from 6-7 kg/m^2.

11. Agroforestry

Agroforestry is a collective name for land use systems and technologies, in which woody perennials (trees, shrubs, palms, bamboos etc) are deliberately combined on the same

land-management unit as agricultural crops and/or animals, either in some form of spatial arrangement or in a temporal sequence.

In agroforestry systems, there are ecological and economical interactions among different components. That implies that: (i) agroforestry normally involves two or more species of plants (or plants and animals) at least one of which is woody perennials; (ii) an agroforestry system always has two or more outputs; (iii) the cycle of an agroforestry system is always more than one year; and (iv) even the simplest agroforestry system is structurally, functionally, and socio-economically more complex than a monocropping system. Agroforestry is important for meeting fodder, fuel wood and small timber of farmers, conserving soil and water, maintenance of soil fertility, controlling salinity and water logging, positive environment impact and alternate land use for marginal and degraded lands. Selection of proper land use systems conserve biophysical resources of non-arable land besides providing day-to-day needs of farmer and livestock within the farming system.

Different commonly followed agro-forestry systems in India are:

(1) Agri-silviculture (crops + trees), which is popularly known as farm forestry

(2) Agri-horti-silviculture (crops + fruit trees + MPTS + pasture);

(3) Silvi-pasture (Trees + pasture + animals);

(4) Horti-silvi-pasture (fruit trees + MPTs+ Pasture);

(5) Agri-silvi-pasture (crops + trees + Pasture);

(6) Pastoral silvicultural system

(7) Agri-horticulture (crops + fruit trees)

(8) Homestead agroforestry (multiple combination of various components);

(9) Silvi-apiculture (trees + honey bees);

(10) Agri-pisci-silviculture (crops + fish + MPTS);

(11) Pisci-silviculture (Fish + MPTs) etc.

(1) Agri-silviculture systems: This system emphasizes raising of trees and cultivation of field crops and/or fodder crops in the available space between the trees. In arid and semi-arid regions hardy trees like *Prosopis cineraria* (*Khejri*), *Eucalyptus sp*., *Acacia tortilis*, *Hardwickia binata* (Anjan), *Azadirachta indica (*Neem), *Ailanthes excelsa*, *Ziziphus jujuba* etc. could be grown along with dry land crops such as pulses (pigeonpea, blackgram), millets (finger millet, sorghum) etc. This is practiced mostly on arable lands, wherein multipurpose trees used for fuel and fodder can be grown with crops in the fields as alley farming. The hedges follow contour and compromise trees and shrubs like *Leucaena* or pigeonpea. Leguminous perennials are more suitable due to fixation of nitrogen.

(2) Agri-horti-silviculture: In this system fruit trees are grown along with crops and multipurpose trees (MPTs). Under rainfed situation hardy fruit trees like ber, aonla, pomegranate, guava could be grown along with dryland crops like pigeonpea, til, mothbean, mustard etc. Grafted ber (Var., Gola, Seb, Mundiya, Banarasi Kasak) may be planted at 6 x 6 m with 2 plants of subabul in between.

Under partial irrigation, Guava, pomegranate, Lemon, Kinnow have been successfully grown at 6 x 5 m along with crop like wheat, groundnut and subabul (200 pl/ha) for quick leaf fodder and fuel wood production. For further protecting fruit crops from desiccating hot summer and cold winter planting of subabul/sesbania at every 2 m apart as wind breaks. Alternate plants of subabul/sesbania could be harvested for quick fodder and fuel wood production every 3rd year. Relative grain yield was 70-85% even in 3rd and 4th year.

(3) Silvi-Pastoral system: In the silvi-pastoral system, improved pasture species are introduced with tree species. In this system grasses or grass legume mixture is grown along with the woody perennial simultaneously on the same unit of land. In the marginal, sub-marginal and other degraded lands silvipastoral system has been found to be most economic agroforestry system especially in arid and semi-arid regions. It involves lopping trees and grazing understory grasses and bushes in forests or plantations. It helps in reduction of the cost of concentrated feed to

animal during lean period. A number of fodder trees like *Leucaena latisiliqua, Bauhinia variegata, Albizzia labbek, Albizzia amara, Moringa olerifera, Sesbania sesban, S. grandiflora, Hardwickia binata* are identified for different regions of the country for silvi pastoral systems. Trees provide fuel and timber in the extreme dry season and lean periods, animal graze on pastures and feed on the leaves of nutritious trees and shrubs. Multilayered vegetation covers are very effective in controlling run-off and soil loss from erosion prone areas.

(4) Horti-silvi-pasture system: It involves integration of fruit trees with pasture. In the degraded arid and semi arid rangeland regimes number of over grazed plants of *Ziziphus nummularis* are found which could be successfully budded with improved variety of ber (*viz.*, Gola, Seb, Umran, Banaras, Kaska) besides planting MPTs like anjan, Subabul, *Khejri* along grasses and legumes like *Cenchrus, Lasiurus, Chrysopogon, Stylosanthes, Sirato* etc.

(5) Agri-silvi-pasture: It is a combination of agri-silviculture and silvi-pastoral system. In arid degraded lands of Rajasthan, Gujarat and Haryana often dryland crops viz. bajra, moth, urad, til

etc. are grown in strips along with grass strips to avoid shifting sand reaching cropped area. MPTs could be introduced both in the pasture strips as well as in the crop strips, which besides protecting the crops from desiccating hot and cold wind would also provide leaf fodder, timber etc. besides pasture when there is a crop failure. Woody plants could be *Acacia senegal*, ber, anjan, neem etc. Grasses like *Cenchrus, Lasiurus* and legume *Stylo spp*.

(6) Pastoral silvicultural system: Integrated crop farming is practiced to meet the requirements of grasses and fodder for livestock. The pastoral silvicultural system is the practice in which grazing is the main component with scattered trees grown in the area. This practice is adopted in semi-arid regions of the country comprising the states of Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Madhya Pradesh.

The cultivators leave the fields fallow with existing trees and protect the same. *Dichanthium annulatum* is an important grass under this system. The important planted trees in the system are *Eucalyptus* hybrid, *Casuarina equisetifolia, Borassus flabellifa* and *phoenix sylvestris.* Generally trees are lopped for fuel and fodder. Custard apple, mango, Zizyphus and tamarind fruits are used for domestic consumption.

12. Biogas

A biogas unit is an asset to a farming family. It produces good manure and clean fuel and improves sanitation. Biogas is a clean, unpolluted and cheap source of energy, which can be obtained by a simple mechanism and little investment. The gas is generated from the cow dung during anaerobic decomposition. Biogas generation is a complex biochemical process. The celluloitic material is broken down to methane and carbondioxide by different groups of microorganisms. It can be used for cooking purpose, burning lamps, running pumps etc.

Selection of a model:

The two main designs of biogas plants are the floating gas holder and fixed-dome types. The merits and demerits of each design need to be considered while selecting a model.

(i) Float dome type: Different models are available in this category e.g., KVIC vertical and horizontal, Pragati model, Ganesh model.

(ii) Fixed dome type: The gas plant is dome shaped underground construction. The masonary gasholder is an integral part of the digester called dome. The gas produced in the digester is collected in dome at vertical pressure by displacement of slurry in inlet and outlet. The entire construction is made of bricks and cement. The models available in this category are Janata and Deen-Bandhu.

Selection of Size:

The size of the biogas plant is decided by the number of family members and the availability of dung. One cubic meter capacity plant will need two to three animals and 25 kg of dung. The gas produced will meet the requirement of a family of 4-6 members. It would suffice to have a 2 cubic meter plant to cater to the needs of a family of 6-10 members.

Biogas slurry:

Slurry is obtained after the production of bio-gas. It is enriched manure. Another positive aspect of this manure is that even after weeks of exposure to the atmosphere, the slurry does not attract fleas and worms.

Factors influencing the selection and size of components in farming systems

1. Climatic conditions - Rainfall, temperature, solar radiation, wind, humidity, etc.
2. Soil type
3. Farmers preferences
4. Size of the Farm
5. Knowledge, skill and technology
6. Storage, transport and marketing
7. Resource mobilizing power of the farmer
8. Credit facilities available
9. Socio-economic condition
10. Customs, sentiments and believes

IFS for different agro-climatic zones (India)

1. *High altitude cold deserts:* Pastures with forestry, goats, angora rabbits and limited settled agricultural crops like millets, wheat, barley and fodder.
2. *Arid and desert region*: Centering mainly in animal husbandary with the camels, sheep and goat and with moderate cropping components involving pearlmillet, wheat, pulses, gram and fodder crops.
3. *Western and central Himalayas:* Horticultural crops as major component have less intensive agriculture mainly on the hill terraces and slopes with maize, rice, wheat, pulses and fodder crops.
4. *Eastern Himalayas:* Primitive crop husbandry with rice, millets, pulses etc. Agro- forestry system is also common. Piggery and poultry are the chief livestock activity.
5. *Indo-Gangetic plains:* Intensive crop husbandry involving rice, wheat, maize, mustard, pulses and livestock inclusive of dairy cattle and buffaloes.
6. *Central and southern highlands:* Cotton, sorghum, millet, pulses with dairy cattle, sheep and goats and poultry are the secondary livestock and animal husbandry enterprises.

7. *Western Ghats:* Major activity on plantation crops, cultivation of rice and pulses are the secondary agricultural activity. Cattle, sheep and goats are the livestock components which in most parts are maintained as large herds and allowed to range.

Delta and Coastal plains: Rice cultivation along with fish culture, poultry and piggery enterprises, capture fisheries of the marine ecosystem is a specialized enterprise and does not mix with cropping activity.

Criteria for enterprise selection

The basic points that are to be considered while choosing appropriate enterprise in IFS are:

1. Soil and climatic features of an area/locality.
2. Social status of the family and social customs prevailing in the locality.
3. Economical condition of the farmer (return/income from the existing farming system).
4. Resource availability at farm and present level of utilisation of resources.
5. Economics of proposed IFS and credit facilities.
6. Farmer's managerial skills.
7. Household demand.
8. Institutional infrastructure and technological know-how.
9. Market facilities.

The IF (integrated farming) is system oriented multi-component agriculture. It views the farming in a holistic manner emphasizing the interactions between components. Given the multi-biological components as its central part, integrated farming is a complex biological- social-economic system. Final goal of management is to seek for the integrated effects of the whole system, not the effects of its individual components (Fig.7.1)

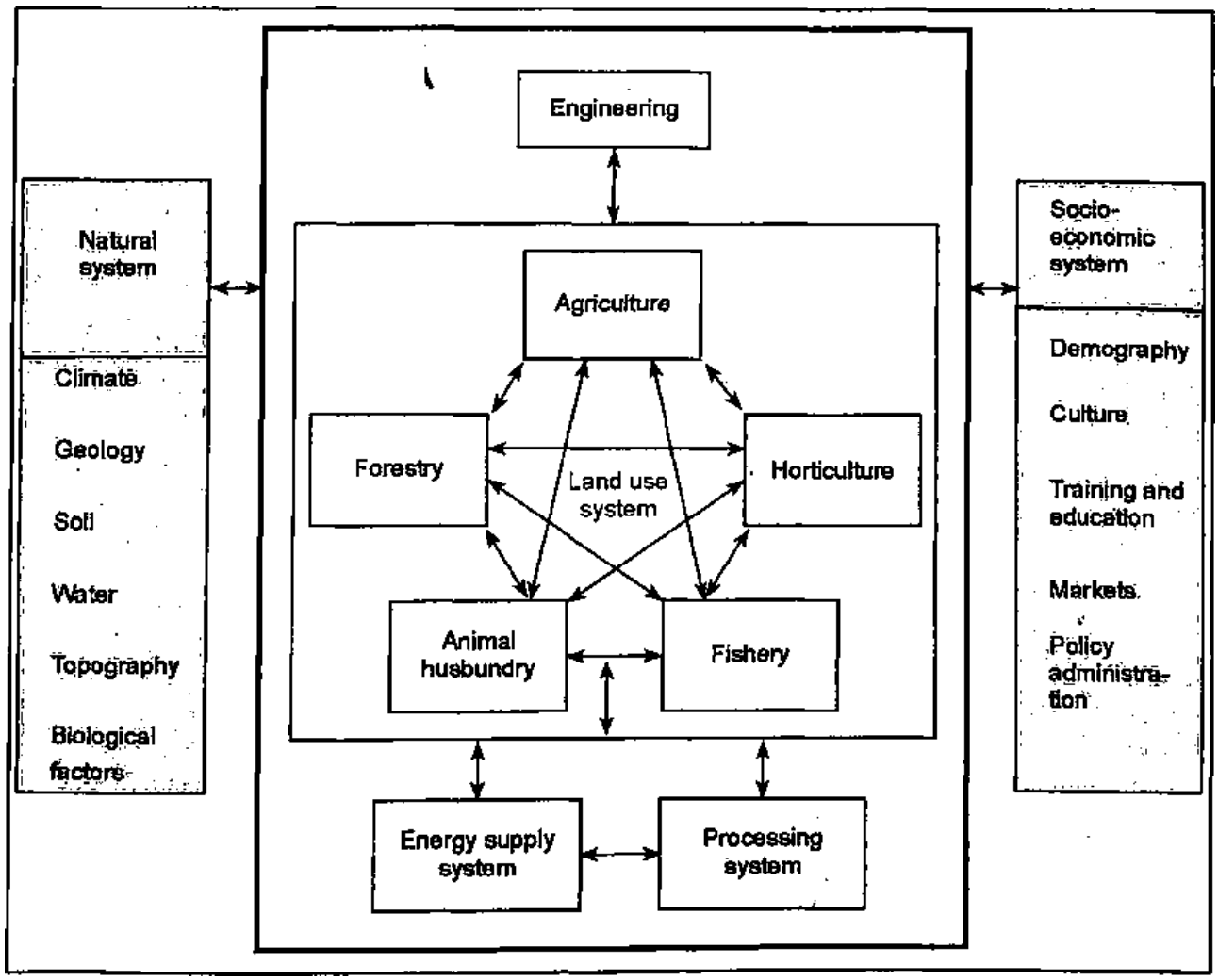


Fig.7.1 Structure of an IFS

Steps for preparation of a model integrated farming system to a specific situation:

1. Assessment of available resources
2. Identifying the existing cropping system
3. Identifying component(s) to be integrated
4. Fixing the size of the individual components
5. Working out the requirement of the components
6. Modifying the existing cropping system to suit the requirements of the components integrated
7. Working out the economics of individual components and for the IF system as a whole
8. Identifying constraint and suggesting remedy measures/modifications for technical feasibility, economic viability and practical utility.
9. Indigenous technological knowledge (ITK).

Chapter 8: IFS MODEL

There are mainly 3 IFS model systems for different agro-climatic zones.

A. Wetland integrated farming system

Cropping in low land (Wetland) is considered to be less risky due to abundant availability of water. In addition, most of the low land soils are heavy type of soils, which are fairly fertile soil. *Mostly rice is the principle crop in our low lands.* Crops like Banana, Sugarcane and Coconut are also grown in this ecosystem. Diversified farming (IFS) can be adopted in the low lands with the components like Fish, Duck and Mushroom. The possible IFS that can be practiced using these components are

Example:

a) Rice + Fish + Azolla
b) Rice + Fish + Duck
c) Rice + Fish + Mushroom

B. Irrigated upland

The possibility of having a viable integrated farming system in irrigated uplands is possible. The control and management of available resources in more effective manner paves way to integrate two are more components with cropping.

There is a lot of choice of components in irrigated upland compared to lowlands and *rainfed* lands. Wide range of crops and varieties can be grown. Effective resource utilization and management is possible due to controlled irrigation system.

Components like Dairy, poultry, goat, sheep, piggery, sericulture, apiculture, *etc.* can be easily integrated in an irrigated upland farm. In addition perennial trees like coconut and other fodder and multipurpose farm forestry trees can be grown along the borders of the fields and boundary of the farm.

1. Crop + dairy + biogas unit
2. Crop + poultry + biogas unit
3. Crop + sheep / goat rearing + biogas unit
4. Crop + sericulture
5. Crop + piggery
6. Crop + sericulture + biogas unit
7. Crop + dairy + biogas unit + homestead garden
8. Crop + dairy + biogas unit + vermicompost

C. Dry land ecosystem

The dry land ecosystem is characterized by :

1. Inadequate and uneven distribution of rainfall
2. Poor and marginal soils
3. Low cropping intensity
4. Limited crop diversification

5. Low value crops
6. Poor resource mobilizing power of farmers

The agriculture in drylands is seasonal. The cropping season is restricted to 4-5 months and people remain without employment for rest of the year. Diversification of cropping by integrating with components like livestock (Sheep/Goat rearing), silviculture, horticulture tree crops and pastures would improve the standard of living and employment opportunities of the dryland farmers.

Integrated farming system is a boon to dry land farmers. When compatible components/ allied activities/ associated enterprises are suitably combined, farming in drylands becomes less risky and remunerative. IFS on a watershed approach are the best way of alternative agriculture in dryland areas. The following components are identified as appropriate to dryland situations.

Possible combinations are

1. Crop + silvipasture + goat / sheep rearing
2. Crop + silviculture + hort. fruit trees
3. Crop + agro-forestry + goat + farm pond
4. Crop + silvipasture + goat + pigeon + farm pond
5. Crop + silvipasture + buffalo + farm pond

IFS model in Gujarat

In Gujarat, this project is being operated under GAU since its inception in the year 1972 with two components *viz.*, "Model agronomic experiments" with three centres at Sardarkrushinagar, Junagadh and Navsari for on station research and "Simple fertilizer trials". Prior that it was functioning under State Government. The head quarter of the project is located at Sardarkrushinagar.

As per Gujarat Government Gazette on 6th March, 2004, the Gujarat Agricultural University was dissolved and formatted four new Agricultural Universities as AAU, Anand, NAU, Navsari, JAU, Junagadh and SDAU, Sardarkrushinagar.

At present, Main On Station Integrated Farming System Research Centre, Sardarkrushinagar is working under SDAU, Sardarkrushinagar and sub centres of FSR, Junagadh under Junagadh Agricultural University and Navsari under Navsari Agricultural University.

The mandates of IFS

1. Identification of sustainable and profitable cropping sequences to suit the specific needs of different Agro-climatic regions.
2. To develop capacity building of stakeholders in Integrated Farming Systems through training.
3. To characterize existing farming systems to know the productivity, viability and constraints.
4. To develop resource efficient, economically viable and sustainable integrated farming system model.

IFS Model at S. D. Agricultural University

Sr. No.	Enterprises identified	Area (ha)	Treatment/Remarks
1	Crops and cropping system	0.70	Cropping Systems: • C_1: Castor + Green gram (0.32) • C_2: groundnut - Wheat – Multicut Fodder Rajka Bajra (0.08) • C_3: Green gram - Mustard – Pearl millet (0.24) • C_4: Hybrid Napier + Cowpea(F) -Lucerne + Fodder Chicory (0.06)
2	Multistoried horticulture fruits and vegetables	0.25	Fruit trees: • Mango: 8m x 8m (40 plants) • Lemon: In between two rows at 4 m distance (80 plants) • Custard apple: In between 2 plants of mango (36 plants) • Seasonal Vegetables in between fruit trees
3	Boundary plantation	-	Boundary plantation: • Timber wood/Fruit/Vegetable/ Medicinal plants 1. Ardusa: 101 6. Mulberry: 03 2. Eucalyptus: 10 7. Drum stick: 15 3. Subabool: 10 8. Aonla: 03 4. Custard apple: 10 9. Bamboo: 01 5. Jambun: 04 10. Teak: 35 • Fodder crops: *Dhaman* and Hybrid Napier on bunds
4	Livestock	0.025	Mehsani breed buffalo (Two)
5	Vermicompost, compost and nursery unit	0.010	Use of FYM, Farm wastes and cattle feed wastage
6	Water harvesting for recharging	0.015	IR is 15cm/hr. Source of irrigation is tube well. Water table is increasing at present
Total		1.000	-

Economics of different components of IFS during year 2017-18 of SDAU

Name of component	Year of commencement	Area allotted (m^2)	Total cost (`/ha)	Gross return (` /ha)	Net return (`/ha)
1. Cropping systems	2010-11	7000	88621	137297	48676
2. Multistoried Horticulture Fruits and Vegetables	2010-11	2500	35778	45375	9598
3. Boundary plantation	2010-11		6340	83528	77188
4. Livestock + Vermicompost, compost and nursery unit	2010-11	350	82848	152292	69444
5. Water recharging	2010-11	150	0	0	0
Total		**10000**	**213586**	**418492**	**204906**

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SYLLABUS

ICAR-Revised syllabus for B.Sc. (Agri.) programme, as suggested by the Fifth Deans' Committee on Higher Education in India

GEOINFORMATICS FOR PRECISION FARMING

CREDIT HOURS: 2 (1+1)

THEORY

Precision agriculture: concepts and techniques: their issues and concerns for Indian agriculture: Geo-informatics- definition, concepts, tool and techniques; their use in precision agriculture. Crop discrimination and yield monitoring, soil mapping; fertilizer recommendation using geospatial technologies; Spatial data and their management in GIS; Geodesy and its basic principles; Remote sensing concepts and application in agriculture; Image processing and interpretation; Global positioning system (GPS), components and its functions, System Simulation- Concepts and principles, Introduction to crop Simulation Models and their uses for optimization of Agricultural Inputs; STCR approach for precision agriculture.

PRACTICAL

Introduction to GIS software, spatial data creation and editing. Introduction to image processing software. Visual and digital interpretation of remote sensing images. Generation of spectral profiles of different objects. Supervised and unsupervised classification and acreage estimation. Multispectral remote sensing for soil mapping. Creation of thematic layers of soil fertility based on GIS. Creation of productivity and management zones. Fertilizers recommendations based of VRT and STCR techniques. Crop stress (biotic/abiotic) monitoring using geospatial technology. Use of GPS for agricultural survey.

CHAPTER-1: PRECISION AGRICULTURE

Precision agriculture (PA) or precision farming (PF) aims at optimizing profitability and protecting environment through efficient use of inputs based on temporal and spatial variability of soils and crops. Both sensor based and satellite image based technologies have been developed and are being promoted in the developed world. Economic analyses of adoption of precision farming have indicated marginal profitability to already existing best management practices (BMPs) and higher productivity levels. Wide gap between potential and actual yield levels in developing world necessitates promotion of PF to achieve the intended benefits.

Gap between average farm yields and yield potential ceiling must shrink during the next 5 years because the yield potential of major crops appears to be stagnant. Rice, maize and wheat yield potentials are increasing more slowly than the expected increase in demand. Hence sustainable crop yields that exceed at least 70 per cent of yield potential barrier depend on sophisticated management of soil, water resources and other inputs. Precision agricultural approach is required to insure that the requisite resources for crop growth are available and crop protection needs are met without deficiency or excess at each point in time during the growing season. Precision management can be applied based on the requirement to the field at right time, right place, right quantity and by right method.

CONCEPTS OF PRECISION FARMING

Precision farming basically depends on measurement and understanding of variability. Main components of precision farming system must address the variability. Precision farming is a farm management concept based on modern information technologies. Components (enabling technologies) of precision farming include:

- Remote sensing (RS).
- Geographical information system (GIS).
- Global positioning system (GPS).
- Soil testing.
- Yield monitors.
- Variable rate technology (VRT).

Precision farming needs the requisition, management, analysis and output of large amount of spatial and temporal data. Mobile computing systems were needed to function on the go in farming operations because desktop systems in the farm office were not sufficient. Precision farming is concerned with spatial and temporal variability and it is information based and decision focused. It is the spatial analysis capabilities of GIS that enable precision agriculture. The GPS and DGPS has greatly enabled precision farming and of great importance to precision farming, particularly for guidance and digital evaluation modeling position accuracies at the centimeter level are possible in differential global positioning system (DGPS) receivers. In India,

we have all these technologies available and they can be implemented through agricultural training centers by giving training to agriculture officers in these technologies.

Precision agriculture is a phrase that captures the imagination of many concerned with the production of food, feed and fiber. The concept of precision agriculture offers the promise of increasing productivity while decreasing production cost and minimizing environmental impacts. Precision agriculture conjures up images of farmers overcoming the elements with computerized machinery that is precisely controlled via satellites and local sensors and using planning software that accurately predicts crop development. This image has been called the future of agriculture.

In Indian contest, precision farming may be defined as an accurate application of agricultural inputs for crop growth, considering relevant factors such as soil, weather and crop management practices. It is actually information and technology based farming system where inputs are managed and distributed on a site-specific basis for long-term benefits.

Precision farming system (PFS) is based on the recognition of spatial and temporal variability in crop production. Variability is accounted for in farm management with the aim of increasing productivity and reducing environmental risks. In developed countries, farms are often large (sometimes 1000 ha or more) and comprise several fields. The spatial variability in large farms, therefore, has two components: within-field variability and between-field variability. The concepts of PF can be presented as shown in Fig 1.1.

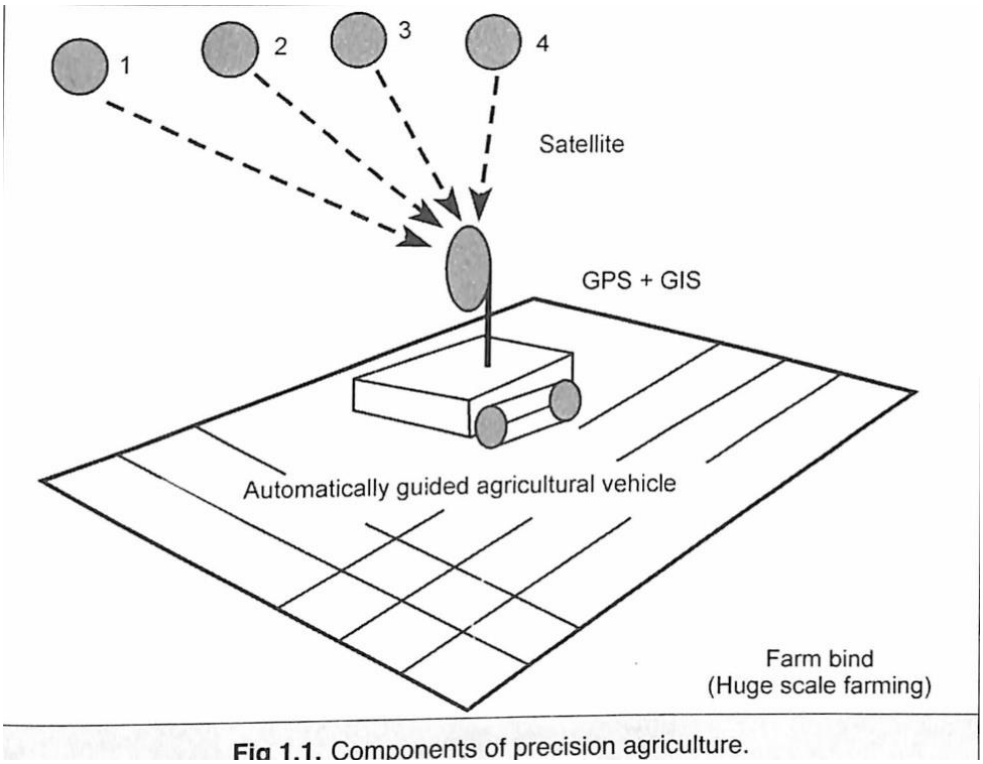


Fig 1.1. Components of precision agriculture.

Precision farming system within a field is also referred to as site-specific crop management (SSCM). According to the Second International Conference on Site-Specific Management for Agricultural Systems, held in Minneapolis, Minnesota, in March 1994 precision farming or SSCM refers to a developing agricultural management system that promotes variable management practices within a field according to site or soil condition, (national Research Council 1997).

However, according to Batte and Van Buren (1999), SSCM is not a single technology but an integration of technologies permitting:

1. Collection of data on an appropriate scale at a suitable time.
2. Interpretation and analysis of data to support a range of management decisions.
3. Implementation of management response on appropriate scale and at suitable time.

Precision farming is concept of using the new technologies and collected field information. Precision farming provides farmers with a tool to apply fertilizer according to the need of a particular sub-field and no longer based on the average of the field. The savings made with this variable application can be fairly large. Precision farming technology would be a viable alternative to improve profitability and productivity (Fig 1.2).

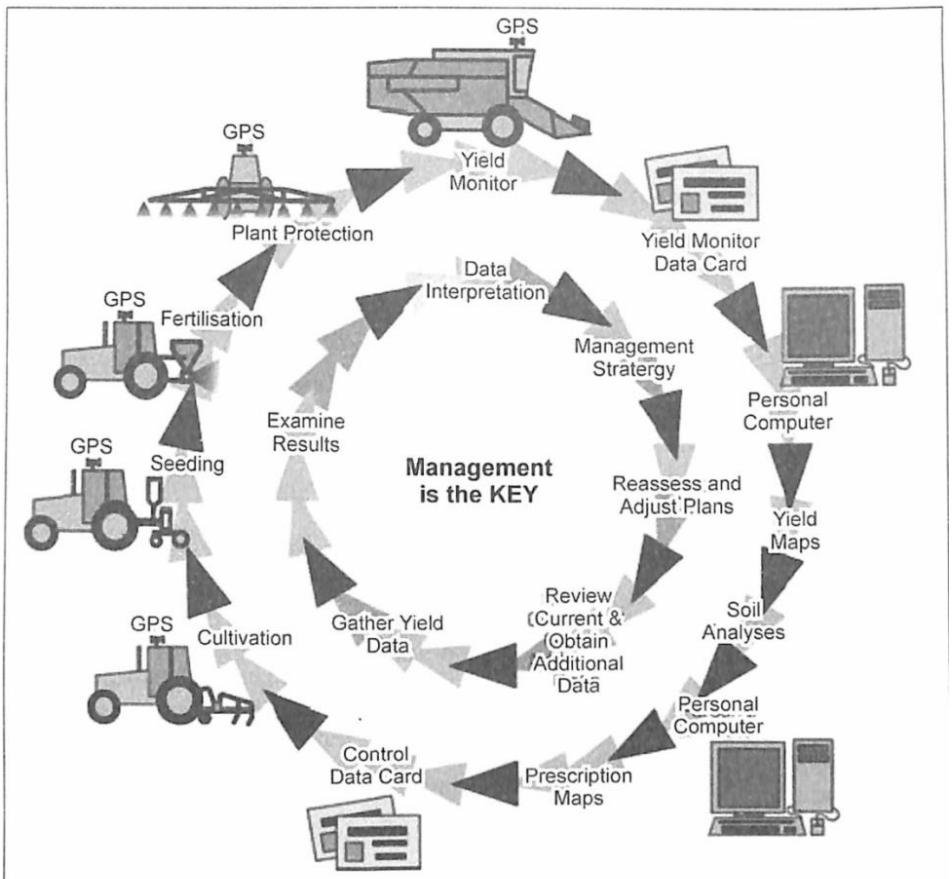


Fig 1.2. Precision agriculture: a comprehensive approach.

Precision agriculture can be presented as management of three conceptual components: data collection, data analysis/interpretation and application/variable rate treatment. Another way of presenting these components is shown in Fig l.3, in the form of cycles and the technology/operations involved in SSCM.

Production of food, feed and fiber are dependent on the quantity and quality of soil, plant, water and air. No matter what agricultural systems are used, without protecting the natural resources, yields will decrease until the point of no return. The concept that precision agriculture is a system, (Webster: interrelated, interacting, independent elements forming a complex whole), provides a more useful foundation for understanding precision agriculture. An agricultural system that can be used for:

- Land preparation.
- Seeding.
- Chemical application.
- Fertilizer application.
- Crop monitoring.
- Nutrient auditing.
- Soil and leaf testing.
- Pest management.
- Conservation practices.
- Gross margin analysis.

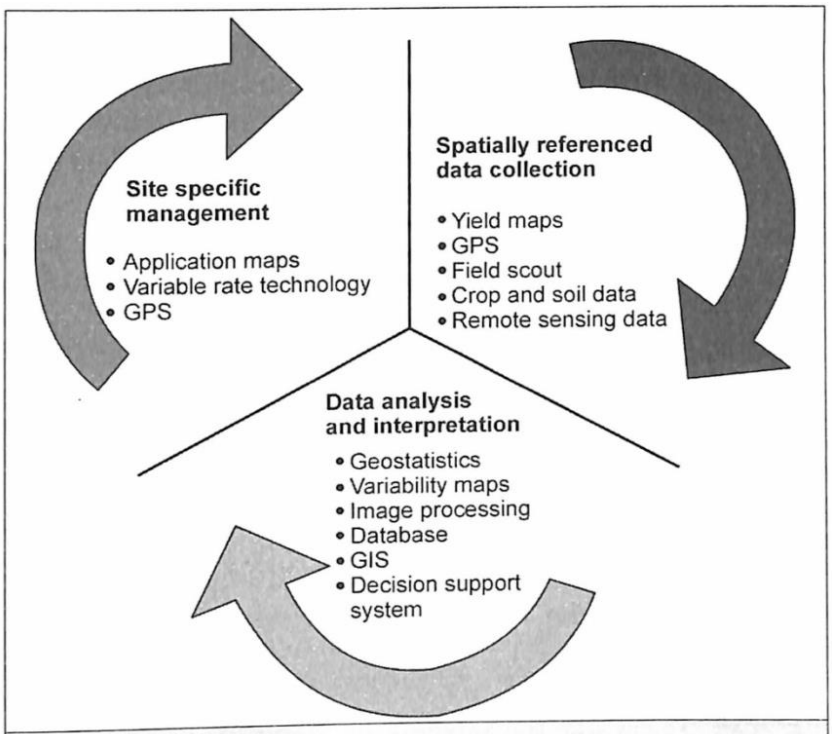


Fig 1.3. Data processing and management cycles for precision farming.

In other way, precision agriculture (PA) can loosely be defined as the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for improving production and environmental quality. Simply put, precision agriculture can help farmers improve their margins by decreasing their operating costs. The biggest benefit of precision farming is that it gives producers the ability to manage their farm on a production zone basis rather than a whole field basis. This shift allows farmers to save time and money and helps them offset the rising cost of chemicals, nutrients, fuel and fertilizer.

Agro-geo-information, the agricultural-related geo-information, is the key information in the agricultural decision making and policy formulation process. Agro-geo-informatics, a branch of geo-informatics, is the science and technology about handling digital agro- geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, and analyzing, synthesizing, presenting and disseminating agro-geo-information. Recent advances in geo-informatics have created new opportunities and challenges in applying agro-geo-informatics to agriculture monitoring, assessment and decision making.

STEPS IN PRECISION FARMING

Two basic steps in precision agriculture are: (1) Identification and assessment of variability and (2) Management of variability.

1. Identification and Assessment of Variability

Grid soil sampling: Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling compared to the traditional sampling. Soil samples collected in a systematic grid also have location information that allows the data to be mapped. The goal of grid soil sampling is to generate a map of nutrient/water requirement, called an application map.

Yield map: Yield mapping is the first step to determine the precise locations of the highest and lowest yield areas of the field and to analyze the factors causing yield variation. One way to determine yields map, is to take samples from the land in a 100 x 100 m grid pattern to test for nutrient levels, acidity and other factors. Results can then be combined with the yield map to see if application levels need to be adjusted for more effective, yet more economical placement that produces higher crop yields.

Crop scouting: In-season observations of crop conditions like weed patches (weed type and intensity); insect or fungal infestation (species and intensity) and crop tissue nutrient status can be helpful later when explaining variations in yield maps.

Use of precision technologies for assessing variability: Faster and in real-time assessment of variability is possible only through advanced tools of precision agriculture.

2. Management of Variability

Variable rate application: Grid soil samples are analyzed in the laboratory and an interpretation of crop input (nutrient/water) needs is made for each soil sample. Then the input application map is plotted using the entire set of soil samples. The input application map is loaded into a computer mounted on a variable-rate input applicator. The computer uses the input application map and a GPS receiver to direct a product-delivery controller that changes the amount and/or kind of input (fertilizer/water), according to the application map.

Yield monitoring and mapping: Yield measurements are essential for making sound management decisions. However, soil, landscape and other environmental factors should also be weighed when interpreting a yield map. Used properly, yield information provides important feedback in determining the effects of managed inputs such as fertilizer amendments, seed, pesticides and cultural practices including tillage and irrigation. Since yield measurements from a single year may be heavily influenced by weather, it is always advisable to examine yield data of several years including data from extreme weather years that helps in pinpointing whether the observed yields are due to management or climate induced.

Quantifying on farm variability: Every farm presents a unique management puzzle. Not all the tools described above will help determine the causes of variability in a field and it would be cost-prohibitive to implement all of them immediately. An incremental approach is a wiser strategy, using one or two of the tools at a time and carefully evaluating the results and then proceeding further.

Flexibility: All farms can be managed precisely. Small-scale farmers often have highly detailed knowledge of their land based on personal observations and could already be modifying their management accordingly. Appropriate technologies Here might make this task easier or more efficient. Larger farmers may find the more advanced technologies necessary to collect and properly analyze data for better management decisions.

Advantages of PFS to farmers

1. Overall yield increase: Precise selection of crop varieties, application of exact types and doses of fertilizers, pesticides and herbicides and appropriate irrigation meet the demands of crops for optimum growth and development. This leads to yield increase, especially in areas or fields where uniform crop management practices were traditionally practised.
2. Efficiency improvement: Advanced technologies, including machinery, tools and information, help farmers to increase the efficiency of labour, land and time in farming. In developed countries like United States, a mere 2 hours are sufficient to grow 1 ha of wheat or maize.
3. Reduced production costs: Application of exact quantities at the appropriate time reduces the cost of agrochemical inputs in crop production. In addition, the overall high yield reduces the cost per unit of output.
4. Better decision-making in agricultural management: Agricultural machinery, equipment and tools help farmers acquire accurate information, which is processed and analysed for

appropriate decision making - in land preparation, seeding, fertilizer, pesticide and herbicide application, irrigation and drainage and post production activities.

5. Reduced environmental impact: Timely application of agrochemicals at an accurate rate avoids excessive residue in soils and water and thus reduces environmental pollution.
6. Accumulation of farmers' knowledge for better management with time: All PFS Field activities produce valuable field and management information and the data are stored in tools and computers. Farmers can thus accumulate knowledge about their farms and production systems to achieve better management.

TOOLS and TECHNIQUES

In addition to mechanization, other tools and equipment (techniques) used in PF, are briefly presented.

1. Global Positioning System (GPS)

The GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m. GPS allows farmers to locate the exact position of field features, such as soil type, pest occurrence, weed invasion, water holes, boundaries and obstructions. There is an automatic controlling system, with light or sound guiding panel (DGPS), antenna and receiver. GPS satellites broadcast signals that allow GPS receivers to calculate their position. In many developed countries, GPS is commonly used as a navigator to guide drivers to a specific location.

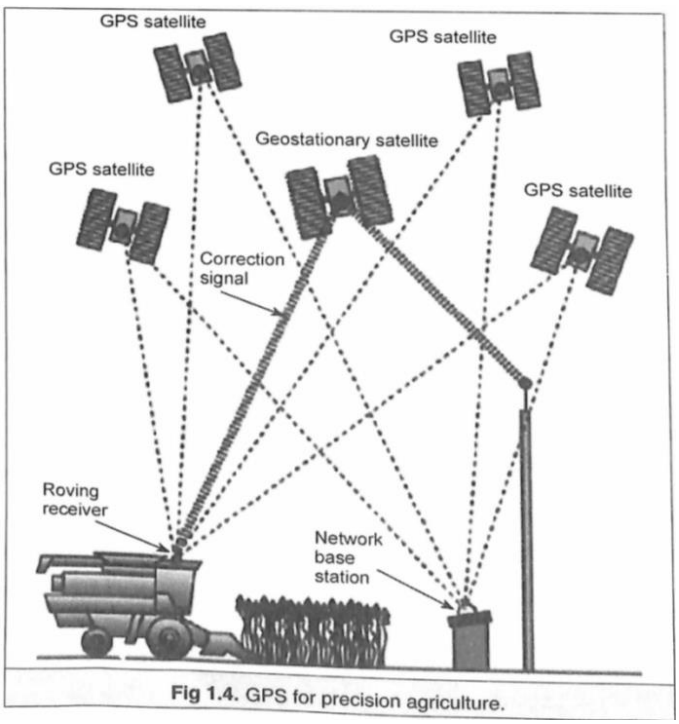


Fig 1.4. GPS for precision agriculture.

The GPS provides the same precise guidance for field operations. The system allows farmers to reliably identify field locations so that inputs (seeds, fertilizers, pesticides, herbicides

and irrigation water) can be applied to an individual field, based on performance criteria and previous input applications. Specific advantages of GPS in farm operations include:

1. Farm machines are guided along a track hundreds of meters long making only centimetre scale deviations.
2. Rows are not forgotten and overlaps are not made.
3. Number of rows can be counted during work.
4. Tools and equipment can be operated in the same way from year to year.
5. It is possible to work at night or in dirt with precision.
6. The system is not affected by wind.
7. An additional recorder can store field information to be used in making a map.

2. Sensor Technologies

Various technologies - electromagnetic, conductivity, photo-electricity, ultrasound- are used to measure humidity, vegetation, temperature, vapour, air etc. Remote sensing data are used to: distinguish crop species, locate stress conditions, discover pests and weeds and monitor drought, soil and plant conditions. Sensors enable the collection of immense quantities of data without laboratory analysis. The specific uses of sensor technologies in farm operations are as follows:

1. Sense soil characteristics: Texture, structure, physical character, humidity, nutrient level and presence of clay.
2. Sense colours to understand conditions relating to: Plant population, water shortage and plant nutrients.
3. Monitor yield: Crop yield and crop humidity.
4. Variable rate system: To monitor the migration of fertilizers and discover weed invasion.

3. Geographic Information! System (GIS)

Use of GIS began in 1960. This system comprises hardware, software and procedures designed to support the compilation, storage, retrieval and analysis of feature attributes and location data to produce maps. GIS links information in one place so that it can be extrapolated when needed. Computerized GIS maps are different from conventional maps and contain various layers of information (yield, soil survey maps, rainfall, crops, soil nutrient levels and pests). GIS helps convert digital information to a form that can be recognised and used. Digital images are analyzed to produce a digital information map of the land use and vegetation cover. GIS is a kind of computerized map, but its real role is using statistics and spatial methods to analyze characters and geography. Further information is extrapolated from the analysis. A farming GIS database can provide information on: filed topography, soil types, surface drainage, subsurface drainage, soil testing, irrigation, chemical application rates and crop yield. Once analyzed, this information

is used to understand the relationships between the various elements affecting a crop on a specific site.

4. Variable-Rate Technologies (VRT)

Variable rate technologies (VRT) are automatic and may be applied to numerous farming operations. The VRT systems set the rate of delivery of farm inputs depending on the soil type noted in a soil map. Information extrapolated from the GIS can control processes, such as seeding, fertilizer and pesticide application and herbicide selection and application, at a variable (appropriate) rate in the right place at the right time. The VRT is perhaps the most widely used PFS technology.

5. Grain Yield monitors For Mapping

A monitor mounted on a combine continuously measures and records the flow of grain in the grain elevator. When linked with a GPS receiver, yield monitors can provide data for a yield map that helps farmers to determine the sound management of inputs, such as fertilizer, lime, seed, pesticides, tillage and irrigation.

CROP MANAGEMENT

Precision farming system employs the innovations and technologies described above. With satellite data, farmers have a better understanding of the variation in soil conditions and topography that influence crop performance within the field. Farmers can, therefore, precisely manage production factors, such as seeds, fertilizers, pesticides, herbicides and water control, to increase yield and efficiency. The management scheme of typical PFS comprises the following practical steps:

1. Determine management zones to be applied with PFS.
2. Establish yield goals.
3. Carry out soil sampling and data interpretation.
4. Make decisions regarding management of land preparations, varieties, fertilizers and other nutrients to achieve yield goals.
5. Establish maps to discover the pest population: insects, diseases and weeds, using an integrated pest management (IPM) approach.
6. Apply precision irrigation.
7. Apply logging and automated record keeping.
8. Monitor and establish yield maps, evaluate PFS response and identify strengths and weaknesses for future improvement.

DEVELOPING SYSTEM TECHNOLOGY FOR PF

Developing system technology for precision farming is shown in Fig 1.5. First of all, it is necessary to describe and understand the variability within and between fields. Field sensors with GPS and monitors for machine application make this easier. The next stage is to develop machines, which can be operated by remote control.

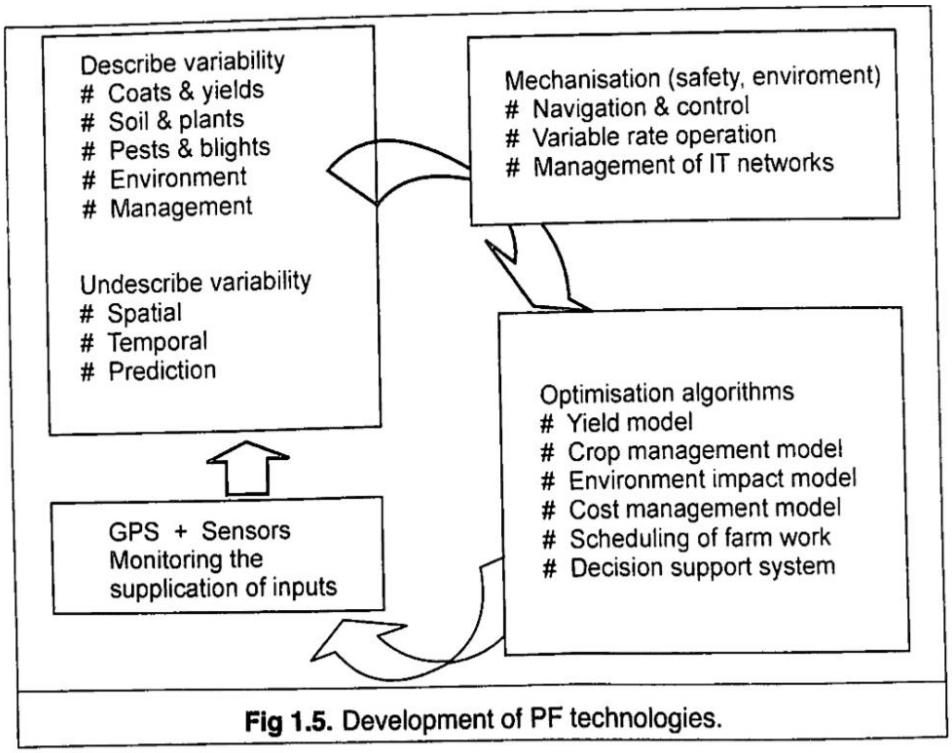


Fig 1.5. Development of PF technologies.

There are three steps in technology development and three strategies for precision farming.

Step 1: is based on conventional farming technology, with intensive mechanisation to reduce the labour input.

Step 2: involves the development of mapping techniques.

Step 3: implies the maturity of wisdom-oriented technologies.

Scenario 1 is based on a "high-input and high-output" conventional strategy. Scenario 2 has a strategy for "low-input but constant-output". Scenario 3 aims at "optimized input- output" as the goal of precision farming. Advanced technology levels allow us to choose freely between these three scenarios. Effective regulations will encourage progress in precision farming.

Precision Farming Concerns for Indian Agriculture

Farmers in developed countries typically own large farms (10-1000 ha or more) and crop production systems are highly mechanized in most cases. Large farms may comprise several fields in differing conditions. Even within a relatively small field (<30 ha) the degree of pest infestation, disease infection and weed competition may differ from one area to another.

In conventional agriculture, although a soil map of the region may exist, farmers still tend to practice the same crop management throughout their fields: crop varieties, land preparation, fertilizers, pesticides and herbicides are uniformly applied in spite of variation. Optimum growth

and development are thus not achieved. Furthermore, there is inefficient use of inputs and labour. Availability of information technology since the 1980s provides farmers with new tools and approaches to characterize the nature and extent of variation in the fields, enabling them to develop the most appropriate management strategy for a specific location, increasing the efficiency of input application.

Practical Problems in Indian Agriculture

Precision agriculture has been mostly confined to developed countries. Reasons of limitations of its implementation in developing countries like India are:

1. Small land holdings.
2. Heterogeneity of cropping systems and market imperfections.
3. Complexity of tools and techniques requiring new skills.
4. Lack of technical expertise knowledge and technology (India spends only 0.3 per cent of its agricultural GDP in research and development).
5. Infrastructure and institutional constraints including market imperfections.
6. High cost.

In India, major problem is the small field size. More than 58 per cent of operational holdings in the country have size less than 1 ha. Only in the states of Punjab, Rajasthan, Haryana and Gujarat more than 20 per cent of agricultural lands have operational holding size of more than 4 ha. There is scope of implementing precision agriculture for crops like, rice and wheat especially in the states of Punjab and Haryana. Commercial as well as horticultural crops show a wider scope for precision agriculture.

In India, broadly two types of agriculture viz. high input agriculture characterized by provision of assured irrigation and other agricultural inputs and subsistence farming, which is confined mostly to rainfed or dryland regions are prevalent. Nearly two-third arable land in India is rainfed. Crop yields are very low (near 1.0/ha) and good potential exists for increasing productivity of rainfed cropping systems.

Steps to be taken for Implementing PF in India

In the present situation, potential of precision agriculture in India is limited by the lack of appropriate measurement and analysis techniques for agronomically important factors. High accuracy sensing and data management tools must be developed and validated to support both research and production. Limitation in data quality/availability has become a major obstacle in the demonstration and adoption of the precision technologies. Adoption of precision agriculture needs combined efforts on behalf of scientists, farmers and the government. The following methodology could be adopted in order to operationalize precision farming in the country:

1. Creation of multidisciplinary teams involving agricultural scientists in various fields, engineers, manufacturers and economists to study the overall scope of precision agriculture.
2. Formation of farmer's co-operatives since many of the precision agriculture tools (GIS, GPS etc.) are costly.

3. Government legislation restraining farmers using indiscriminate farm inputs and thereby causing ecological/environmental imbalance would induce the farmer to go for alternative approach.
4. Pilot study should be conducted on farmer's field to show the results of precision agriculture implementation.
5. Creating awareness amongst farmers about consequences of applying imbalanced doses of farm inputs like irrigation, fertilizers, insecticides and pesticides.

Realising the potential of space technology in precision farming, the Department of Space, Government of India has initiated eight pilot studies in well-managed agricultural farms of the ICRISAT, the Indian Council of Agricultural Research and the Agricultural Universities, as well as in farmers' fields. Pilot studies aim at delineating homogeneous zones with respect to soil fertility and crop yield, estimation of potential yield, yield gap analysis, monitoring seasonally-variable soil and crop conditions using optical and microwave sensor data and matching the farm inputs to bridge the gap between potential and actual yield through Spatial Decision Support Systems (SDSS). The test sites are spread over a fairly large area across a cross section of agroclimatic zones of the Indian sub-continent and cover some of the important crops like wheat, rice, sorghum, pigeonpea, chickpea, soybean and groundnut.

The next step would be to generate detailed-level information on soil resources addressing potentials and limitations of individual fields since except for states like Punjab, Haryana, Madhya Pradesh and Maharashtra where fields size is quite large, practically individual field could be treated as a homogenous management unit for the purpose of precision farming.

Agriculture has continued to be the cornerstone of Indian economy. In the years to come, precision agriculture may help the Indian farmers to harvest the fruits of frontier technologies without compromising the quality of land and produce. Adoption of such a novel technique would trigger a techno-green revolution in India which is the need of the hour.

CHAPTER-2: GEO-INFORMATICS

Natural resources provide the basis for human survival and development. Because of increasing demands on these resources and decrease in its availability, there is urgent need for coordinated approach to their sustainable management. Sustainable use and management of natural resources demands an interdisciplinary approach and sound knowledge on each specific resource, as well as on the ecological, economic and social perspectives related to their use.

Natural resource management activities seek to increase agricultural productivity through adoption of practices that maintain the long-term ecological and biological integrity of natural resources. Hence, towards achieving the goal of livelihood security, it is important to conserve the natural resource bases and improve economic viability of farming.

Geo-informatics deal with handling digital geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, analyzing, synthesizing, presenting and disseminating geo-information.

Geo-informatics is a modem technology that provides accurate means of measuring the extent and pattern of changes and other related information about environment (Boakye *et al*., 2008). The term geo-information consists of two main words: geo means earth's surface or the environment and informatics stands for fact about something. Thus, geo-information is the science and technology of communicating the evidences about the state of the earth's surface.

It is known for technological robustness to assess spatial and temporal change occurring on the earth's surface. In the recent years, geo-informatics has been used to provide electronic representation about earth's surface and man's interaction with the earth. Geo-informatics has emerged, in the last two decades, as an exciting multi-disciplinary endeavour, spanning such areas as geography, cartography, remote sensing, image processing, environmental and computer aspects of environmental studies.

Geo-informatics may be broadly defined as the combination of technology and science dealing by means of the spatial information, its acquisition, its qualification and classification, its processing, storage and dissemination. Geo-informatics is an integrated tool to collect process and generate information from spatial and non-spatial data. Geo-informatics is an appropriate blending of modules like remote sensing (RS), global positioning system (GPS), geographical information system (GIS) and relational data base management system (RDBMS).

In general, the science and technology of geo-informatics encompasses application of remote sensing and GIS data and methodology. The GIS is an acronym that stands for geographic information systems while the remote sensing data are those data collected through various devices without human (researcher) contact with field. The GIS, in actual sense, is not a new development, it is only recently that it has gained widespread acceptance as a tool to assess both spatial and non-spatial issues. The GIS was initially referred to as the management of information with a geographic component primarily stored in vector form with associated attributes. This

definition quickly became too limiting with advances in software and recent digital ideas about earth. The GIS involves spatiotemporal data analysis using software, hardware, people and approaches to acquire, store, update and manipulate for presenting information about the human environment. The GIS could be seen as a digital computing environment and human interactions with the environment. For environmental change analysis, the GIS uses both remote sensing and non-remote sensing data. Non-remote sensing data may include field observation, topographic, geological and edaphic data. It may also include terrain data, as well as socio-economic survey data and reports relating to human environmental relation. Though non-remote sensing data are those data acquired by other means than remote sensing approach, they are sometimes used in geo-informatics analysis, for identification and interpretation of environmental features and their significant change over time. In general, it has been shown in several other recent studies that geo-informatics is not only good for preparing precise environmental change assessment, but also for observing changes at regular intervals of time, it is cost and time effective.

Recent advances in **geo-informatics** have created new opportunities and challenges in applying geo-informatics to agriculture monitoring, assessment and decision making. Geo-informatics are incredibly helpful in being able to map and project current and future fluctuations in precipitation, temperature, crop output and more. By mapping geographic features (potential), scientists and farmers can work together to create more effective and efficient farming techniques for increasing food production in parts of the world that are struggling to produce enough for the people around them. GIS can analyze soil data combined with historical farming practices to determine ideal crops for different agro-climates and how to maintain soil productivity for sustainable agriculture.

Application of geo-informatics includes land use mapping and farm planning, assessing crop variability and performance tracking, plant nutrition assessments, in-field plant vigour zone delineation, irrigation and drainage assessments, storm, frost or fire crop damage insurance assessments, crop yield management, monitoring and prediction, impacts of soil compaction, pest and disease management, spatial management systems and databases, sustainable agricultural engineering and many more. Therefore, geo-informatics is playing an increasing role in agriculture throughout the world by helping farmers increase production, reduce costs and manage their land more efficiently. While natural inputs in farming cannot be controlled, they can be better understood and managed with geo-informatics tools. Climate change poses a serious challenge for natural resource management. As temperatures, rainfall patterns and disturbance regimes change and sea levels rise, ecosystems are being transformed. Some species of plants and animals are already shifting their distributions in response to climate change and changes in phenology are disrupting ecological relationships and species interactions. In the present context of climate change, there is possibility of decrease in crop yield in various regions of the world.

Geo-informatics widely believed that it can play an increasingly important role in natural resource management in face of climate change. Global climate change and shrinking resources have compelled to develop our understanding about the dependence on the dynamic and complex earth system and its environment. Geo-informatics enables to take advantage of the unprecedented amount of digital geo-database and computational capability through electronic networks. Thus, it facilitates multi/interdisciplinary research and capacity to understand the earth as dynamic and complex system to manage natural resources in a sustainable way.

Agro-geo-information, the agricultural-related geo-information, is the key information in the agricultural decision making and policy formulation process. Agro-geo-informatics, a branch of geo-informatics, is the science and technology about handling digital agro-geo-information, such as collecting (mainly through remote sensing and field investigation), processing, storing, archiving, preservation, retrieving, transmitting, accessing, visualization, and analyzing, synthesizing, presenting and disseminating agro-geo-information. Recent advances in geo-informatics have created new opportunities and challenges in applying agro-geo-informatics to agriculture monitoring, assessment and decision making. The International Conference on Agro-geo-informatics is a major venue for professionals and students to exchange ideas, research results, professional experiences and future vision in the fields of geo-information science, remote sensing, and their applications in agriculture.

GEOINFORMATIC CONCEPT, TOOLS AND PRINCIPLES

Geo-informatics is a new discipline concerned with the modeling of spatial data and the processing techniques in spatial information systems. It is a multidisciplinary science that integrates the technologies and principles of digital cartography, remote sensing, photogrammetry, surveying, global positioning systems (GPS), geographic information systems (GIS) and automated data capture systems using high-resolution geo-referenced spatial information from aerospace remote sensing platforms.

Thus, geo-informatics provide tools that allows for the processing, manipulation and analysis of spatial data into information tied explicitly to, and used to make decisions, about portions of the earth and environmental problems. The techniques can include all stages of data collection, data processing, data base management, data analysis and modeling and data presentation to end use in the creation of maps and spatial information products. We can understand the concepts clearer when we consider the principles of the following component sub-fields:

Cartographic principles involve map, map design and map visualization and production in analogue or digital computer environment.

Remote sensing involves the acquisition of spatial data of the environment without physical contact with the objects or features sensed by using electromagnetic energy radiation, interaction and detection principles in analogue or digital formats.

Photogrammetric principles involve the art and scientific processes of obtaining reliable information about the physical environment by interpreting remotely sensed aerospace data (aerial photographs and satellite imageries) in analogue or digital formats.

Surveying principles involve the adroit use of fundamental methods (processes) and technologies (instruments) to determine the precise position and dimensions of points (features) on the earth's surface and the presentation of the results in analogue or digital format.

Global positioning systems (GPS) involve precise surveying (determination of position dimensions of points) by applying resection and satellite constellation principles and the presentation of the results in analogue (maps, tables) or digital formats.

Geographic information systems (GIS) principles involve data gathering, data processing, database management, data modeling and visualization in a digital environment.

Automated data capture systems include multi-spectral remote sensing processes, GPS data, map digitization and scanning and computer input and output technologies.

RELEVANCE OF GEOINFORMATICS IN AGRICULTURE

Geo-informatics, and in particular remote sensing, geographic information systems and global positioning systems technologies have become indispensable in modem agriculture. Advances in remote sensing have revolutionised the gathering of information on agricultural activities, including land-use, soil condition, weather condition etc. that are essential for site characterisation and consequent site selection for farming. For instance, the biophysical components of the soil and environment can readily be deduced from information interpreted from satellite imagery, which will in turn serve as the basis for determining site suitability for specific agricultural purposes when duly analyzed in a geographic information system environment.

Remote Sensing System

Since remote sensing techniques have the unique capability of recording data in visible as well as invisible (including ultraviolet, reflected infrared, thermal infrared and microwave) parts of the electromagnetic spectrum, it enables us see beyond the capability of the human eye. For instance, trees or plants, which are affected by diseases or insect attack, can be detected by remote sensing technique much before human eye sees them. Such early detection is vital for the application of remedial measures. Remote sensing techniques are also useful in the determination the spatial distribution of plant status (health or efficiency) and corollary expected yield by measuring the greenness of the field.

Detection, identification, measurement and monitoring of agricultural phenomena are predicated on the assumption that agricultural landscape features (such as crops, livestock, and crop infestation and soil anomalies) have consistently identifiable signatures on the type of remote sensing data. These identifiable signatures are a reflection of crop type, state of maturity, crop density, crop geometry, crop vigour, crop moisture, crop temperature and soil moisture as well as soil temperature. Detection of features to a large extent depends on the type of sensor

used and the portion of the electromagnetic spectrum used in sensing. Areas of specific application of remote sensing in agricultural surveys include:

1. **Applicable to Crop Survey**

Crop identification, area under crop, crop vigour, crop density, stage of crop growth, crop growth rates, yield forecasting, actual yield, soil fertility, effects of fertilizers, toxicity on crops, water quality, irrigation requirement, pests and diseases incidence, water availability and location of canals.

2. **Applicable to Range Survey**

Delineation of forest types, condition of range, carrying capacity, forage, time of seasonal change, location of water, water quality, soil fertility, soil moisture, insects infestations, wild life inventory.

3. **Applicable to Livestock Survey**

Cattle population, sheep population, pig population, poultry population, age sex distribution, distribution of animals, animal behaviour, disease identification, types of farm buildings.

Geographic Information System

Geographic information system is another geo-informatics technique that is quite relevant in agricultural development. There are numerous definitions of geographic information systems in the literature. For our purpose geographic information system can be defined as a system for capturing, storing, checking, manipulating, analyzing and displaying data, which are spatially referenced to the earth. Thus, a true geographic information system is designed to accept, organize, statistically analyze and display diverse types of spatial information that are geographically referenced to a common coordinate system of a particular projection and scale.

Geographic information system comprises five major components and three main subsystems. Main components of geographic information systems are:

1. The hardware which include a host computer, data acquisition device(s) such as digitizer, scanner, digital image processing system, digital theodolite, analytical and digital photogrammetric plotter and output device(s) such as plotter, printer, high resolution screen among others.
2. The spatial database, containing the objects of interest, including the objects' geometric (position and spatial relationships) and thematic data in structured form.
3. Software for the acquisition, manipulation and management of data in the database.
4. Procedures (conventions and algorithms to guide its operations).
5. Expertise in terms of skilled human operators.

The main subsystems of a geographic information system are:

1. Data acquisition subsystem for collecting and/or processing spatial data from existing maps, remotely sensed data, aerial photography, land survey among others.

2. Database management subsystem for the storage, retrieval, manipulation and analysis of data.
3. Visualization and reporting subsystem for displaying database query results in graphic and/or alphanumeric form.

Geographic information systems are needed for the collection, analysis and management of agricultural data for the purpose of timely decision-making. Database will contain layers of spatial data from remote sensors, existing maps or field surveys. Information system has the capability to integrate diverse data sets from these diverse sources and ensure compatibility of the various data sources.

Geographic information system analysis, basically, includes rectification for geometrical correction of digital image data, spatial and spectral enhancements, classification and visualization of digital images. In this way, information on vegetation and soil types, plant stress, crop infestation etc. can be harnessed. Geographic information system modeling capability through analytical functions like overlay, cluster analysis, clumping functions, reclassification, indexing and spatial searching provides information on which agricultural land-use planning can be based. For instance, spatial models will allow for the production of fertility and pest infestation maps as well as maps of spatial distribution of plant nutrients and productivity potential (expected yield). Yield can be achieved with geographic information system technology when yield and moisture sensors are combined with global system to provide geo-referenced location specific yield data for the generation of yields maps.

Global Positioning System

The global positioning system is yet another geo-informatics tool required for agricultural development. Global positioning system enables accuracy in the location of terrain features. It receives signals and positioning information from a series of satellites in space. Global positioning system is basically for the geo-referencing of terrain attributes. Geo-referencing is done because location serves as a means to link terrain data collected by different mapping disciplines through overlay analysis. Therefore, global positioning system capability is necessary in the integration of the diverse agricultural data sets from diverse sources, in geographic information system environment. Spatial data collected by global positioning system can be automatically recorded with the geographic information system programme. In addition, the use of global positioning system allows for the accurate location of soil sample points within a field and hence the determination of physical, chemical and biological characteristics of the soil at different locations. Consequently, fertility levels can be mapped across the field to serve as a basis for the application of farm inputs. The global positioning system is also required to establish the accurate location of yield data collected. It is thus needed for the production of yield maps and for yield monitoring.

GEOINFORMATICS AND PRECISION AGRICULTURE

Integration of remote sensing, geographic information system and global positioning system technologies has taken agriculture to the space age. This has given rise to a new concept variously termed precision agriculture (PA), precision farming (PF) or site specific crop management (SSCM). Precision farming is an information and technology-based agricultural management system that identifies analyses and manage site-soil spatial and temporal variability within paddocks (farm fields) for optimum yield or productivity, profitability, sustainability and protection of the environment. The concept identifies the agricultural suitability of land parcels from the spatial variability of soil fertility status and other land qualities (water and oxygen availability and retention capacity, plant root conditions, salt hazards and topographic conditions). The concept recognizes that variations occur within agricultural fields and thus seeks to identify the spatial location and extent of such variations. The objective is to assess the causes of such variations to ensure that the right decision is taken with regards to type of crops to be cultivated, time to cultivate and management practices required. Precision farming implies doing the right thing, in the right way, at the right place and at the right time.

Components of precision farming are remote sensing, geographic information systems (GIS), differential global positioning system (DGPS) and variable rate applicator (VRA). Remote sensing techniques play a pivotal role in precision farming by providing continuous data on spatial and temporal variability in agricultural fields. Sensors provide data on soil properties, crops condition and yield, fertilizer flow, as well as weed detection. GIS is a potential tool for handling voluminous remotely sensed data and has capability to support spatial statistical analysis, presentation of spatial data in the form of a map, as well as storage, management, modeling of input data and presentation of model results.

Differential global positioning system (DGPS) is used for precise location of activities. Global positioning system (GPS) device makes use of a series of military satellites that identify the location of farm equipment within a meter of an actual site in the field. This is required to accurately link location and result of soil samples to a soil map, prescribe farm inputs to fit soil properties, adjust tillage to suit field conditions and determine yield data across the field.

Variable rate applicator is used to operationalize precision farming at the farm level. **Variable rate technology (VRT)** consists of the machines and systems used to apply a desired rate of crop production materials at a specific time and by implication, a specific location. The components are a control computer, a locator and an actuator. The control computer co-ordinates field operations with the aid of database in its memory. Based on the desired activity, the computer from the locator (which holds a GPS) receives the current location of equipment and issue command to the actuator, which does the input application.

The operational procedure of precision farming requires geo-referenced point data obtained with grid spacing with minimal number of observations. Patterns are obtained by geo-statistical interpolation of these point data. Techniques involves the integration of databases or sensors that provide information needed to develop input response to site- specific conditions,

positioning capabilities to know where equipment is located and real-time mechanism for controlling crop production inputs. The new paradigm is being adopted in the United States and Europe since the middle of 1990s.

CROP DISCRIMINATION

Currently computers are being used for automation and to expand **decision support systems (DSS)** for the agricultural research. Recently, **geographic information systems (GIS) and remote sensing technology** has come up with a capable role in agricultural research, predominantly in crop yield prediction in addition to crop suitability studies and site specific resource allocation. Role of geo-informatics to discriminate different crops at various levels of classification, monitoring crop growth and prediction of the crop yield has been briefly presented.

Remote sensing is an efficient technology and worthy source of earth surface information, as it can capture images of reasonably large area on the earth. Due to advancement in the sensor technologies, there is availability of high spatial as well as spectral resolutions imageries and also non-imaging spectro-radiometer. With the use of these imaging and non-imaging data, we can easily characterize the different species.

Different crops show distinct phonological characteristics and timings according to their nature of germination, tillering, flowering, boll formation (cotton), ripening etc. Even for the same crop and growing season, the duration and magnitude of each phonological stage can differ between the varieties, which introduce data variability for crop type discrimination with imaging systems. Agricultural crops are significantly better characterized, Classified, modeled and mapped using **hyper-spectral data**.

1. Feature Extraction

Feature extraction is the process of defining image characteristics or features which effectively provides meaningful information for image interpretation or classification. The ultimate goals of feature extraction are:

1. Effectiveness and efficiency in classification.
2. Avoiding redundancy of data.
3. Identifying useful spatial as well as spectral features.
4. Maximizing the pattern discrimination.

For crop type discrimination, spatial features are useful. Crops are planted in rows, either multiple or single rows, as per the crop types for convenience and to maximize yields. Different spatial arrangement of the crops gives better spatial information, but it requires high spatial resolution images. In spatial image classification, spatial image elements are combined with spectral properties in reaching a classification decision. Most commonly used elements are texture, contexture and geometry (shape). Due to the availability of commercial high resolution multispectral satellite imagery such as Geoeye-1. IKONOS-2. Quick Bird-2 with less than 4 m spatial resolution, it has become possible to identify small-scale features from complex environments. However, there have been limitations when using only the spectral information

because of the complex spatial arrangement of features and the spectral heterogeneity within each class.

2. Role of Texture in Classification

In general, it is possible to distinguish between the regular textures manifested by man- made objects from the irregular manner that natural objects exhibit texture. Hence, the texture characteristic can be used to discriminate between divergent objects. Therefore, they support their segmentation from remotely sensed data, both the conventional texture analysis and the grey level co-occurrence matrix (GLCM) methods describing the grey value relationships in the neighbourhood of the current pixel. However, in the GLCM method, this is analyzed within the GLCM space and not from the original grey values, as is the case in the former method.

3. Grey Level Co-Occurrence Matrix (GLCM)

The GLCM can be viewed as a two-dimensional histogram of the frequency with which pairs of grey level pixels occur in a given spatial relationship, defined by a specific inter-pixel distance and a given pixel orientation. Hence, in the segmentation of urban objects, texture analysis is usually performed within a GLCM matrix space. A variety of texture measures can be extracted from the GLCM. Four useful measures that can be derived from the probability density are energy, variance, dissimilarity and homogeneity where energy measures the uniformity of the texture; variance measures the heterogeneity of the pixel values. Similar to contrast dissimilarity measures, the difference between adjoining pixels and homogeneity measures the tonal uniformity.

4. Local Binary Pattern (LBP)

It is a simple yet very efficient texture operator which labels the pixels of an image by thresh-holding the neighbourhood of each pixel and considers the result as a binary number. Due to its discriminative power and computational plainness, LBP texture operator has become a popular approach in various applications. It can be seen as a uniting approach to the traditionally divergent statistical and structural models of texture analysis. Possibly, the most important assets of the LBP operator in real-world applications is its robustness to monotonic gray-scale changes instigated, for example, by illumination differences. Another important property is its computational simplicity, which makes it possible to analyze images in challenging real-time settings. Spatial feature extraction for crop type discrimination works well if we have high spatial resolution satellite imagery. Rather than this, spatial information is also useful in spectral based classification for visual interpretation in supervised learning.

YIELD MONITORING

Estimation of crop yield well-before the harvest at regional and national scale is imperative for planning at micro-level and predominantly the demand for crop insurance. Crop yield estimation plays a significant role in economy development. Currently, it is being done by extensive field surveys and crop cutting experimentation. This enables decision makers and planners to predict the amount of crop import and export. In most of the developing countries,

the crop yield estimation is, generally, based on traditional methods of data collection which is based on ground based field surveys.

Conventional methods have been found to be expensive, time consuming and are prone to large errors due to incomplete and inaccurate ground observations leading to deprived crop area estimations and crop yield assessment. In most of the developing countries, required data is, generally, available too late for any appropriate decision making. Objective, consistent and possibly inexpensive and or faster methods that can be used for monitoring of crop growth and an early estimation of crop yield are imperative. Data captured through remote sensing has the prospective, capacity and the potential to exhibit spatial information at global scale. Different approaches and technologies used for crop inventory are briefly presented.

1. Aerial Photography

To obtain crop yield information, one must be able to recognise tone, pattern, texture and other features. Crop yield information is used in conjunction with crop area statistics to obtain crop production. There are two distinct aspects of yield determination: (1). Forecast of yield based on characteristics of the plant or crop and relationship based on experience in prior years and (2) Estimates of the yield known from the actual weight of the harvest crop for the current year. After the World War II, various researchers used the emerged concept of aerial photography for optimised use of resources for agriculture and crop inventory. Black and white photography has been used for crop identification, primarily based on ground appearance and the equivalent aerial photographic form of selected fields at nine intervals during the growing season.

2. Multispectral Scanners

Multispectral scanners (MSS) have certain advantages and disadvantages compared to photography. Ability to differentiate wheat from other agricultural crops using multispectral data in a computer format with pattern recognition techniques has been shown. An important consideration in the task of species identification is the stage of growth of the crop.

3. Radar

Advantages and limitation of using either air-borne or space-borne radars for crop identification have been discussed in the past. It has been pointed out that many of the radar studies have concentrated on seasonal change between crops and that numerous variables must be considered in making even the simplest determinations.

4. Satellite Data

Estimation models for crop area and yield have been studied for a long time and numerous good quality models have been developed. These conventional models have been developed primarily from the point of view of meteorology and biology without concern of remote sensing and thus cannot meet the requirements of today's society. Utilisation of remote sensing data for agricultural development was investigated in the USA in 1971 under Com Blight Watch Experiment (CBWE). Remote sensing data has been proved effective in predicting crop

yield and provide representative and spatially exhaustive information on the development of the model for the crop growth monitoring.

In India remarkable spurt in the remote sensing activities has started with the launch of the IRS (Indian Remote Sensing Satellite) 1A in the year 1988. India launched a variety of satellites devoted to particular area of relevance such as ResourceSat, CartoSat and OceanSat.

Remote sensing data has been proven effective in predicting crop yield and provide representative and spatially exhaustive information on the development of the model for the crop growth monitoring. Various indices, based on remote sensing, have been employed to estimate the yield of several types of crops. Normalized difference vegetation index (NDVI) has been used to estimate the yield of rice. However, yield estimation with remote sensing has limitations, mainly due to the indirect nature of the link between the NDVI and biomass but also due to the sensor spatial resolution or insufficient repeat coverage.

The current stage of the technological development engrossed the amalgamation of the remote sensing, GIS and GPS. Due to theoretical and scientific achievements in the yield estimation using remote sensing, researchers and the application scientists frequently use multi-date high resolution satellite and meteorological data with the support of the GIS to estimate yield and they also operate on coarse resolution data as a sampling tool to improve the precision. Chronological growth in terms of crop inventory using geo-informatics is shown below.

Chronological growth of crop inventory using geo-informatic

Period	Technology	Features
Before 1940	Crop cutting experiments	Qualitative analysis.
1950-1970	Aerial photography and computers.	Regression models based on statistical data.
1970-1990	Satellite imagery.	Crop yield at global scale.
1990-2000	High resolution satellite imagery.	Statistical as well as vegetation indices.
2000 onwards	Amalgamation of remote sensing, GIS and GPS.	Crop inventory based on crop simulation models and crop growth models.
Period	Technology	Features

CHAPTER-3: REMOTE SENSING, IMAGE PROCESSING AND GLOBAL POSITIONING SYSTEM

Remote sensing techniques play an important role in crop identification, crop area and production estimation, disease and stress detection, soil and water resources etc. Remote sensing applications have become very important for making macroeconomic decisions related to food security, poverty alleviation and sustainable development in the country.

WHAT IS REMOTE SENSING?

Remote sensing is the science (and to some extent, art) of acquiring information about the earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing and applying that information. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved. Remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

1. **Energy source or illumination (A).** The first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. **Radiation and the atmosphere (B).** As the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.
3. **Interaction with the target (C).** Once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4. **Recording of energy by the sensor (D).** After the energy has been scattered by or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.
5. **Transmission, reception and processing (E).** The energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).
6. **Interpretation and analysis (F).** The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. **Application (G).** The final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information or assist in solving a particular problem.

Definitions :

- Remote sensing can be defined as the science, technology and art of acquiring information about an object which are not in physical contact with the object itself.

- Remote sensing is the technique of collecting and interpreting the information about an object or phenomena without any physical contact with the object.
- Remote sensing is defined as any process whereby information is gathered about an object, area or phenomenon without being in contact with it.
- The term remote sensing has come to be associated with the gauging of interactions between earth surface materials and electro magnetic energy.
- Remote sensing is the science and art of obtaining useful information (Spectral, Spatial, and Temporal) about an object; area or phenomenon through the analysis of data acquired by a device is not in contact with the object, area or phenomenon under investigation.

Remote sensing in its broader sense refers to the activities of recording, observing, perceiving object or events at far away (Remote) places.

Remote sensing actually deals with inventory, monitoring and assessment of natural resources through the analysis of data obtained by observation are synoptic, provide repetitive coverage of large areas and the data is quantifiable

Our eyes are an excellent example of a remote sensing device. We are able to collect information about our surroundings by measuring the amount of visible light energy from sun or an electric bulb. A thermometer, measuring air, soil or water temperature is in contact with the phenomenon it measures. Hence it is not a remote sensing device, whereas the infrared thermometer which measures canopy temperature is a remote sensing device.

Art and science of Remote Sensing

Remote sensing is the art and science of obtaining information from a distance about objects or phenomena without being in physical contact with them. The science of remote sensing provides the instruments and theory to understand how objects and phenomena can be detected. The art of remote sensing is in the development and use of analysis techniques to generate useful information.

Components of remote sensing:

A remote sensing system using EMR has four components:

1. A source of energy
2. Interactions of energy with the atmosphere
3. Interactions of energy with earth surface
4. A sensor with platform.

Stages of remote sensing:

The field of remote sensing encompasses techniques that obtain precise information about earth's surface. Different stages in remote sensing process are:

1. Energy source
2. Energy interaction with the atmosphere
3. Interaction of energy with earth's surface feature

4. Recording of energy by the sensor
5. Data transmission and processing
6. Image processing and analysis
7. Application

The first and for most requirement for remote sensing is the energy source which illuminates the target or objects. Sun is the natural source of energy and transmitters are the artificial source of energy to illuminate the objects.

The energy from the source comes in contact and interacts with the atmosphere, while travelling to earth surface. The energy which are not absorbed in the atmosphere reaches to earth and interacts with surface objects and features. A portion of incident energy are either reflected, transmitted or absorbed by the surface.

The energy after interactions with earth's objects reaches the sensor, where it is recorded in a form which can be transmitted to and used by the users.

The energy recorded by the sensor is transmitted to a receiving and a processing station where the data are processed in to an image.

Then the processed image is interpreted to extract the information about the object.

The extracted information is utilized to make decisions for solving problems.

Principles of remote sensing:

The basic principle in remote sensing is that the different objects based on their structure, chemical and physical properties reflect or emit different amount of energy in different wavelength ranges of the electro magnetic spectrum. Everything in nature has its own characteristic features of reflecting, emitting and absorption of radiation. For example, in the atmosphere the sun's radiation are selectively scattered or absorbed depending upon the composition of the atmosphere and wavelengths. According to the law of conservation of energy, the energy can not be destroyed but be converted to another form. Thus the portion of incident radiation is reflected by the surface, transmitted in to the surface and absorbed by the surface. However, the magnitude of each component depended on the nature of surface, the wavelength of the energy and the angle of illumination. Over water surface, majority of the radiation is either absorbed or transmitted but not reflected. Whereas over soil surface, the majority of radiation is either reflected or absorbed and little is transmitted. Over vegetated surfaces the reflectivity varied with wavelength because of its flexibility unlike soil and water.

- The underlying principle in which the whole remote sensing techniques is developed, is that " All objects on the surface of the earth have their own characteristic spectral signature"
- The responses of materials on the earth surface to incidence radiation are the energy emitted by all objects is a function of their temperature and structure. Hence, all objects have their own reflectivity depending on their own temperature and emissivity. Hence,

by utilization of different reflectivity and emissivity of objects we can identify and classify them.

Very often we ask the question that how information of an object can be collected without touching it. The information from an object to the sensor is carried by the EME and recorded by the sensor. This could be encoded in the form of frequency, intensity and polarization of the electromagnetic wave. The information is propagated by electromagnetic wave at the velocity of light from the object directly through free space as well as indirectly by reflection, scattering and re-radiation by aerosols to the sensor.

Concept of Remote Sensing

The concept of remote sensing involves six stages

- Source of electromagnetic energy (EME), sun or transmitter is the source of the energy.
- Transmission of the energy from the source to the surface of earth (as well as absorption and scattering by the atmosphere)
- Interaction of energy with the objects on the surface of earth. Due to interaction the processes like reflection, absorption, transmission and emission take place.
- Transmission of energy to the remote sensing sensor.
- Generation of data in pictorial and/or digital form.

Types of remote sensing:

Based on source of energy, remote sensing can be divided in to two types:

1. Passive remote sensing
2. Active remote sensing

Remote sensing systems, which use naturally available energy is called passive remote sensing and the remote sensing systems which provide their own source of energy is called active remote sensing. These sources have the advantage of obtaining data any time of day or season.

Based on range of electromagnetic spectrum there are three types of remote sensing:

(1) Optical remote sensing: remote sensing is visible, NIR, MIR ranging from 0.3 to 3.0 μm.

(2) Thermal remote sensing: Remote sensing of emitted radiation

(3) Microwave remote sensing in the range of 3 to 5 and 8 to 16 μm.

Remote sensing in higher wavelengths from 1mm to 1 m can penetrate the clouds.

Origin of remote sensing:

The advent of aerial photography which is the origin of emote sensing techniques have provided valuable information on the earth resources. The remote sensing techniques ranges between very short wavelengths at which gamma rays are emitted to long wavelengths at which radar operates. As compared to conventional photography which is limited to the visible band of the spectrum, the aerial photography provide much more information about an area and object.

Advantages of remote sensing:

With growing population and rising of living standard, pressure on natural resources has been increasing day by day. Hence it has become necessary to manage the available resources. For effective management of natural resources it is essential to monitor these resources periodically with great accuracy and speedy techniques. The main advantages of remote sensing techniques are:

- The remote sensing techniques provide the synoptic (overall) view of large area which is not possible by traditional ground survey methods.
- The data are recorded on permanent basis
- The data are very accurate and unbiased
- The data are amenable (useful) to multidisciplinary uses i.e. the same data can be used for agriculture, forestry, fishery, soil science, hydrology, geology etc.
- The process of data acquisition, analysis and communication is faster than the conventional methods.
- Remote sensing techniques have the unique capability of recording data in visible as well as invisible (UV, IR, microwave etc) parts of the EMS.

Hence the major advantages of remote sensing are synoptic view, accessibility, accuracy, time saving and multidisciplinary applications.

SATELLITE REMOTE SENSING TECHNOLOGY is useful to gather information beyond simple visual technique with respect to extent of coverage, permanent of record, spectral and spatial resolution, speed and consistency of interpretation of data, cost effective and reliable information etc.

1. Extent of coverage

By using satellite technology information from a large area can be covered with short time with much accuracy as compared to traditional methods, for example, one LANDSAT scene covers about 185 Km × 185 Km area and takes less than 30 Seconds to record one scene from a height ranging from 550- 1600Km .

2. Permanent record

Aerial and satellite data are the permanent and reliable record of ground features present at the time of sensing by photographic camera or multispectral scanner (MSS).

3. Spectral and spatial resolution

Greater fineness of the image and the details of the objects can be obtained by using spatial resolution of any sensor. For example, spatial resolution of LANDSAT MSS is 80m and of IRS LISSS-II is 36m.

By using spectral resolution we can distinguish the different objects. We may be able to see number of terrain features like forested and denudated hills, slopping of mountains, floods, sand dunes, crops and forested area, problematic area etc. in one scene.

4. Speed and consistency of interpretation

With the use of digital image processing system we can analyse the data consistently and speedily.

5. Cost effective and reliability

Remote sensing offers cost effective and reliable monitoring systems. At times when the conventional field survey were not done honestly due to various difficulties, remote sensing offers help to cross check , verify and have more realistic and accurate data.

The advantages of remote sensing techniques over conventional methods

- The remote sensing techniques provide the synoptic view of large area which is not possible by traditional ground survey methods.
- The data are recorded on the permanent basis.
- The data are unbiased record of the objects or phenomena.
- The data are amenable to multi-disciplinary use i.e. the same data can be used for agriculture, forestry, soil science, hydrology, geology etc.
- The process of data acquisition and analysis is faster than in conventional methods.
- Satellite data are received periodically varying from 14days to 28 days depending on the satellite. This capability of satellite helps in updating the information and monitoring the changes at short intervals.
- Remote sensing technique have the unique capability of recording data in visible as well as invisible parts of the spectrum (UV, IR, Microwave etc.)

Scope of remote sensing:

The scope of remote sensing covers the application of remote sensing techniques to diverse fields. The same information can be useful to investigations of different disciplines in many ways. The data gathered by remote sensing process can be used by the users, investigators of different disciplines like agriculture, geology, forestry, hydrology, soil science, fishery, land use engineers etc.

- The oldest application of remote sensing techniques is in military operation. The infrared (IR) sensing is useful to locate an army's position.
- Geologists use remote sensing to find deposits of mineral and petroleum.
- Agriculturalists and farmers can determine the kind of crops and trees which grow in an area and can assess the growth, health and estimate the yields.
- Soil scientists can prepare soil maps based on soil characteristics.
- Hydrologists can locate useful aquifers and can estimate the volume of watersheds.
- Geographers can analyze land use pattern over large area and can study the effect of climate.
- Civil engineers use remote sensing for planning and designing large construction of roads and reservoirs.
- Oceanographers can map the movements of ocean currents.
- Meteorologists can use remote sensing for forecasting of weather.

REMOTE SENSING APPLICATION IN AGRICULTURE

Agriculture plays a dominant role in economies of both developed and developing countries. Whether agriculture represents a substantial trading industry for an economically strong country or simply sustenance for a hungry, overpopulated one, it plays significant role in almost every nation. Production of food is important to everyone and producing food in a cost-effective manner is the goal of every farmer. A farmer needs to be informed to be efficient and that includes having the knowledge and information products to forge a viable strategy for farming operations. These tools will help him understand the health of his crop, extent of infestation or stress damage or potential yield and soil conditions. Commodity brokers are also very interested in how well farms are producing, as yield (both quantity and quality) estimates for all products control price and worldwide trading.

Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability and monitor farming practices. Agricultural applications of remote sensing include the following:

- **Soil properties sensing:** Soil texture, structure and physical condition, soil moisture and soil nutrients.
- **Crop sensing:** Plant population, crop stress and nutrient status.
- **Yield monitoring systems:** Crop yield, harvest swath width and moisture content of grain.
- **Variable rate technology systems:** Fertilizer flow, weed detection etc.

Crop Type Happing

Identifying and mapping crops is important for a number of reasons. Maps of crop type are created by national and multinational agricultural agencies, insurance agencies and regional agricultural boards to prepare an inventory of what was grown in certain areas and when. This serves the purpose of forecasting grain supplies (yield prediction), collecting crop production statistics, facilitating crop rotation records, mapping soil productivity, identification of factors influencing crop stress, assessment of crop damage due to storms and drought and monitoring farming activity.

Key activities include identifying the crop types and delineating their extent (often measured in acres). Traditional methods of obtaining this information are census and ground surveying. In order to standardize measurements however, particularly for multinational agencies and consortiums, remote sensing can provide common data collection and information extraction strategies.

Remote sensing offers an efficient and reliable means of collecting the information required, in order to map crop type and area. Besides providing a synoptic view, remote sensing can provide structure information about the health of the vegetation. The spectral reflection of a field will vary with respect to changes in the phenology (growth), stage type, and crop health and thus can be measured and monitored by multispectral sensors. Radar is sensitive to the structure, alignment and moisture content of the crop and thus can provide complementary

information to the optical data. Combining the information from these two types of sensors increases the information available for distinguishing each target class and its respective signature and thus there is better chance of performing more accurate classification. Interpretations from remotely sensed data can be input to a geographic information system (GIS) and crop rotation systems and combined with ancillary data, to provide information of ownership, management practices etc.

Crop identification and mapping benefit from the use of multi-temporal imagery to facilitate classification by taking into account changes in reflectance as a function of plant phenology (stage of growth). This in turn requires calibrated sensors and frequent repeat imaging throughout the growing season. For example, crops like canola may be easier to identify when they are flowering, because of both the spectral reflectance change and the timing of the flowering.

Multi-sensor data are also valuable for increasing classification accuracies by contributing more information than a sole sensor could provide. The VIR sensing contributes information relating to the chlorophyll content of the plants and the canopy structure, while radar provides information relating to plant structure and moisture. In areas of persistent cloud cover or haze, radar is an excellent tool for observing and distinguishing crop type due to its active sensing capabilities and long wavelengths, capable of penetrating through atmospheric water vapour.

Crop Monitoring and Damage

Early detection and assessment of crop pest and pathogen infestations and soil moisture stress is critical in effective plant protection leading to optimum yield. This process requires that remote sensing imagery be provided on a frequent basis (at a minimum, weekly) and be delivered to the farmer quickly, usually within a day or two.

Also, crops do not generally, grow, evenly across the field and consequently crop yield can vary greatly from one spot in the field to another. These growth differences may be due to soil nutrient deficiencies or other forms of stress. Remote sensing allows the farmer to identify problem areas (nutrient deficiencies, pesticide and herbicide needs etc) within a field, so that the farmer can take up timely remedial measures for improving the productivity of crops.

There are many people involved in the trading, pricing and selling the produce that never actually set foot in a field. They need information regarding crop health worldwide to set prices and to negotiate trade agreements. Many of these people rely on products such as a crop assessment index to compare growth rates and productivity between years and to see how well each country's agricultural industry is producing. This type of information can also help target locations of future problems. Identifying such areas facilitates in planning and directing humanitarian aid and relief efforts.

Remote sensing has a number of attributes that lend themselves to monitoring the health of crops. One advantage of optical (VIR) sensing is that it can see beyond the visible wavelengths into the infrared, where wavelengths are highly sensitive to crop vigour as well as crop stress and

crop damage. Remote sensing imagery also gives the required spatial overview of the land. Recent advances in communication and technology allow a farmer to observe images of his fields and make timely decisions about managing the crops. Remote sensing can aid in identifying crops affected by conditions that are too dry or wet, affected by insect, weed or fungal infestations or weather related damage. Images can be obtained throughout the growing season to not only detect problems, but also to monitor the success of the treatment.

Healthy vegetation contains large quantities of chlorophyll, the substance that gives most vegetation its distinctive green colour. In referring to healthy crops, reflectance in the blue and red parts of the spectrum is low since chlorophyll absorbs this energy. In contrast, reflectance in the green and near-infrared spectral regions is high. Stressed or damaged crops experience a decrease in chlorophyll content and changes to the internal leaf structure. Reduction in chlorophyll content decrease reflectance in the green region and internal leaf damage results in decrease in near-infrared reflectance. These reductions in green and infrared reflectance provide early detection of crop stress. Examining the ratio of reflected infrared to red wavelengths is an excellent measure of vegetation health. This is the premise behind some vegetation indices, such as the normalized differential vegetation index (NDVI). Healthy plants have a high NDVI value because of their high reflectance of infrared light and relatively low reflectance of red light. Phenology and vigour are the main factors in affecting NDVI. An excellent example is the difference between irrigated crops and non-irrigated land. Irrigated crops appear bright green in a real-colour simulated image. Darker areas are dry rangeland with minimal vegetation. In a CIR (colour infrared simulated) image, where infrared reflectance is displayed in red, the healthy vegetation appears bright red, while the rangeland remains quite low in reflectance.

Examining variations in crop growth within one field is possible. Areas of consistently healthy and vigorous crop would appear uniformly bright. Stressed vegetation would appear dark amongst the brighter, healthier crop areas. If the data is geo-referenced and if the farmer has a GPS (global position satellite) unit, he can find the exact area of the problem very quickly, by matching the coordinates of his location to that on the image.

Detecting damage and monitoring crop health requires high-resolution imagery and multispectral imaging capabilities. One of the most critical factors in making imagery useful to farmers is a quick turnaround time from data acquisition to distribution of crop information. Receiving an image that reflects crop conditions of two weeks earlier does not help real time management or damage mitigation. Images are also required at specific times during the growing season and on a frequent basis.

Remote sensing doesn't replace the field work performed by farmers to monitor their fields, but it does direct them to the areas in need of immediate attention.

IMAGE PROCESSING AND INTERPRETATION

Image processing and interpretation/analysis can be defined as the "act of examining images for the purpose of identifying objects and judging their significance" Image analyst study the remotely sensed data and attempt through logical process in detecting, identifying, classifying, measuring and evaluating the significance of physical and cultural objects, their patterns and spatial relationship. Some procedures commonly used in analyzing/interpreting remote sensing images are briefly presented.

1. Pre-Processing

Prior to data analysis, initial processing on the raw data is usually carried out to correct for any distortion due to the characteristics of the imaging system and imaging conditions. Depending on the user's requirement, some standard correction procedures may be carried out by the ground station operators before the data is delivered to the end-user. These procedures include radiometric correction to correct for uneven sensor response over the whole image and geometric correction to correct for geometric distortion due to earth's rotation and other imaging conditions (such as oblique viewing). The image may also be transformed to conform to a specific map projection system. Furthermore, if accurate geographical location of an area on the image needs to be known, ground control points (GCP's) are used to register the image to a precise map (geo-referencing).

2. Image Enhancement

In order to aid visual interpretation, visual appearance of the objects in the image can be improved by image enhancement techniques such as grey level stretching to improve the contrast and spatial filtering for enhancing the edges. A bluish tint all-over the image, producing a hazy appearance is due to scattering of sunlight by atmosphere into the field of view of the sensor. This effect also degrades the contrast between different land covers.

It is useful to examine the image histograms before performing any image enhancement. The x-axis of the histogram is the range of the available digital numbers (0 to 255). The y- axis is the number of pixels in the image having a given digital number. The histograms of the three bands of this image are shown below.

Histograms of the three bands of the image.

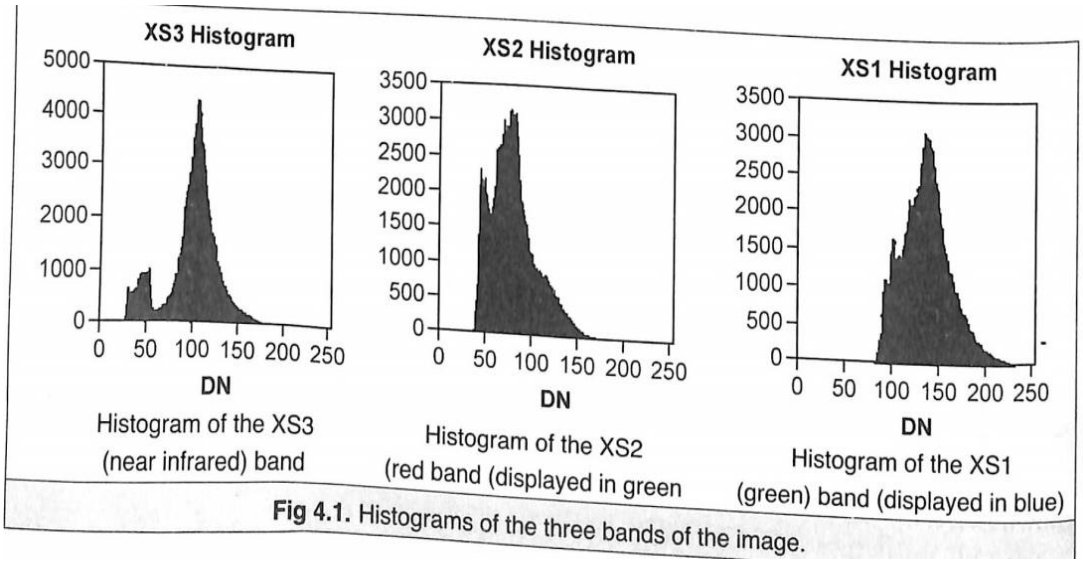


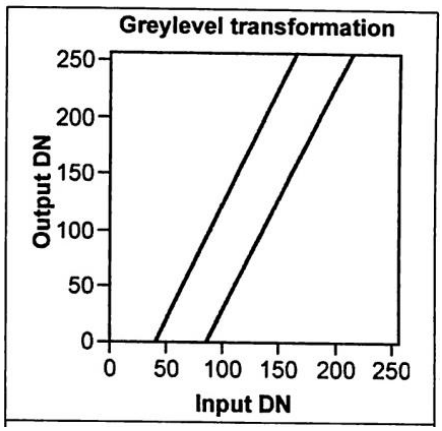
Fig 4.1. Histograms of the three bands of the image.

Note that the minimum digital number for each band is not zero. Each histogram is shifted to the right by a certain amount. This shift is due to the atmospheric scattering component adding to the actual radiation reflected from the ground. The shift is particularly large for the XS1 band compared to the other two bands due to the higher contribution from Rayleigh scattering for the shorter wavelength.

Maximum digital number of each band is also not 255. The sensor's gain factor has been adjusted to anticipate any possibility of encountering a very bright object. Hence, most of the pixels in the image have digital numbers well below the maximum value of 255.

The image can be enhanced by a simple linear grey-level stretching. In this method, a level threshold value is chosen so that all pixel values below this threshold are mapped to zero. An upper threshold value is also chosen so that all pixel values above this threshold are mapped to 255. All other pixel values are linearly interpolated to lie between 0 and 255. The lower and upper thresholds are usually chosen to be values close to the minimum and maximum pixel values of the image. The grey-level transformation table is shown in Fig 4.2.

The result of applying the linear stretch is that the hazy appearance will be removed, except for some parts near to the top of the image. The contrast between different features will be improved.



Grey-level transformation table for performing linear grey-level stretching of the three bands of the image. Red line: XS3 band, green line: XS2 band, blue line: XS1 band.

3. Image Classification

Different land covers types in an image can be discriminated using some image classification algorithms using spectral features, i.e. the brightness and "colour" information contained in each pixel. Classification procedures can be "supervised" or "unsupervised".

In **supervised classification**, the spectral features of some areas of known land covers types are extracted from the image. These areas are known as the training areas. Every pixel in the whole image is then classified as belonging to one of the classes depending on how close its spectral features are to the spectral features of the training areas.

In **unsupervised classification**, the computer program automatically groups the pixels in the image into separate clusters, depending on their spectral features. Each cluster will then be assigned a land covers type by the analyst.

Each class of land covers is referred to as a theme and the product of classification is known as a thematic map.

4. Spatial Feature Extraction

In high spatial resolution imagery, details such as buildings and roads can be seen. The amount of details depends on the image resolution. In very high resolution imagery, even road markings, vehicles, individual tree crowns and aggregates of people can be seen clearly. Pixel-based methods of image analysis will not work successfully in such imagery.

In order to fully exploit the spatial information contained in the imagery, image processing and analysis algorithms utilizing the textural, contextual and geometrical properties are required. Such algorithms make use of the relationship between neighbouring pixels for information extraction. Incorporation of a-priori information is sometimes required. A multi-resolution approach (analysis at different spatial scales and combining the resolute) is also a useful strategy when dealing with very high resolution imagery. In this case, pixel- based method can be used in

the lower resolution mode and merged with the contextual and textural method at higher resolutions.

5. Measurement of Biogeophysical Parameters

Specific instruments earned on-board the satellites can be used to make measurements of the biogeophysical parameters of the earth. Some of the examples are: atmospheric water vapour content, stratospheric ozone, land and sea surface temperature, sea water, chlorophyll concentration, forest biomass, sea surface wind field, troposphere aerosol etc. Specific satellite missions have been launched to continuously monitor the global variations of these environmental parameters that may show the causes or the effects of global climate change and the impacts of human activities on the environment.

6. Geographical Information System (GIS)

Different forms of imagery such as optical and radar images provide complementary information about the land covers. More detailed information can be derived by combining several different types of images. For example, radar image can form one of the layers in combination with the visible and near infrared layers when performing classification.

Thematic information derived from the remote sensing images is often combined with other auxiliary data to form the basis for a geographic information system (GIS). A GIS is a database of different layers, where each layer contains information about a specific aspect of the same area which is used for analysis by the resource scientists.

CHAPTER-4: GIS- SPATIAL DATA AND THEIR MANAGEMENT

Most data management professionals are more experienced with classical tabular data in **Cartesian** (rows and columns) structures as found in most business, government and scientific databases.

Geospatial data has significantly different structure and function. It includes structured data about objects in the spatial universe - their identity, location, shape and orientation and other things we may know about them. **Geographical data** describe an incredibly wide range of objects or business assets - roads, buildings, property lines, terrain, infrastructure, hydrology and ecosystems. All these objects can be described in terms of points, lines and polygons - and tables of these objects constitute the tabular portion of geospatial data.

Geographical information system (GIS) technology also accommodates some kinds of unstructured data (usually raster imagery) that can be tagged and geocoded (given precise positional characteristics) and integrated by GIS software to the other kinds of map data.

Thus, the management of GIS data and metadata is somewhat different. Whereas traditional tabular data could be understood by a human looking at any printed expression of the data (usually in rows and columns, even on paper), raw GIS data is generally meaningless to the human eye until converted into a map. This is what GIS software does.

What is a GIS?

A **geographic information system (GIS)** is a computer-based tool for mapping and analyzing things that exist and events that happen on earth. GIS technology integrates common database operations such as query and statistical analysis with the unique visualisation and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes and planning strategies.

Whether a new business, finding the best soil for growing crops or figuring out the best route for an emergency vehicle, local problems also have a geographical component. GIS will give you the power to create maps, integrate information, visualize scenarios, solve complicated problems, present powerful ideas and develop effective solutions like never before. GIS is a tool used by individuals and organizations, schools, governments and businesses seeking innovative ways to solve their problems.

Mapmaking and geographic analysis are not new, but a GIS performs these tasks better and faster than do the old manual methods. Before GIS technology, only a few people had the skills necessary to use geographic information to help with decision making and problem solving.

Today, GIS is a multibillion-dollar industry employing hundreds of thousands of people worldwide. GIS is taught in schools, colleges and universities throughout the world. Professionals in every field are increasingly aware of the advantages of thinking and working geographically.

Importance of GIS

Importance of GIS has been briefly presented below:

1. Perform Geographic Queries and Analysis

The ability of GISs to search databases and perform geographic queries has saved many companies literally millions of dollars. GISs have helped reduce costs by:

1. Streamlining customer service.
2. Reducing land acquisition costs through better analysis.
3. Reducing fleet maintenance costs through better logistics.
4. Analyzing data quickly, as in this example: A realtor could use a GIS to find all houses within a certain area that have tiled roofs and five bedrooms, then list their characteristics.

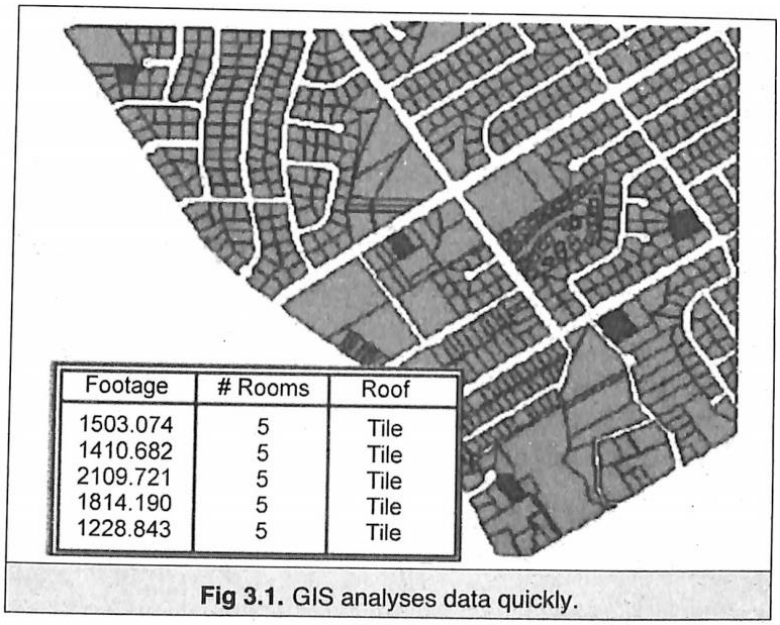


Fig 3.1. GIS analyses data quickly.

2. Improve Organizational Integration

Many organizations that have implemented GIS have found that one of its main benefits is improved management of their own organisation and resources. Because GISs have the ability to link data sets together by geography, they facilitate interdepartmental information sharing and communication. By creating a shared database, one department can benefit from the work of another - data can be collected once and used many times.

As communication increases among individuals and departments, redundancy is reduced, productivity is enhanced and overall organisational efficiency is improved (Fig 3.2). Thus, in a utility company the customer and infrastructure databases can be integrated so that when there is planned maintenance, affected customers can be sent a computer-generated letter.

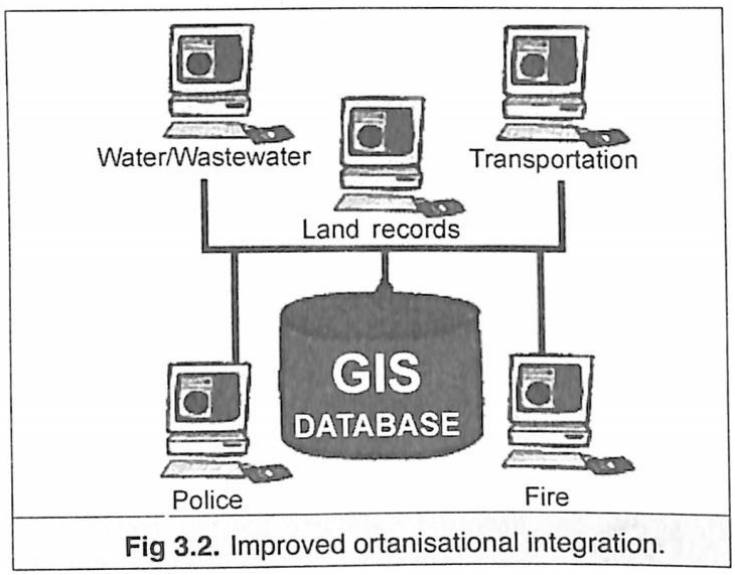


Fig 3.2. Improved ortanisational integration.

3. Make Better Decisions

The old adage "better information leads to better decisions" is as true for GIS as it is for other information systems. A GIS, however, is not an automated decision making system but a tool to query, analyze and map data in support of the decision making process. The GIS technology has been used to assist in tasks such as presenting information at planning inquiries, helping resolve territorial disputes and siting **pylons** in such a way as to minimize visual intrusion.

The GIS can be used to help reach a decision about the location of a new housing development that has minimal environmental impact, is located in a low-risk area and is close to a population canter. The information can be presented succinctly and clearly in the form of a map and accompanying report, allowing decision makers to focus on the real issues rather than trying to understand the data. Because GIS products can be produced quickly, multiple scenarios can be evaluated efficiently and effectively.

4. Making Maps

Maps have a special place in GIS. The process of making maps with GIS is much more flexible than are traditional manual or automated **cartography** approaches. It begins with database creation (Fig 3.3). Existing paper maps can be digitized and computer-compatible information can be translated into the GIS. The GIS-based cartographic database can be both continuous and scale tree. This allows the creation of map products which are cantered on any location, at any scale and showing selected information symbolized effectively to highlight specific characteristics.

The characteristics of atlases and map series can be encoded in computer programmes and compared with the database at final production time. Digital products for use in other GISs can also be derived by simply copying data from the database. In a large organization, topographic databases can be used as reference frameworks by other departments.

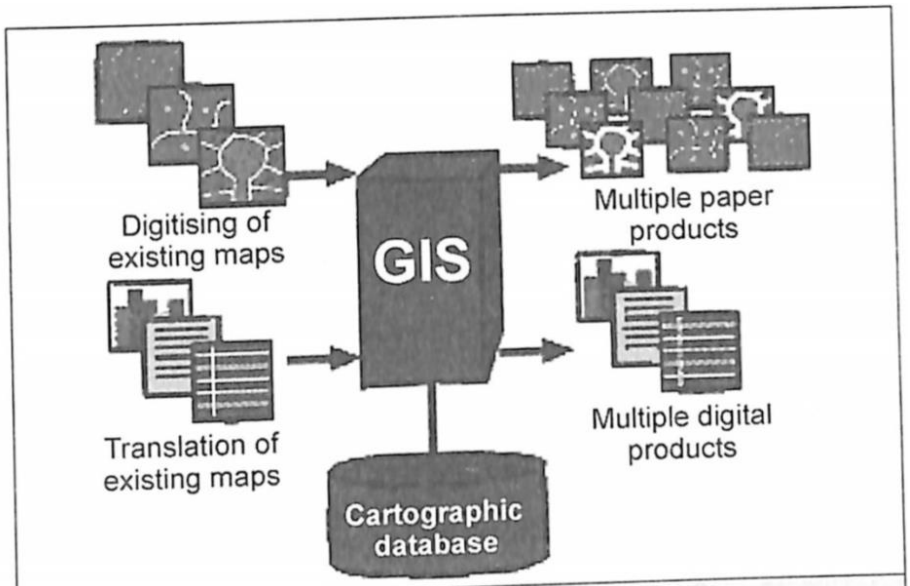


Fig 3.3. Creation of map products.

How GIS Works?

A GIS stores information about the world as a collection of thematic layers that can be linked together by geography. This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world problems from tracking delivery vehicles, to recording details of planning applications, to modeling global atmospheric circulation.

Geographic References

Geographic information contains either an explicit **geographic reference**, such as a latitude and longitude or national grid coordinate or an implicit reference such as an address, postal code, census tract name, forest stand identifier or road name. An automated process called **geocoding** is used to create explicit geographic references (multiple locations) from implicit references (descriptions such as addresses). These geographic references allow location of features, such as a business or forest stand and events, such as an earthquake, on the earth's surface for analysis.

Vector and Raster Models

Geographic information systems work with two fundamentally different types of geographic models - the "vector" model and the "raster" model. In the **vector model**, information about points, lines and polygons is encoded and stored as a collection of x, y coordinates. The location of a point feature, such as a bore-hole, can be described by a single x, y coordinate. Linear features, such as roads and rivers, can be stored as a collection of point coordinates. **Polygonal features**, such as sales territories and river catchments, can be stored as a closed loop of coordinates.

The **vector model** is extremely useful for describing discrete features, but less useful for describing continuously varying features such as soil type or accessibility costs for hospitals. The **raster model** has evolved to model such continuous features. A raster image comprises a collection of grid cells rather like a scanned map or picture. Both the vector and raster models for storing geographic data have unique advantages and disadvantages. Modem GISs are able to handle both models.

Components of a GIS

A working GIS integrates five key components: hardware, software, data, people and methods.

Hardware

It is the computer on which a GIS operates. Today, GIS software runs on a wide range of hardware types, from centralized computer servers to desktop computers used in stand-alone or networked configurations.

Software

The GIS software provides the functions and tools needed to store, analyze and display geographic information. Key software components are:

1. Tools for the input and manipulation of geographic information.
2. A database management system (DBMS).
3. Tools that support geographic query, analysis and visualisation.
4. A graphical user interface (GUI) for easy access to tools.

Data

Possibly, the most important component of a GIS is the data. Geographic data and related tabular data can be collected in-house or purchased from a commercial data provider. A GIS will integrate spatial data with other data resources and can even use a DBMS, used by most organizations to organize and maintain their data, to manage spatial data.

People

The GIS technology is of limited value without the people who manage the system and develop plans for applying it to real-world problems. The GIS users range from technical specialists who design and maintain the system to those who use it to help them perform their everyday work.

Methods

A successful GIS operates according to a well-designed plan and business rules, which are the models and operating practices unique to each organisation.

CHAPTER-5: SOIL MAPPING AND FERTILIZER RECOMMENDATION

SOIL MAPPING

Soil maps are required on different scales varying from 1:1 million to 1:4,000 to meet the requirements of planning at various levels. As the scale of a soil map has direct correlation with the information content and field investigations that are carried out, small scale soil maps of 1:1 million are needed for macro-level planning at national level. Soil maps at 1:250,000 scale provide information for planning at regional or state level with generalized interpretation of soil information for determining the suitability and limitations for several agricultural uses and requires less intensity of soil observations and time. Soil maps at 1:50,000 scale where association of soil series are depicted, serve the purpose for planning resources conservation and optimum land use at district level and require moderate intensity of observations in the field. Large scale soil maps at 1:8,000 or 1:4,000 scale are specific purpose maps which can be generated through high intensity of field observations based on maps at 1:50,000 scale of large scale aerial photographs or very high resolution satellite data. Similarly, information on degraded lands like salt affected soils, eroded soils, waterlogged areas, *jhum* lands (shifting cultivation) etc. is required at different scales for planning strategies for reclamation and conservation of degraded lands.

Remote Sensing for Soil and Land Degradation Mapping

Though conventional soil surveys were providing information on soils they are subjective, time consuming and laborious. Remote sensing techniques have significantly contributed speeding up conventional soil survey programmes. In conventional approach approximately 80 per cent of total work requires extensive field traverses in identification of soil types and mapping their boundaries and 20 per cent in studying soil profiles, topographical features and for other works. In the case of soil surveys with aerial photographs or satellite data, considerable field work with respect to locating soil types and boundaries is reduced owing to synoptic view. Remote sensing techniques have reduced field work to a considerable extent and soil boundaries are more precisely delineated than in conventional methods. Satellite data were utilized in preparing small scale soil resource maps showing soil subgroups and their association for about three decades. Remote sensing data from LandSat MSS are used for mapping soils and degraded lands like eroded lands, ravine lands, salt- affected soils and shifting cultivation areas. LandSat TM, SPOT and IRS satellites enabled to map soils at 1:50,000 scale at the level of association of soil series due to higher spatial and spectral resolutions. In one of the major projects in Department of Space, Government of India - “Integrated Mission for Sustainable Development”-the soil mapping has been taken up at 1:50,000 scale for about 175 districts/blocks in the country. With the availability of PAN data with 5.8 m spatial resolution from IRS-1C/1D satellites soil resources mapping at 1:25,000 or larger scale has been attempted using PAN merged LISS-III data. The IKONOS data has the potential for farm level soil mapping (>1:10,000). At NRSA, the maps of salt affected soils for entire country have been prepared at 1:250,000 scale using satellite data from

LandSat TM / IRS sensors with accepted nation-wide legend for mapping salt affected soils in association with Central and State government organizations. Salt affected soils are also mapped at 1:50,000 scale on limited scale using satellite data. Multi-temporal satellite data is being used for monitoring salt affected soils on operational basis. Satellite data have also been utilized in qualitative assessment of soil erosion in north-eastern states of Manipur, Tripura and Arunachal Pradesh and to monitor eroded and shifting cultivation areas in Tripura. Similarly, remotely sensed data from TM and IRSLISS-I/II have also been used in studying ravine lands, waterlogged areas and impact of mining on forest environment.

Soil Mapping Methods

Soil surveyors consider the topographic variation as a base for depicting the soil variability. Even with the aerial photographs, only physiographic variation in terms of slope and aspects and land cover are being practiced for delineating the soil boundary. Multispectral satellite data are being used for mapping soil up to family association level (1.50,000). Methodology in most of the cases involves visual interpretation. However, computer aided digital image processing technique has also been used for mapping soil and advocated to be a potential tool.

Visual Image Interpretation

Visual interpretation is based on shape, size, tone, shadow, texture, pattern, site and association. This has the advantage of being relatively simple and inexpensive. Soil mapping needs identification of a number of elements. The elements which are of major importance for soil survey are land type, vegetation, land-use, slope and relief. Soils are surveyed and mapped, following a three-tier approach, comprising interpretation of remote sensing imagery and/or aerial photograph, field survey (including laboratory analysis of soil samples) and cartography. Several workers have concluded that the technology of remote sensing provides better efficiency than the conventional soil survey methods at the reconnaissance (1:50,000) and detailed (1:10,000) scale of mapping.

Computer-Aided Approach

Numerical analysis of remote sensing data utilizing the computers has been developed because of requirement to analyze faster and extract information from the large quantities of data. Computer aided techniques utilize the spectral variations for classification. Pattern recognition in remote sensing assists in identification of homogeneous areas, which can be used as a base for carrying out detailed field investigations and generating models between remote sensing and field parameters. Major problem with conventional soil survey and soil cartography is accurate delineation of boundary. Field observations based on conventional soil survey are tedious and time consuming. Remote sensing data in conjunction with ancillary data provide the best alternative, with a better delineation of soil mapping units. However, there is need to have an automated method for accurate soil boundary delineation with a trans-disciplinary and integrated approach.

Fertilizer recommendation using GIS

Morden frontier technologies involving system approach for efficient crop and input management is the need of present century to optimize yields and reduce pressure on natural resources leading to **sustainable agricultural management**. This vision, reflected in the concept of **precision farming**, offers the promise of increasing productivity while decreasing production costs and minimizing environmental impacts. The high-tech tools of precision farming are: an integration of several advanced technologies like geographic information system (GIS), global positioning systems (GPS), remote sensing, crop models, ground-based sensors and the internet. With the rapid pace of sensor improvement in the current satellite series (IRIS, LANDSAT, SPOT and IKONOS) and some future missions (EYE GLASS, ORB VIEW and GREENSAT), a range of high resolution both spatial and temporal would be available to map and quantify field scale crop response to variable soil, weather condition and farm management practices leading to precise crop management.

Geospatial technologies for precision farming (PF) involves an integrated technology such as GPS, GIS, remote sensing, variable rate technology (VRT), crop models, yield monitors and precision irrigation. Various configurations of these technologies are suitable for different precision farming operations. **Information technology** such as the internet is good means for some agri-business companies to deliver their services and products.

Site specific nutrient management (SSNM) approach, relatively new approach of nutrient recommendations, is mainly based on the indigenous nutrient supply from the soil and nutrient demand of the crop for achieving targeted yield. The SSNM recommendations could be evolved on the basis of solely plant analysis or soil-cum-plant analysis.

PLANT ANALYSIS BASED SSNM

It is considered that the nutrient status of the crop is the best indicator of soil nutrient supplies as well as nutrient demand of the crops. Thus, the approach is built around **plant analysis**. Initially, SSNM was tried for lowland rice, but subsequently, it proved advantageous to several contemporary approaches of fertilizer recommendations in rice, wheat and other rice-based production systems prevalent in Asian countries. Five key steps for developing field-specific fertilizer NPK recommendations have been developed for rice, through the basic principles remain the same for other crops as well.

1. Selection of the Yield Goal

A yield goal exceeding 70-80 per cent of the variety-specific potential yield (Ymax) has to be chosen. Ymax is defined as the maximum possible grain yield limited only by climatic conditions of the site, where there are no other factors limiting crop growth. The logic behind selection of the yield goal to the extent of 70-80 per cent of the Ymax is that the internal NUES decrease at very high yield levels near Ymax. Crop growth models (DSSAT) can be used to work out Ymax of crop variety under a particular climatic conditions.

2. Assessment of Crop Nutrient Requirement

The nutrient uptake requirements of a crop depend both on yield goal and Ymax. In SSNM, nutrient requirements are estimated with the help of quantitative evaluation of fertility of tropical soils (QUEFTS) models. Nutrient requirements for a particular yield goal of a crop variety may be smaller in a high yielding season than in a low yielding one.

3. Estimation of Indigenous Nutrient Supplies

Indigenous nutrient supply (INS) is defined as the total amount of a particular nutrient that is available to the crop from the soil during the cropping cycle, when other nutrients are non-limiting. The INS is derived from soil incorporated crop residues, water and atmospheric deposition. It is estimated by measuring plant nutrient uptake in an omission plot embedded in the farmers' field, wherein all other nutrients except the one (N, P or K) in question, are applied in sufficient amounts.

4. Computation of Fertilizer Nutrient Rates

Field-specific fertilizer N, P or K recommendations are calculated on the basis of above steps (1-3) and the expected **fertilizer recovery efficiency** (RE, kg of fertilizer nutrient taken up by the crop per kg of the applied nutrient). Studies indicated RE values of 40-60 % for N, 20-30 % for P and 40-50 % for K in rice under normal growing conditions, when the nutrients are applied as water soluble fertilizer sources.

5. Dynamic Adjustment of N Rates

Whereas fertilizer P and 11, as computed above, are applied basally (at the time of I sowing/planting), the N rates and application schedules can be further adjusted as per the crop demand using **chlorophyll meter** (popularly known as **SPAD**) or **leaf colour chart (LCC)**. Recent on-farm studies in India and elsewhere have revealed a significant advantage of SPAD/LCC-based N management schedules in rice and wheat in terms of yield gain, N use efficiency and economic returns over the conventionally recommended N application involving 2 or 3 splits during crop growth irrespective of N supplying capacity of the soils. In winter season maize crop, SPAD-based (≤ 37) N application resulted in a saving of 55 Kg N/ha as compared to soil test crop response equation-based N application without any yield reduction. **Agronomic efficiency** was also higher in the crop. In wheat, timing of N application at SPAD value ≤ 42 resulted in 9 % higher wheat yield along with 20 kg/ha N saving, than the recommended soil based N supply.

SOIL-CUM-PLANT ANALYSIS BASED SSNM

In this case, nutrient availability in the soil, plant nutrient demands for a higher target yield (not less than 80% of Ymax) and RE of applied nutrients are considered for developing fertilizer use schedule to achieve maximum economic yield of a crop variety. In order to ascertain desired crop growth, not limited by apparent or **hidden huger** of nutrients, soil is analyzed for all macro and micronutrients well-before sowing/planting. Total nutrient requirement for the **targeted yield** and RE are estimated with the help of documented information available for similar crop growing environments. **Field-specific fertilizer rates** are then suggested to meet the nutrient demand of the crop (variety) without depleting soil reserves. These **soil-test crop**

response (STCR) based recommendations are now in practice to achieve desired yield targets in many field crops. Thus, recent studies with intensive cropping systems have shown that fertilizer recommendations with above approach offer greater economic gains as compared with NPK fertilizer schedules conventionally prescribed by **soil testing laboratories.**

1. Decision Support Systems

Nutrient Expert® (NE) is an easy-to-use, interactive and computer-based decision support tool that can rapidly provide nutrient recommendations for an individual farmer field in the presence or absence of **soil testing** data. NE is nutrient decision support software that uses the principles of SSNM and enables farm advisors to develop fertilizer recommendations tailored to a specific field or growing environment. NE allows users to draw required information from their own experience, farmers' knowledge of the local region and farmers' practices. NE can use experimental data but it can also estimate the required SSNM parameters using existing site information. The **algorithm** for calculating fertilizer requirements in NE is determined from a set of on-farm trial data using SSNM guidelines. The parameters needed in SSNM are usually measured in **nutrient omission trials** conducted in farmers' fields, which require at least one crop season. With NE, parameters can be estimated using proxy information, which allows farm advisors to develop fertilizer guidelines for a location without data from field trials.

2. Decision Rules to Estimate Site-Specific Nutrient Management Parameters

The NE estimates attainable yield and yield response to fertilizer from site information using decision rules developed from on-farm trials. Specifically, NE uses characteristics of the growing environment—water availability (irrigated, fully rainfed and rainfed with supplemental irrigation) and any occurrence of flooding or drought, soil fertility indicators- soil texture, soil color and organic matter content, soil test for P or K (if available), historical use of organic materials (if any) and problem soils (if any), crop sequence in farmer's cropping pattern; crop residue management and fertilizer inputs for the previous crop and farmers' current yields. Data for specific crops and specific geographic regions are required in developing the decision rules for NE. The datasets must represent diverse conditions in the growing environment characterized by variations in the amount and distribution of rainfall, crop cultivars and growth durations, soils and cropping systems.

3. Current Versions of Nutrient Expert

The NE has been developed for specific crops and geographic regions. Nutrient Expert® for hybrid maize (**NEHM**) for favourable tropical environments (South-East Asia) was developed in late 2009 and underwent field evaluation in Indonesia and the Philippines. Using NEHM as a model, the NE concept has been adapted to other crops and geographic regions or countries. In 2011, beta versions of NE for maize were developed for South Asia, China, Kenya and Zimbabwe. Likewise, beta versions of NE for wheat were developed for South Asia as well as China. In 2013, field validated versions of NE maize and NE wheat have been released for public use in South Asia and China.

CHAPTER-6 : GLOBAL POSITIONING SYSTEM (GPS) COMPONENTS AND ITS FUNCTIONS

Global positioning system (GPS) is a satellite-based navigation system, consisting of more than 20 satellites and several supporting ground facilities, which provides accurate, three dimensional position, velocity and time, 24 hours a day, everywhere in the world and in al weather conditions. The global positioning system consists of three main components.

GPS Components

Basic components of global positioning are briefly presented.

I. GPS Ground Control Stations

The ground control component includes the master control station at Falcon Air Force Base, Colorado Springs, Colorado and monitor stations at Falcon AFB, Hawaii, Ascension Island in the Atlantic, Diego Garcia in the Indian Ocean and Kwajalein Island in the South Pacific. The control segment uses measurements collected by the monitor stations to predict the behaviour of each satellite's orbit and atomic clocks. Prediction data is linked up to the satellites for transmission to users. The control segment also ensures that GPS satellite orbits remain within limits and that the satellites do not drift too far from nominal orbits.

II. GPS Satellites

The space segment includes the satellites and the delta rockets that launch the satellites from Cape Canaveral in Florida, United States. GPS satellites orbit in circular orbits at 17,440 km altitude, each orbit lasting 12 hours. The orbits are tilted to the equator by 55 A° to ensure coverage in Polar Regions. The satellites are powered by solar cells to continually orientate themselves to point the solar panels towards the sun and the antennas towards the earth. Each satellite contains four atomic clocks.

III. GPS Receivers

When you buy a GPS, you are actually buying only GPS receiver and get free use of the other two main components, worth billions of dollars - compliments of the Government of the United States.

The ground stations send control signals to the GPS satellites. The GPS satellites transmit radio signals and the GPS receivers, receive these signals and use it to calculate its position.

Calculations used to determine your GPS receiver's position is based on very small time differences, from when the satellite transmitted the signal, to, when the GPS receiver received the signal. These small differences are then used to calculate the distance from the receiver to the satellite. However, when receiving only one signal, we can only calculate how far away from the satellite we are. When receiving two signals, we can determine two likely positions where we are. We need three satellite signals to determine our exact position on the earth's surface. (2D/2 dimensional positioning). When more than three satellites are 'visible' to the GPS receiver, it will also calculate the altitude of the receiver (3D/3 dimensional positioning).

The GPS receiver requires signals from at least three satellites to determine your unique position on the earth's surface. With a fourth signal, altitude can also be determined. Receiving

signals from more than four different satellites, the position of the GPS receiver can more accurately be determined.

The GPS satellite constellation is designed in such a manner as to guarantee that at least four satellites are visible from any place on earth at any moment in time. Most of the time (+95%) however, we should have at least six satellites visible. Many commercial GPS receivers can receive and process signals from 12 satellites for increased reliability and accuracy.

The GPS satellites carry atomic clocks that measure time to a high degree of accuracy. Time information is placed in the codes broadcast by the satellite so that a receiver can continuously determine the time the signal was broadcast. The signal contains data that a receiver uses to compute the locations of the satellites and to make other adjustments needed for accurate positioning. Receiver uses the time difference between the time of signal reception and the broadcast time to compute the range to the satellite. Receiver must account for propagation delays caused by the ionosphere and the troposphere. With three ranges to three satellites and knowing the location of the satellite when the signal was sent, the receiver can compute its three-dimensional position.

To compute ranges directly, however, the user must have an atomic clock synchronised to the global positioning system. By taking a measurement from an additional satellite, the receiver avoids the need for an atomic clock. The result is that the receiver uses four satellites to compute latitude, longitude, altitude and time.

GPS Functions

The GPS functions include:

1. **Giving a location:** This is the whole point of a navigation system: its ability to accurately triangulate your position based on the data transmissions from multiple satellites. It will give your location in coordinates, either latitude and longitude or Universal Transverse Mercators (UTMs). Developed by the military, UTMs are used to pinpoint a location on a map. Most topographical maps have UTM gridlines printed on them.
2. **Point-to-point navigation:** This GPS navigation feature allows you to add waypoints to your trips. By using a map, the coordinates of a trailhead or road or the point where you are standing, you can create a point-to-point route to the place where you are headed. You will have the trip mapped out, including any stops you add in.
3. **Plot navigation:** This feature in a global positioning system allows you to combine multiple waypoints and move point-to-point. Once you reach the first waypoint, the GPS can automatically point you on your way to the next one. The waypoint management software comes with most handheld GPS units for easy database management.
4. **Keeping track of your track:** Tracks are some of the most useful functions of portable navigation systems. You can map where you have already been. This virtual map is called a track and you can programme the GPS system to automatically drop track-points as you

travel, either over intervals of time or distance. This can be done on land or in a nautical setting and allows you to retrace your steps.

GPS Applications

The GPS applications include:

Guidance

- Point guidance.
- Swath guidance.

Control

- Variable rate application.
- Variable tillage depth.
- Variable irrigation.

Mapping

- Soil properties.
- Chemical application.
- Chemical prescriptions.
- Tillage maps.
- Yield mapping.
- Pest mapping.
- Topographic maps.
- Planting maps.

CHAPTER-7: CROP SIMULATION MODEL

Modeling and simulation is a discipline for developing a level of understanding of the interaction of the parts of a system and of the system as a whole. The level of understanding which may be developed via this discipline is seldom achievable via any other discipline.

Modeling and simulation is a discipline, it is also very much an art form. One can learn about riding a bicycle from reading a book. To really learn to ride a bicycle one must become actively engaged with a bicycle. Modeling and simulation follows much the same reality. You can learn much about modeling and simulation from reading books and talking with other people. Skill and talent in developing models and performing simulations is only developed through the building of models and simulating them. It is very much learn as you go process. From the interaction of the developer and the models emerges an understanding of what makes sense and what doesn't.

Simulation can be broadly defined as a technique for studying real-world dynamical systems by imitating their behaviour using a mathematical model of the system implemented on a digital computer.

Simulation can also be viewed as a numerical technique for solving complicated probability models, ordinary differential equation and partial differential equation, analogously to the way in which we can use a computer to numerically evaluate the integral of a complicated function. That is why science of simulation is considered as an interdisciplinary subject as shown in Fig 5.1.

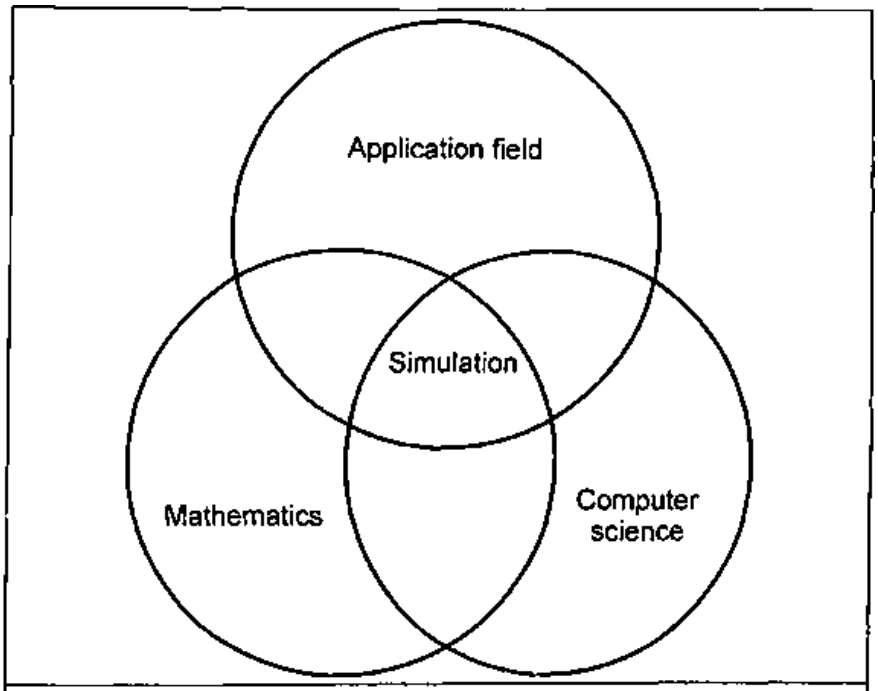


Fig 5.1. Simulation is interdisciplinary.

Computer simulation is a powerful methodology for design and analysis of complex systems. Overall approach in computer simulation is to represent the dynamic characteristics of a real-world system in a computer model. The model is subjected to experiments to obtain predictive information useful in making informed decision making about the characteristics of the real-system. Simulations are suitable for problems in which there are no closed-form analytical solutions. Since most dynamic problems in practice cannot be represented and solved fully using mathematical equations, computer simulation is a powerful and flexible methodology in complex systems analysis.

Simulations can be classified into continuous and discrete simulations. In continuous simulations, the state variables, i.e. the collection of variables needed to describe the system, change continuously over time and the behaviour of the system is typically described by differential equations. Examples of continuous systems include the modeling of thermal or hydraulic systems. Discrete simulations are event-driven where the state variables change at discrete time points. Examples of discrete-event simulations include service industry applications such as queues in a grocery store and manufacturing applications involving material flow analysis. In general, there are three different methods to study a real-system.

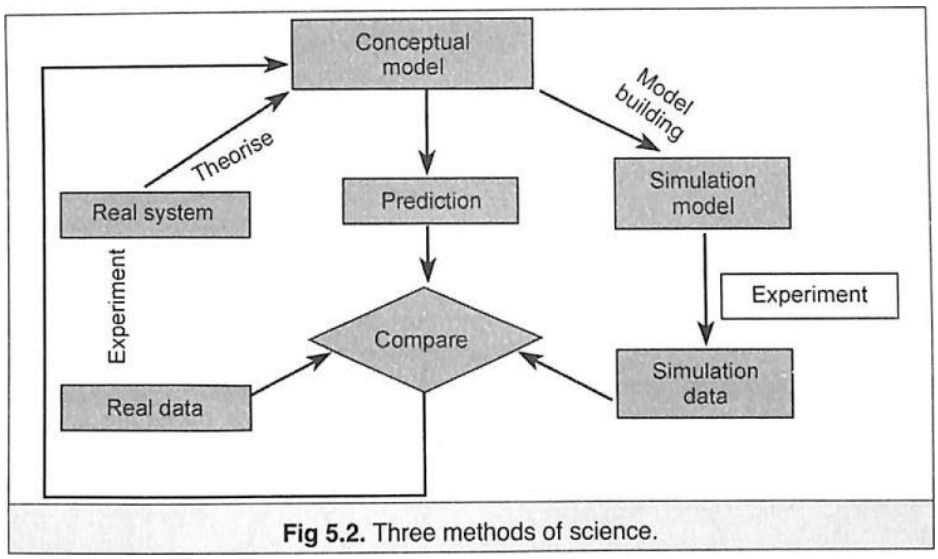


Fig 5.2. Three methods of science.

Briefly we can say that:

- Simulated system imitates operation of actual system over time.
- Artificial history of system can be generated and observed.
- Internal (perhaps unobservable) behaviour of system can be studied.
- Time scale can be altered as needed.
- Conclusions about actual system characteristics can be inferred, actual system (real system) is compared with simulation.

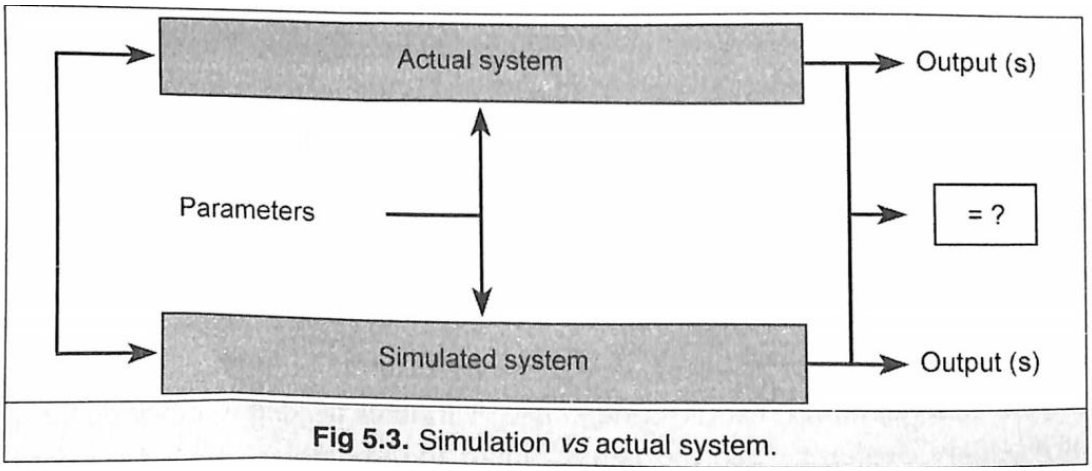


Fig 5.3. Simulation *vs* actual system.

WHEN TO USE SIMULATION?

There are several situations in which simulations can be used as indicated below: Study internals of a complex system e.g. biological system.

- Optimize an existing design e.g. routing algorithms, assembly line.
- Examine effect of environmental changes e.g. weather forecasting.
- System is dangerous or destructive e.g. atom bomb, atomic reactor, missile launching.
- Study importance of variables.
- Verify analytic solutions (theories).
- Test new designs or policies.
- Impossible to observe/influence/build the system.
- When it allows inspection of system internals that might not otherwise be observable.
- Observation of the simulation gives insights into system behaviour.
- System parameters can be adjusted in the simulation model allowing assessment of their sensitivity (scale of impact on overall system behaviour).
- Simulation verifies analysis of a complex system or can be used as a teaching tool to provide insight into analytical techniques.
- A simulator can be used for instruction, avoiding tying up or damaging an expensive, actual system (e.g. a flight simulation *v/s* use of multimillion dollar aircraft).

MODELLING CONCEPTS

There are several concepts underlying simulation. These include system and model, events, system state variables, entities and attributes, list processing, activities and delays and finally the definition of discrete-event simulation.

The process of making and testing hypotheses about models and then revising designs or theories has its foundation in the experimental sciences. Similarly, computational scientists use modeling to analyze complex, real-world problems in order to predict what might happen with some course of action. For example, Dr Julianne Collins, a genetic epidemiologist (statistical

genetics) at the Greenwood Genetics Canter, runs genetic analysis programmes and analyses epidemiological studies using the Statistical Analysis Software (SAS). Scientists are using a combination of mathematics, signal processing and scientific visualization to model, image and discover land mines.

1. System, Model and Events

A model is a representation of an actual system presents modeling and simulation concepts as introduced by Zeigler.

- A model is an abstraction of the real system.
- Simplifying assumptions are used to capture (only) important behaviours.
- Linearization, time-bound behaviours etc. may make analysis tractable.

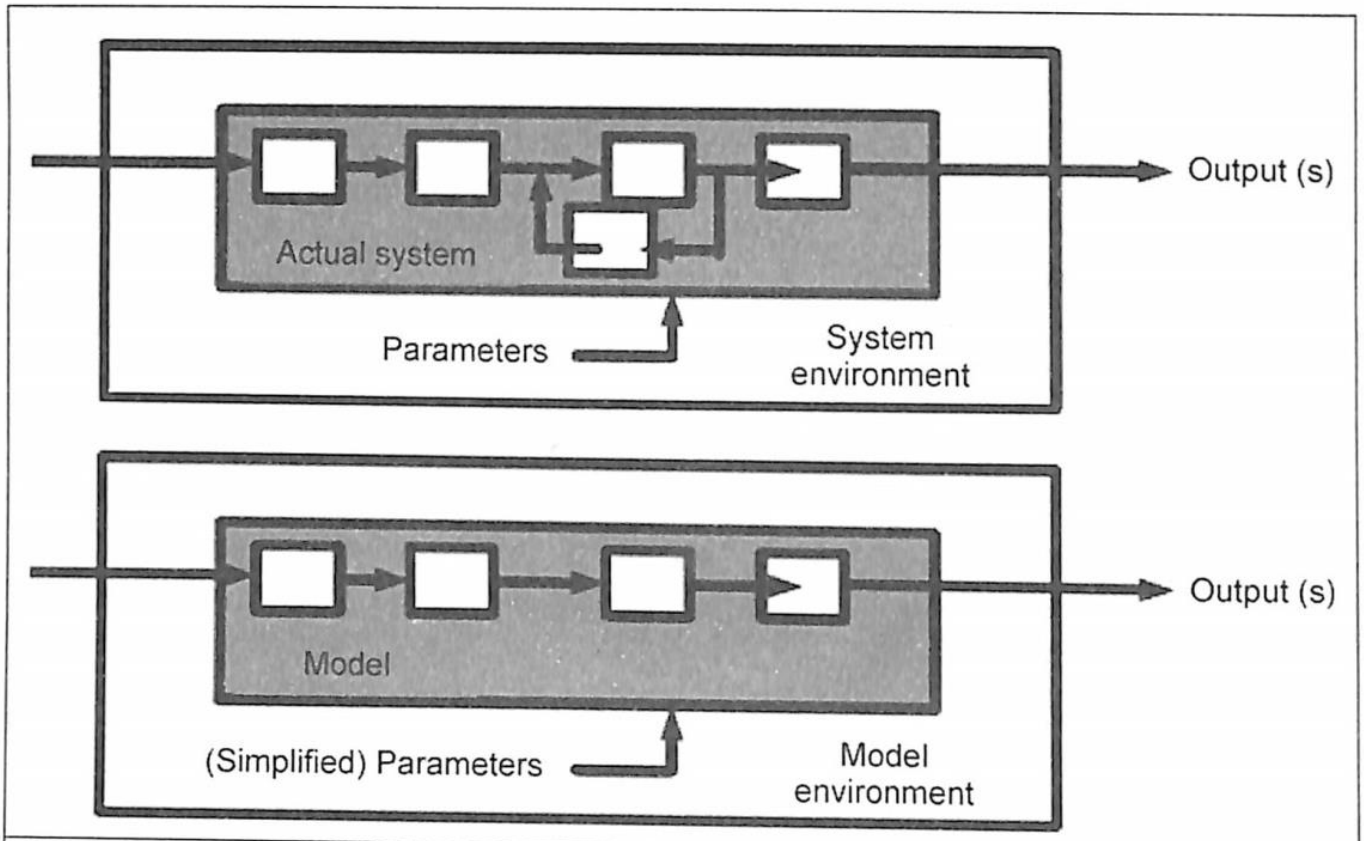


Fig 5.4. Pictorial representation of system model.

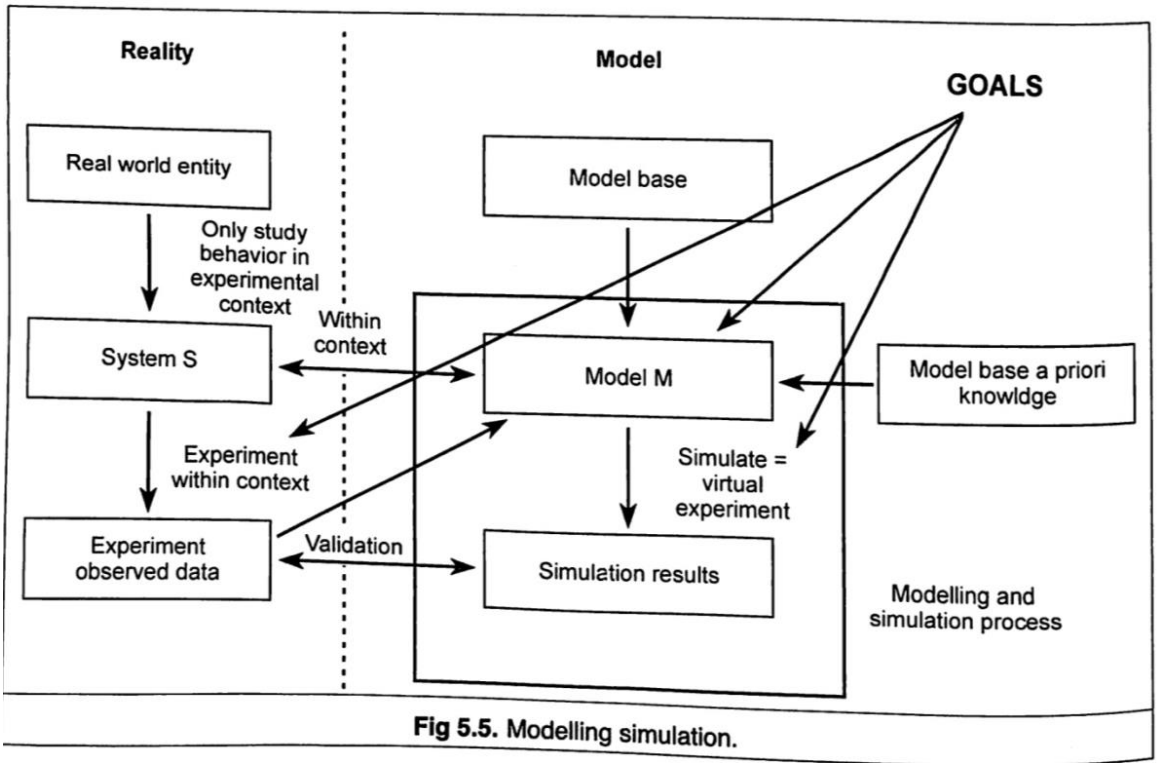


Fig 5.5. Modelling simulation.

Modeling is defined as the application of methods to analyze complex, real-world problems in order to make predictions about what might happen with various actions.

Object: It is some entity in the real-world. Such an object can exhibit widely varying behaviour depending on the context in which it is studied, as well as the aspects of its behaviour which are under study.

Base model: It is the hypothetical, abstract representation of the object's properties, in particular, its behaviour, which is valid in all possible contexts and describes all the object's facets. A base model is hypothetical as we will never, in practice, be able to construct/represent such a total model. The question whether a base model exists at all is a philosophical one.

System: System is a well-defined object in the real-world under specific conditions, only considering specific aspects of its structure and behaviour.

Experimental frame: When one studies a system in the real-world, the experimental frame (EF) describes experimental conditions (context), aspects, within which that system and corresponding models will be used. As such, the experimental frame reflects the objectives of the experimenter who performs experiments on a real system or through simulation on a model.

Immediately, there is a concern about the limits or boundaries of the model that supposedly represent the system. The model should be complex enough to answer the questions raised, but not too complex. Consider an event as an occurrence that changes the state of the system. In the example, events include the arrival of a customer for service at the bank, the beginning of service for a customer and the completion of a service. There are both internal and

external events, also called endogenous and exogenous events, respectively. For example, an endogenous event in the example is the beginning of service of the customer since that is within the system being simulated. An exogenous event is the arrival of a customer for service since that occurrence is outside of the simulation. However, the arrival of a customer for service impinges on the system and must be taken into consideration.

Discrete-event simulation models are contrasted with other types of models such as mathematical models, descriptive models, statistical models and input-output models. A discrete-event model attempts to represent the components of a system and their interactions to such an extent that the objectives of the study are met. Most mathematical, statistical and input output models represent a system's inputs and outputs explicitly, but represent the internals of the model with mathematical or statistical relationships. An example is the mathematical model from physics, based on theory. Discrete-event simulation models include a detailed representation of the actual internals.

Force = Mass x Acceleration

Discrete-event models are dynamic, i.e. the passage of time plays a crucial role. Most mathematical and statistical models are static in that they represent a system at a fixed point of time. Consider the annual budget of a firm. This budget resides in a spreadsheet. Changes can be made in the budget and the spreadsheet can be recalculated, but the assage of time is usually not a critical issue. Further comments will be made about discrete-event models after several additional concepts are presented.

Models have many uses, typically:

- To understand the behaviour of an existing system (why does my network performance die when more than 10 people are at work?).
- To predict the effect of changes or upgrades to the system (will spend 100,000 on a new switch cure the problem?).
- To study new or imaginary systems (let's bin the ethernet and design our own scalable custom routing network).

2. System State Variables

System state variables are the collection of all information needed to define what is happening within the system to a sufficient level {i.e. to attain the desired output) at a given point in time. Determination of system state variables is a function of the purposes of the investigation, so what may be the system state variables in one case may not be the same in another case even though the physical system is the same.

Determining the system state variables is as much an art as a science. However, during the modelling process, any omissions will readily come to light. (And, on the other hand, unnecessary state variables may be eliminated.) Having defined system state variables, a contrast can be made between discrete-event models and continuous models based on the variables needed to track the system state. System state variables in a discrete-event model remain

constant over intervals of time and change value only at certain well-defined points called event times. Continuous models have system state variables defined by differential or difference equations giving rise to variables that may change continuously over time.

Some models are mixed discrete-event and continuous. There are also continuous models that are treated as discrete-event models after some re-interpretation of system state variables and vice versa.

Entities and Attributes

An entity represents an object that requires explicit definition. An entity can be dynamic in that it "moves" through the system or it can be static in that it serves other entities. In the example, the customer is a dynamic entity, whereas the bank teller is a static entity.

An entity may have attributes that pertain to that entity alone. Thus, attributes should be considered as local values. In the example, an attribute of the entity could be the time of arrival. Attributes of interest in one investigation may not be of interest in another investigation. Thus, if red parts and blue parts are being manufactured, the colour could be an attribute. However, if the time in the system for all parts is of concern, the attribute of colour may not be of importance. From this example, it can be seen that many entities can have the same attribute or attributes (i.e. more than one part may have the attribute "red").

Resources

A resource is an entity that provides service to dynamic entities. The resource can serve one or more than one dynamic entity at the same time i.e. operates as a parallel server. A dynamic entity can request one or more units of a resource. If denied, the requesting entity joins a queue or takes some other action {i.e. diverted to another resource, ejected from the system). Other terms for queues include files, chains, buffers and waiting lines. If permitted to capture the resource, the entity remains for a time and then releases the resource.

There are many possible states of the resource. Minimally, these states are idle and busy. But other possibilities exist including failed, blocked or starved.

List Processing

Entities are managed by allocating them to resources that provide service, by attaching them to event notices thereby suspending their activity into the future or by placing them into an ordered list. Lists are used to represent queues. Lists are often processed according to FIFO (first-in first-out), but there are many other possibilities. For example, the list could be processed by LIFO (last-in-first out), according to the value of an attribute or randomly, to mention a few. An example where the value of an attribute may be important is in SPT (shortest process time) scheduling. In this case, the processing time may be stored as an attribute of each entity. The entities are ordered according to the value of that attribute with the lowest value at the head or front of the queue.

Activities and Delays

An activity is duration of time whose duration is known prior to commencement of the activity. Thus, when the duration begins, its end can be scheduled. The duration can be a constant, a random value from a statistical distribution, the result of an equation, input from a file or computed based on the event state. For example, a service time may be a constant 10 minutes for each entity, it may be a random value from an exponential distribution with a mean of 10 minutes, it could be 0.9 times a constant value from clock time 0 to clock time 4 hours, and 1.1 times the standard value after clock time 4 hours or it could be 10 minutes when the preceding queue contains at most four entities and 8 minutes when there are five or more in the preceding queue. A delay is an indefinite duration that is caused by some combination of system conditions. When an entity joins a queue for a resource, the time that it will remain in the queue may be unknown initially since that time may depend on other events that may occur. An example of another event would be the arrival of a rush order that pre-empts the resource. When pre-empt occurs, the entity using the resource relinquishes its control instantaneously. Another example is a failure necessitating repair of the resource. Discrete-event simulations contain activities that cause time to advance. Most discrete-event simulations also contain delays as entities wait. The beginning and ending of an activity or delay is an event.

3. MODEL CLASSIFICATIONS

Several classification categories for models exist. A system we are modeling exhibits probabilistic or stochastic behaviour if an element of chance exists. For example, the path of a hurricane is probabilistic. In contrast, behaviour can be deterministic, such as the position of a falling object in a vacuum. Similarly, models can be deterministic or probabilistic. A probabilistic or stochastic model exhibits random effects, while a deterministic model does not. The results of a deterministic model depend on the initial conditions and in the case of computer implementation with particular input, the output is the same for each programme execution. As we studied this and other modules, we can have a probabilistic model for a deterministic situation, such as a model that uses random numbers to estimate the area under a curve. Fig 5.6 depicts the classification of different kinds of models.

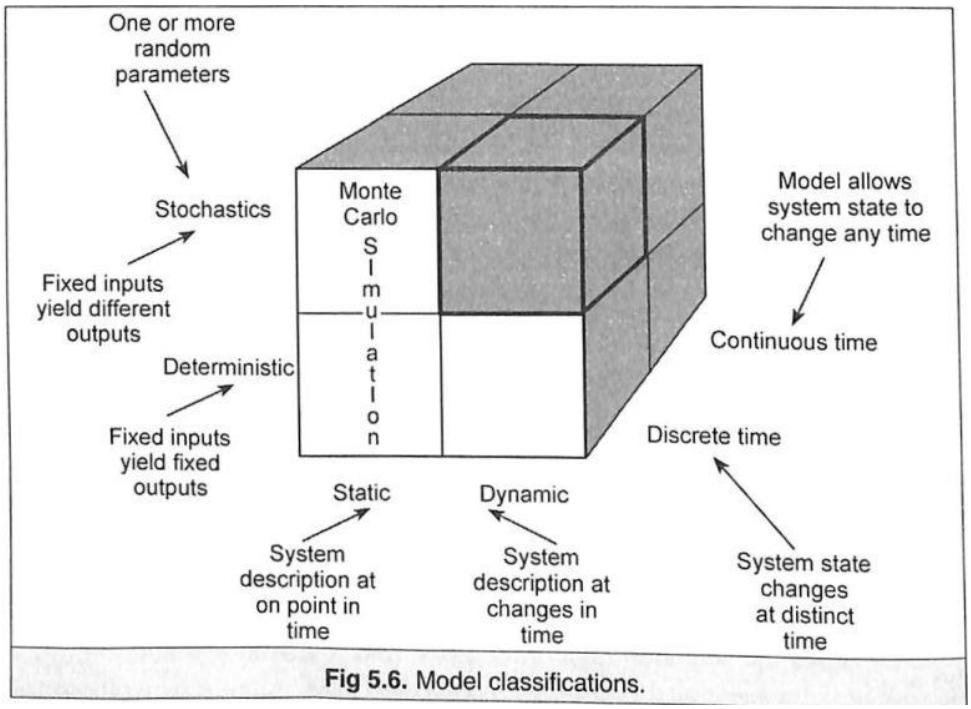


Fig 5.6. Model classifications.

Discrete-Event Simulation Model

Sufficient modeling concepts have been defined so that a discrete event simulation model can be defined as one in which the state variables change only at those discrete points in time at which events occur. Events occur as a consequence of activity times and delays. Entities may compete for system resources, possibly joining queues while waiting for an available resource. Activity and delay times may "hold" entities for durations of time. A discrete-event simulation model is conducted over time ("run") by a mechanism that moves simulated time forward. The system state is updated at each event along with capturing and freeing of resources that may occur at that time.

Stochastic and Deterministic Systems

A system exhibits probabilistic or stochastic behaviour if an element of chance exists. Otherwise, it exhibits deterministic behaviour. A probabilistic or stochastic model exhibits random effects, while a deterministic model does not.

Deterministic: Randomness does not affect the behaviour of the system. The output of the system is not a random variable.

Stochastic: Randomness affects the behaviour of the system. The output of the system is a random variable.

Static and Dynamic Simulations

We can also classify models as static or dynamic. In a static model, we do not consider time, so that the model is comparable to a snapshot or a map. For example, a model of the weight of a salamander as being proportional to the cube of its length has variables for weight and length, but not for time. By contrast, in a dynamic model, time changes, so that such a model is

comparable to an animated cartoon or a movie. For example, the number of salamanders in an area undergoing development changes with time; and, hence, a model of such a population is dynamic. Many of the models we consider in this text are dynamic and employ a static component as part of the dynamic model.

A static model does not consider time, while a dynamic model changes with time.

Static: A simulation of a system at one specific time or a simulation in which time is not a relevant parameter for example, Monte Carlo & steady-state simulations.

Dynamic: A simulation representing a system evolving over time for examples, the majority of simulation problems.

Discrete v/s Continuous Systems

When time changes continuously and smoothly, the model is continuous. If time changes in incremental steps, the model is discrete. A discrete model is analogous to a movie. A sequence of frames moves so quickly that the viewer perceives motion. However, in a live play, the action is continuous. Just as a discrete sequence of movie frames represents the continuous motion of actors, we often develop discrete computer models of continuous situations.

In a continuous model, time changes continuously, while in a discrete model time changes in incremental steps.

Continuous state: Variables change continuously as a function of time and generally analytical method like deductive mathematical reasoning is used to define and solve the system.

State variable (SV) = /(f)

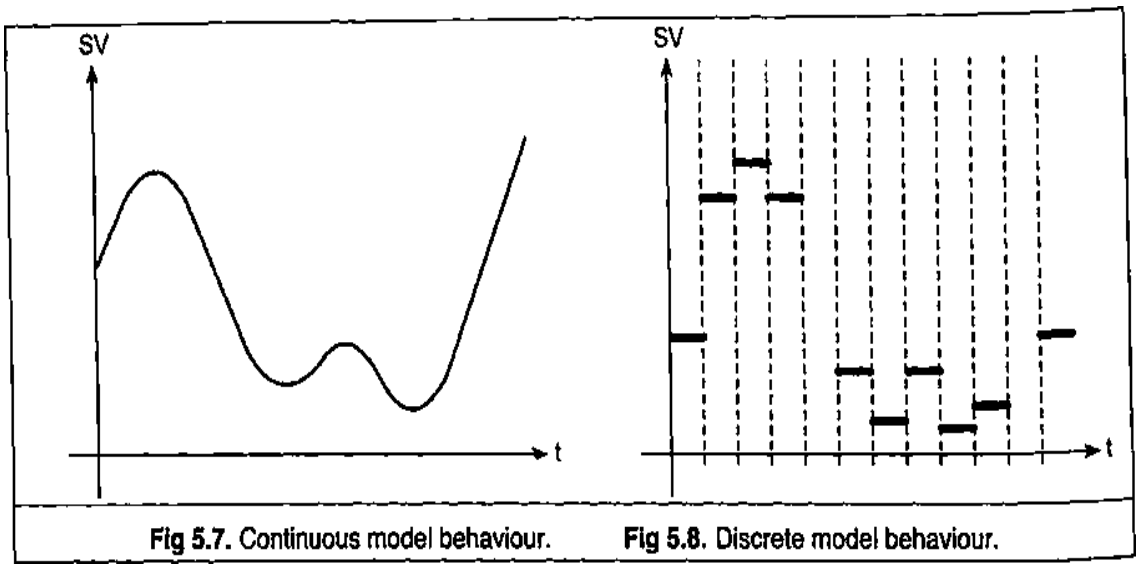


Fig 5.7. Continuous model behaviour. Fig 5.8. Discrete model behaviour.

Discrete: State variables change at discrete points in time and generally numerical method like computational procedures is used to solve mathematical models.

State variable (SV) =f(n t)

Examples of different systems

- Queue length at a cash machine: Stochastic, Discrete Time, Discrete System.
- The motion of the planets: Deterministic, Continuous Time, Discrete System.
- Logic circuit in a computer: Deterministic, Discrete Time, Discrete System.
- Flow of air around a car: Deterministic, Continuous Time, Continuous System.
- Closing prices of the 30 DAX shares: Stochastic, Discrete Time, Discrete System.

A Classic Example of Queue at Bank Counter

We see queues at everywhere. Queues are buffers to smooth out differences in arrival rates and service times. Queue Theory is well-understood. Closed-form queue-theoretic models can be used to speed up simulations. Deriving results from such models requires simulation. Here are we given an example of queue formed at bank counter. At bank counter customers arrive at random intervals and suppose there is only one cashier.

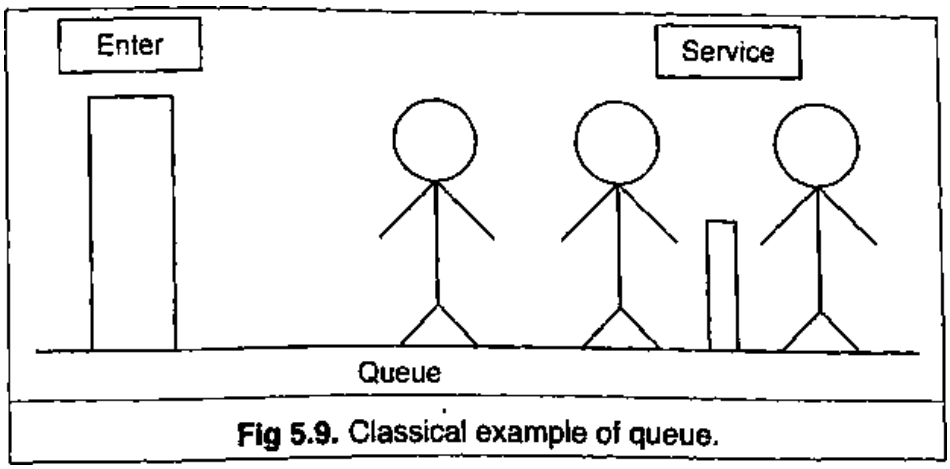


Fig 5.9. Classical example of queue.

Customers must wait in a queue. Service times at the cashier are also random measured inter-arrival times (seconds): 25, 111, 56, 232, 97, 452, 153, 45.... Measured service times (seconds): 45, 32, 11, 61, 93, 56, 30....

Now compute the average length of the queue and the probability that the cashier is busy.

COMPUTER WORKLOAD AND PREPARATION OF ITS MODELS

All simulation studies begin with a specification of objectives and problem formulation. Model development including conceptualization and implementation follows the formulation. Data are collected from the real-world early during model development to adequately provide the parameters of the model entities. Decisions need to be made during the implementation phase on the choice of the platform, language, analysis methods etc. Implemented model must be verified for accuracy and validated for correspondence to the real-world system being represented. Simulation is run several times and statistical analyses of the output data are conducted before a modeller provides recommendations based on the simulation study. The processes involved in simulation modeling and analysis are not strictly linear. An analyst may iterate between different stages in computer simulation development including problem

formulation, model abstraction, implementation, verification and validation and output analysis. The different stages are detailed below:

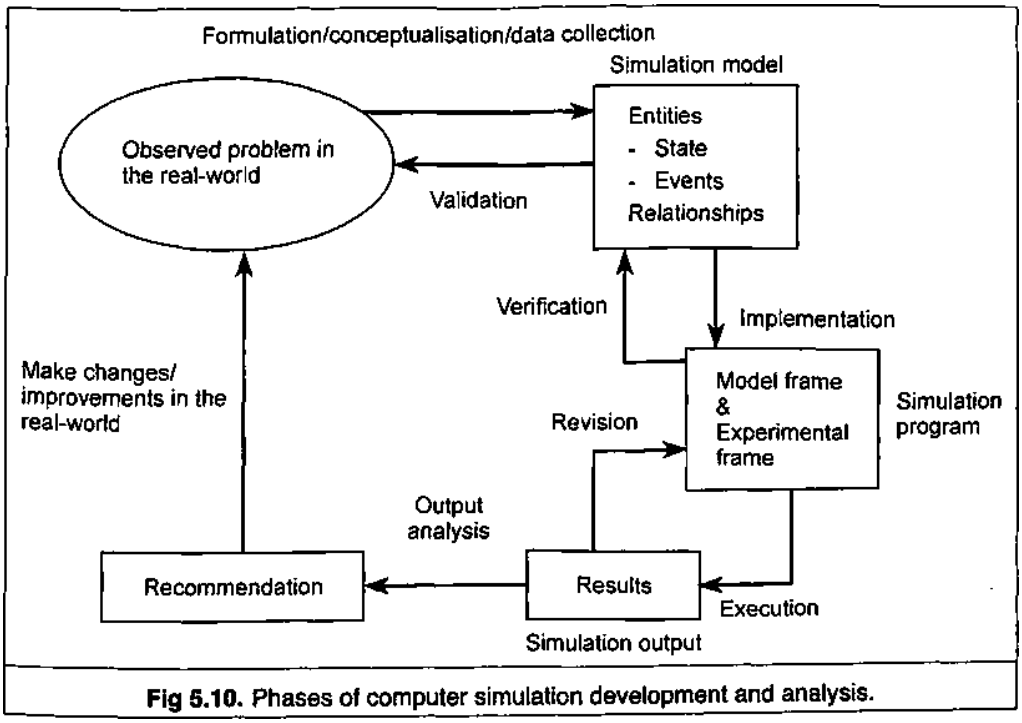


Fig 5.10. Phases of computer simulation development and analysis.

1. Steps of the Modelling Process

The modelling process is cyclic and closely parallels the scientific method and the software development life cycle (SDLC) for the development of a major software project. The process is cyclic because at any step we might return to an earlier stage to make revisions and continue the process from that point.

The steps of the modelling process are as follows:

i. Analyse the Problem

We must first study the situation sufficiently to identify the problem precisely and understand its fundamental questions clearly. At this stage, we determine the problem's objective and decide on the problem's classification, such as deterministic or stochastic. Only with clear, precise problem identification can we translate the problem into mathematical symbols and develop and solve the model.

ii. Formulate a Model

A specific set of goals initiate a simulation study. Goals could be for what-if analysis of a system being designed or for evaluation of variety of prototypical scenarios of an existing system. For example, in a service industry application, simulations of banking systems can be used to evaluate the trade-offs associated with having an additional teller. Performance measures of the system being studied must be made explicit during the problem formulation stage. In the banking system example, performance measures include average customer waiting time, teller utilisation

etc. Decisions on whether simulation is an appropriate methodology must also be made carefully during this stage. In this stage, we design the model, forming an abstraction of the system we are modelling. Some of the tasks of this step are as follows:

(a) Gather data

We collect relevant data to gain information about the system's behaviour.

(b) Make simplifying assumptions and document them

In formulating a model, we should attempt to be as simple as reasonably possible. Thus, frequently we decide to simplify some of the factors and to ignore other factors that do not seem as important. Most problems are entirely too complex to consider every detail and doing so would only make the model impossible to solve or to run in a reasonable amount of time on a computer. Moreover, factors often exist that do not appreciably affect outcomes. Besides simplifying factors, we may decide to return to Step 1 to restrict further the problem under investigation.

iii. Model Abstraction

Following problem formulation, the analyst abstracts relevant features of the system to be represented in the model. Depending on the goals of the simulation study, the analyst decides on the appropriate level of detail or granularity of the model. Aspects of the system relevant to the simulation must be specified. Once the scope has been sufficiently limited, the system boundaries can be drawn. Bounding the system is a very important analytical step because it defines internal and external factors as well as inputs and outputs. The process of bounding the system can help to reduce the level of complexity by reducing the size of the system in some cases. By drawing a boundary around the system, attention is drawn to the impacts on and by other systems interacting with the system of interest. Several valuable questions can be raised in the process of delineating the problem system. The problem focus is sharpened and some attention is drawn to environmental factors outside the system. Frequently, diagramming techniques such as flow charts are helpful in pictorially representing the system in terms of entities, their behaviour and the interactions between entities. Diagrams can be very useful in communicating about the system and can sometimes reveal additional insights about the problem.

It is very helpful when conceptualising a system to have a consistent set of questions to answer for each element of the system. These questions provide a parallel structure for the various elements of the system and ensure that all the relevant information is obtained. Forming these general questions stimulates a broader view of the elements of the system and stimulates comparisons and contrasts among them. In answering these general questions about the system, some simplifying assumptions can be made initially.

There are two basic types of assumptions about systems: structural assumptions and data assumptions. Structural assumptions are made regarding the internal operation of the system.

They concern differences between the way a system is designed to work and the way it actually operates in practice under a variety of conditions. Some steps may be shortened or bypassed completely under some circumstances for the sake of expediency.

Alternate routing can occur in cases of blockage or excessive queuing. More realistic factors can be added to the model gradually as the development proceeds. Data assumptions are made with respect to the entities being processed. Inputs may cycle through peak and slack periods. Individual times may vary for different entities in the same process. These can be included later when they have been more accurately determined. Assumptions made in the problem formulation should be explicitly listed so they can be addressed eventually in a meaningful manner.

iv. Determine Variables and Units

We must determine and name the variables. An independent variable is the variable on which others depend. In many applications, time is an independent variable. The model will try to explain the dependent variables. For example, in simulating the trajectory of a ball, time is an independent variable and the height and the horizontal distance from the initial position are dependent variables whose values depend on the time. To simplify the model, we may decide to neglect some variables (such as air resistance), treat certain variables as constants or aggregate several variables into one. While deciding on the variables, we must also establish their units, such as days as the unit for time.

(a) Establish relationships among variables and sub-models

If possible, we should draw a diagram of the model, breaking it into sub-models and indicating relationships among variables. To simplify the model, we may assume that some of the relationships are simpler than they really are. For example, we might assume that two variables are related in a linear manner instead of in a more complex way.

(b) Determine equations and functions

While establishing relationships between variables, we determine equations and functions for these variables. For example, we might decide that two variables are proportional to each other or we might establish that a known scientific formula or equation applies to the model. Many computational science models involve differential equations or equations involving a derivative.

v. Solve the Model

This stage implements the model. It is important not to jump to this step before thoroughly understanding the problem and designing the model. Otherwise, we might waste much time, which can be most frustrating. Some of the techniques and tools that the solution might employ are algebra, calculus, graphs, computer programmes and computer packages. Our solution might produce an exact answer or might simulate the situation. If the model is too complex to solve, we must return to Step 2 to make additional simplifying assumptions or to Step 1 to reformulate the problem.

vi. Model Implementation

The conceptual model generated during the earlier phase must be implemented in the form of a simulation programme. During implementation, an analyst can use a simulation language such as SIM AN or GPSS or standard programming languages such as C, C++ or Java or special simulators tailored for specific applications. Typically, most simulation languages provide software constructs to represent entities, to perform queuing utilities and standard statistical analysis. The SIM AN simulation language also orients the analyst to make decomposition between the model frame, which is used to represent the structure and overall behaviour of the system and experimental frame, which is used to store data used by the model. Some languages have a graphical front end to configure a system simulation. The graphical environment is intended for analysts without programming background to rapidly simulate and analyse a specific system. It takes longer to use standard programming languages to apply for simulation, but they provide greater levels of control in representing complex decision making behaviour. The specific simulation software or language selected is dependent on the nature of the application, expertise of the analysts and availability of appropriate hardware and software. The fundamental problem in model implementation is to translate the conceptual model to a simulation programme using the constructs of a simulation or software package. Model verification *and validation typically follow the model implementation phase.

vii. Verify and Interpret the Model's Solution

Once we have a solution and the model's solution is used, it may be necessary or desirable to make corrections, improvements or enhancements. In this case, the modeller again cycles through the modelling process to develop a revised solution. We should carefully examine the results to make sure that they make sense (verification) and that the solution solves the original problem (validation) and is usable. The process of verification determines if the solution works correctly, while the process of validation establishes if the system satisfies the problem's requirements. Thus, verification concerns "solving the problem right" and validation concerns "solving the right problem." Testing the solution to see if predictions agree with real data is important for verification. We must be careful to apply our model only in the appropriate ranges for the independent data. For example, our model might be accurate for time periods of a few days but grossly inaccurate when applied to time periods of several years. We should analyse the model's solution to determine its implications. If the model solution shows weaknesses, we should return to Step 1 or 2 to determine if it is feasible to refine the model. If so, we cycle back through the process. Hence, the cyclic modelling process is a trade-off between simplification and refinement. For refinement, we may need to extend the scope of the problem in Step 1. In Step 2, while refining, we often need to reconsider our simplifying assumptions, include more variables, assume more complex relationships among the variables and sub models and use more sophisticated techniques.

Although, we described the modelling process as a sequence or series of steps, we may be developing two or more steps simultaneously. For example, it is advisable to be compiling the report from the beginning. Otherwise, we can forget to mention significant points, such as reasons for making certain simplifying assumptions or for needing particular refinements. Moreover, within modelling teams, individuals or groups frequently work on different sub-models simultaneously. Having completed a sub-module, a team member might be verifying the sub-module while others are still working on solving theirs. The modelling process is a creative scientific endeavour. As such, a problem we are modelling usually does not have one correct answer. The problems are complex and many models provide good, although different solutions. Thus, modelling is a challenging, open-ended and exciting venture.

Validation is the process of assuring that the conceptual model accurately represents the behaviour of the real-system. Verification is the process of assuring that the implemented model accurately represents the conceptual model. These two processes are theoretically distinct but are closely related in practice. Initial conceptual model should have high face validity. Input should be sought from as wide a range as possible of people knowledgeable about the system. There are at least three reasons for this. Primarily, people who work with the system in different ways have different knowledge about the system. Some of this knowledge overlaps with others, but some are unique to a particular perspective. The unique perspectives complete the system concept and correct misconceptions. Secondly, the overlapping areas of knowledge provide crosschecks of the various inputs for consistency. Thirdly, participation in the modelling process reinforces confidence in the simulation. It provides the users the opportunity to question and critique the conceptual model. Involvement enhances acceptance and understanding among the users of the real-system being modelled. Without end-user involvement, user scepticism and resistance can thwart improvements.

After the face validity of the conceptual model has been established, the assumptions, made about the model must be examined. Estimates by those experienced with the system are the best initial values for both types of assumptions. However, careful data collection and statistical analyses are required for refinements. The first step in the input data analysis is the identification of the appropriate statistical distribution for the data. Second, the parameters relevant to that distribution must be estimated from the sampled data. Finally, the fit of the selected distribution to the data can be verified by applying appropriate statistical tests such as the Kolmorgorov - Smirnov (K-S) test or chi-squared test.

Ultimately, the model must accurately predict the system performance for a range of input conditions. Simulation should be robust enough to yield accurate results when assumptions and parameters are varied. Most conclusive test for the model is the simulation of the system under conditions where the outputs of the real system are known. The focus during this process is on the overall transformation of the inputs into outputs. The outputs of the simulation can

then be compared with the historical data. This testing can be only made for situations where historical data are available.

viii. Execution

Most simulations represent random or stochastic characteristics where different quantitative values are obtained for the same model with varying random values. For such simulations, called non-deterministic systems, the simulation model must be executed several times and statistical analysis must be performed on the simulation output to assess variability of the simulation. From an output analysis perspective, there are two types of execution modes: terminating and steady state. Terminating mode is appropriate for systems that start and run for a time then stops for some period. An example of this kind of operation is a store that closes overnight. A steady state simulation is suitable for a system that operates continuously, such a power generating plant or a hospital emergency room. The widest possible set of initial conditions should be tried in both cases.

Initial conditions can have a profound effect on the results of simulations. Initial conditions include such things as whether or not the system resources start up in the busy or idle state. Not only should all possible sets of initial conditions be tried for a given set of conditions, but also the simulations should be run several times for each set of conditions. For terminating simulations, this means that several runs are required. In the case of a steady state simulation, data samples should be taken from several sub-intervals in each run. The sub-intervals should be of equal length in all runs for valid statistical comparisons to be made.

ix. Output Analysis

A simulation is a statistical experiment that imitates the real-system. Appropriate statistical methods should be applied to determine the degree of correspondence between the outputs of the model and those of the real-system. These methods will vary depending upon whether a terminating or steady state simulation is being analysed. The basic goal here is to determine the variability in the estimators chosen to evaluate the system. In general, steady state simulations are more difficult to analyse due to the effects of initial conditions and choice of run time. For steady-state systems, data should not be used if it is collected before statistical equilibrium is reached. Initial condition bias can lead to erroneous conclusions, even for long run times and multiple runs. Estimators may have smaller variation, but they may converge to the wrong value. Typically, a type of hypothesis testing is conducted using confidence intervals as a function of variability of the output data from multiple simulation runs.

x. Report on the Model

Reporting on a model is important for its utility. Perhaps the scientific report will be written for colleagues at a laboratory or will be presented at a scientific conference. A report contains the following components, which parallel the steps of the modelling process:

(a) Analysis of the problem

Usually, assuming that the audience is intelligent but not aware of the situation, we need to describe the circumstances in which the problem arises. Then, we must clearly explain the problem and the objectives of the study.

(b) Model design

The amount of detail with which we explain the model depends on the situation. In a comprehensive technical report, we can incorporate much more detail than in a conference talk. For example, in the former case, we often include the source code for our programmes. In either case, we should state the simplifying assumptions and the rationale for employing them. Usually, we will present some of the data in tables or graphs. Such figures should contain titles, sources and labels for columns and axes. Clearly labelled diagrams of the relationships among variables and sub-models are usually very helpful in understanding the model.

(c) Model solution

In this section, we describe the techniques for solving the problem and the solution. We should give as much detail as necessary for the audience to understand the material without becoming mired in technical minutia. For a written report, appendices may contain more detail, such as source code programmes and additional information about the solutions of equations.

(d) Results and conclusions

Our report should include results, interpretations, implications, recommendations and conclusions of the model's solution. We may also include suggestions for future work.

xi. Recommendation

Ultimately, the results are used to decide what changes to make to the real-system, if any. Naturally, there is a cost associated with changing a system. Any changes will be judged in the long run by the savings or additional revenue generated. Other systems that interact with the system being simulated may be affected by changes. After the simulation has been done and the data has been thoroughly studied, the analyst must look beyond the system on which the attention has been focused. In some, his possibility should be detected in the problem analysis phase preceding simulation, but sometimes elements in the systems environment are overlooked. Finally, although planning and implementing the changes may not be the responsibility of the analyst, any recommendations for change should be described in as much detail as possible. Cost and impact analysis along with a detailed description forms a solid proposal for change. Any changes made to the real-world must be monitored and the data must be collected from the real-system to feed into the simulation model. The usefulness of the model does not end when the analysis is conducted. The model represents as investment of resources and can continue to provide useful data when changes to the system are proposed again.

2. Principles of Successful Simulation

Ten principles (10 commandments) for building a successful simulation product are briefly presented:

I. Simplicity

When building a model, game or simulation, a good team can always envision and implement more details than are really necessary to make the product a success. Professionals can always imagine and programme much more than the customer has asked for, needs or can appreciate.

The team must be bounded by the needs of the specific product. Additional great ideas should be captured and placed on the storyboard for the next product. If allowed to render every vision into software, the final product will be a bloated and confused medley of ideas that are not clearly tied together.

II. Learn from the Past

Successful systems of the past were built by very intelligent and energetic people working with the best tools available at the time. They arrived at solutions that would fit into the computer available and applied considerable ingenuity and feats of engineering to achieve this. It is easy to look backward and smile at those primitive products. But, within each of them are nuggets of gold that should be mined when creating a new system.

Past systems are packed with good ideas that can be reused. Compact solutions to complex problems are embedded in every algorithm. However, these systems continue to grow and improve for decades. Model developers who study these are continually amazed by the complex virtual world that has been squeezed into these old machines. Creativity born of limited resources is capable of achieving what appears impossible to the general observer.

III. Create a Conceptual Model

A team of talented programmers are always eager to start programming immediately. This admirable quality must be harnessed and directed toward very difficult process of creating a conceptual model that will serve as the blueprint and foundation for the product this is part of the design process that attempts to capture the characteristics of the real-world that will be represented in the software.

Conceptual modeling consists of selecting the objects, attributes, events and interactions that will form the product. Without resorting to programming you want to identify and define a set of these that work together to form a complete, complimentary and efficient product. When creating a virtual world, there are an uncountable number of combinations of characteristics and intentions. Some are empowering, some inert and some fatal. A working conceptual model will define a virtual world that operates efficiently and appears to be complete and consistent. Designers can experiment with new ideas and trace their impacts on other algorithms within the system. Constant experimentation arrives at a package that is the best that can be found and docs so without the long development times needed to do so in software.

IV. Build a Prototype

One of the reasons programmers skip the conceptual model phase is the extreme difficulty of mentally envisioning and defining an entire virtual world and the infrastructure that will support it. But, having worked through that process there are always assumptions that cannot be evaluated without working software. A prototype should be written to explore these dark comers of the conceptual model. There is no need for a prototype to look like the final product. It must enlighten the programmers who are about to jump into the problem, give them ideas, options and tools to find the best solution to the problem.

V. Push the User's Desire

Desire for a beautiful work of engineering genius that will be admired by your peers sometimes leads to products that are perfect at solving the wrong pro era. Simulation systems that are never used because they solved a problem that no one has.

Development team must be in touch with the customer and understand what gets them excited. When they use a model today, what really turns them on? What makes their job easier? What makes them recommend the product to others?

Your new product must capture the success of the old products, but overcome their limitations. Capturing success does not mean duplicating the product (though a copycat product is sometimes the solution), but requires that you achieve the same level of user excitement.

It is easy to fall into the trap of creating a product that the developer wants rather than what the customer wants. But the market base for that product is extremely small.

VI. Model to Data Available

Simulations must accurately capture the performance and behaviour of existing systems. These simulations may be used to direct the future structure of the models. If they are not accurate, the results can be catastrophic. Therefore, the models must be based on known characteristics and behaviours of the real-systems being replicated.

Model developers need to be aware of the databases that exist in their areas. They need to understand what data exists and what data is totally unavailable. Every software model requires data that does not exist in any official or unofficial form. Every model requires that data be synthesized from what is available and from the subjective experiences of experts. But, an effort needs to be made to provide a foundation for the model based on the scarce data that does exist.

VII. Separate Data from Software

In the past, the budget for CPU and memory dictated very terse implementations of models. As a result, these tended to be made up of algorithms that had been tuned to the specific situation for which it would be used. Changing the situation required changing the software. However, thanks to improvements from the hardware industry we can now afford the luxury of moving some of our assumptions and system tuning into data that can be changed by the team or by the customer. This results in a product that is much more flexible and valuable to the user.

VIII. Trust Your Creative Juices

When working with a new team that has not created a simulation before, they are afraid to move forward without explicit direction and definition about what they should build. They are afraid that they will head off in the wrong direction and create a product that others will criticise. This fear of criticism is more crippling than their aversion to reworking a programme that has gone wrong.

Experienced members of the team must demonstrate and encourage the brave act of trusting your own creative juices. Team leaders must provide the vision for the entire product, but each programmer, designer and artists must have the freedom and confidence to express their vision in the product.

The fear of making mistakes results in constant repetition of requirements analysis, organizational restructuring, product research and unproductive meetings. The team avoids making concrete decisions about the design of the product. They will not allow programmers to finish a conceptual model or build a prototype.

Good leaders will not abide remaining in this trap. Experienced programmers cannot stand to vacillate around a problem they know how to solve. Self-confident programmers (new and experienced) will march somewhere of their own accord.

IX. Fit Universal Constraints

Every product is bounded by the universal constraints of quality, time, money and competence. When you run out of one of these, the product is finished regardless of any software details. Managers have been taught to fit products into the bounds of the first three, but are largely unaware of the fourth.

The quality, detail and capabilities of a simulation are unlimited in and of themselves. The time to produce the product dictates the level of quality in its many forms. Amount of money available limits the size of the team and is tied directly to the time factor (since we all expect to get paid every month). These three constraints are preached in multiple management courses and are applied to every form of product under the sun.

However, there is a fourth constraint - competence. Some projects require skills that are in short supply. Therefore, a generously funded project with a long schedule may still be strangled by the inability to hire people with the skills needed to do the work. Good leaders, programmers, designers and artists are not available to do all of the work that companies want done. As a result, some projects are understaffed and others are staffed with incompetent people. A successful project must fit into the boundaries formed by all four of these constraints.

X. Distil Your Own Principles

The nine principles listed above have been derived from the experiences of very talented people. However, others associated with building a simulation product have a rich pool of their own experiences. Such rich experience may be used to avoid making the same mistakes they

have made in the past to create a working environment that is productive, rewarding and profitable.

4 MODELLING IN AGRICULTURAL SYSTEMS

The complexity of agricultural systems and models in agriculture are briefly presented.

1. Complexity of Agricultural Systems

Agricultural systems are characterized by having many organizational levels. From the individual components within a single plant, through constituent plants, to farms or a whole agricultural region or nation, lies a whole range of agricultural systems. Since the core of agriculture is concerned with plants, the level that is of main interest to the agricultural modeler is the plant. Reactions and interactions at the level of tissues and organs are combined to form a picture of the plant that is then extrapolated to the crop and their output.

2. Models in Agriculture

Efficient crop production technology is based on a right decision at right time in a right way. Traditionally, crop production functions that are used in agricultural decision making were derived from conventional experienced base agronomic research, in which crop yield were related to some defined variable based on correlation and regression or regression analysis. Crop yield were expressed as polynomial or exponential mathematical function of the defined variables, with regression coefficient. Application of correlation and regression analysis has provided some qualitative understanding of the variable and their interactions that were involved in cropping system and has contributed to the progress of agricultural sciences. However, quantitative information obtained from this type of analysis is very site specific. Information obtained can only be reliably applied to other site where climate, soil parameters and crop management are similar to those used in developing the original functions. Thus, the quantitative application of regression crop based model for decision-making is severely limited.

Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Owing to the complexity of the system and the incomplete status of present knowledge, it becomes impossible to completely represent the system in mathematical terms and hence, agricultural models are images of the reality. Unlike in the fields of physics and engineering, universal models do not exist within the agricultural sector. Models are built for specific purposes and the level of complexity is accordingly adopted. Inevitably, different models are built for different subsystems and several models may be built to simulate a particular crop or a particular aspect of the production system.

Agriculture models are, however, only crude representations of the real-systems because of the incomplete knowledge resulting from the inherent complexity of the systems. Judicious use of such model is possible only if the user has a sound understanding of model structure, scope and limitation. Crop modeling is a new discipline and back-ground literature is scarce. Basic information about crop modeling is briefly presented.

3. Input Data Requirement for Crop Modeling

Crop modeling requires data related to weather, crop, soil, management practices and insect-pests as indicated below:

Weather data: Maximum and minimum temperature, rainfall, relative humidity, solar radiation and wind speed. Weather data is required at daily time step to assess daily crop growth processes.

Crop data: Crop, variety, crop phenology (days to anthesis, days to maturity etc.), leaf area index, grain yield above ground biomass, 1000-grain weight.

Soil data: Thickness of soil layer, pH, EC, N, P, K, soil organic carbon, soil texture, sand and clay per cent (soil moisture, saturation, field capacity and wilting point), bulk density etc.

Crop management data: Date of sowing of crop is required to initiate the simulation process. Generally, sowing date is taken as the start time for the simulation. In case of transplanted rice, date of transplanting is used instead of sowing date. Seed rate and depth of seeding are also required. Use of inputs in the crop field, namely, irrigation, fertilizer, manure, crop residue etc. needs to be mentioned. Amount of these inputs are specified along with their type, date of application and depth of placement. If crop residues or organic nutrient sources are applied, C : N ratio of those sources has to be quantified.

Pest data: Name and type of the pest, their mode of attack, pest population at different crop growth stages. Data on insects or pests are included only in those models which contains the pest module.

5. OPTIMISATION OF AGRICULTURAL INPUTS

Optimizing models have the specific objective of devising the best option in terms of management inputs for practical operation of the system. For deriving solutions, they use decision rules that are consistent with some optimizing algorithm. This forces some rigidity into their structure resulting in restrictions in representing stochastic and dynamic aspects of agricultural systems. Linear and non-linear programming was used initially at farm level for enterprise selection and resource allocation. Later, applications to assess long-term adjustments in agriculture, regional competition, transportation studies, integrated production and distribution systems as well as policy issues in the adoption of technology, industry re-structuring and natural resources have been developed. Optimizing models do not allow the incorporation of many biological details and may be poor representations of reality. Using the simulation approach to identify a restricted set of management options that are then evaluated with the optimizing models has been reported as a useful option.

Some Crop Models Reported In Recent Literature

SOFTWARE	DETAILS
SLAM II	Forage harvesting operation
SPICE	Whole plant water flow
REALSOY	Soybean
MODVEX	Model development and validation system

IRRIGATE	Irrigation scheduling model
COTTAM	Cotton
APSIM	Modelling framework for a range of crops
GWM	General weed model in row crops
MPTGro	*Acacia sp and Leucaena sp*.
GOSSYM-COMAX	Cotton
CropSyst	Wheat and other crops
SIMCOM	Crop (CERES crop modules) and economics
LUPINMOD	Lupin
TUBERPRO	Potato and disease
SIMPOTATO	Potato
WOFOST	Wheat & maize, Water and nutrient
WAVE	Water and agrochemicals
SUCROS	Crop models
ORYZA1	Rice, water
SIMRIW	Rice, water
SIMCOY	Corn
CERES-Rice	Rice, water
GRAZPLAN	Pasture, water, lamb
EPIC	Erosion Productivity Impact Calculator
CERES	Series of crop simulation models
DSSAT	Framework of crop simulation models including modules of CERES, CROPGRO and CROPSIM
QCANE	Sugarcane, potential conditions
AUSCANE	Sugarcane, potential & water stress conditions, erosion
CANEGRO	Sugarcane, potential & water stress conditions.
APSIM-Sugarcane	Sugarcane, potential growth, water and nitrogen stress
NTKenaf	Kenaf, potential growth, water stress

6 AGRICULTURAL MODEL USES AND LIMITATIONS

Models are developed by agricultural scientists but the user-group includes the latter as well as breeders, agronomists, extension workers, policy makers and farmers. As different users possess varying degrees of expertise in the modeling field, misuse of models may occur. Since crop models are not universal, the user has to choose the most appropriate model according to his objectives. Even when a judicious choice is made, it is important that aspects of model

limitations be borne in mind such that modeling studies are put in the proper perspective and successful applications are achieved.

i. Model Uses

Simulation modeling is increasingly being applied in research, teaching, farm and resource management, policy analysis and production forecasts. These models can be applied into three areas, namely, research tools, crop system management tools and policy analysis tools. A summary of some specific applications within the different groups follows:

A. As Research Tools

Research understanding: Model development ensures the integration of research understanding acquired through discreet disciplinary research and allows the identification of the major factors that drive the system and can highlight areas where knowledge is insufficient. Thus, adopting a modeling approach could contribute towards more targeted and efficient research planning. For example, changing the plant density in a sugar beet model resulted in model failure. This failure stimulated studies that gave additional information concerning biomass partitioning in the sugar beet.

Integration of knowledge across disciplines: Adoption of a modular approach in model coding allows the scientist to pursue his discipline-oriented research in an independent manner and at a later stage to integrate the acquired knowledge into a model. For example, the modular aspect of the APSIM software allows the integration of knowledge across crops as well as. Across disciplines for a particular crop. Adoption of a modular framework also allows for the integration of basic research that is earned out in different regions, countries and continents. This ensures a reduction of research costs (e.g. through a reduction in duplication of research) as well as the collaboration between researchers at an international level.

Improvement in experiment documentation and data organization: Simulation model development, testing and application demand the use of large amount of technical an observational data supplied in given units and in a particular order. Data handling forces the modeler to resort to formal data organization and database systems. The systematic organization of data enhances the efficiency of data manipulation in other research areas (e.g. productivity analysis, change in soil fertility status over time).

Genetic improvement: As simulation models become more detailed and mechanistic, they can mimic the system more closely. More precise information can be obtained regarding the impact of different genetic traits on economic yields and these can be integrated in genetic improvement programs, e.g. the NTKenaf model. Researchers used the modeling approach to design crop ideotypes for specific environments.

Yield analysis: When a model with a sound physiological background is adopted, it is possible to extrapolate to other environments. Use of several simulation models to assess climatically-determined yield in various crops. The CANEGRO model has been used along the same lines in the South African sugar industry. Through the modeling approach, quantification of

yield reductions caused by non-climatic causes (e.g delayed sowing, soil fertility, pests and diseases) becomes possible. Almost all simulation models have been used for such purposes. Simulation models have also been reported as useful in separating yield gain into components due to changing weather trends, genetic improvements and improved technology.

B. As Crop System Management Tools

Cultural and input management: Management decisions regarding cultural practices and inputs have major impact on yield. Simulation models, that allow the specification of management options, offer a relatively inexpensive means of evaluating a large number of strategies that would rapidly become too expensive if the traditional experimentation approach were to be adopted. Many publications are available describing the use of simulation models with respect to cultural management (planting and harvest date, irrigation, spacing, selection of variety type) and input application (water and fertilizer).

Risks assessment and investment support: Using a combination of simulated yields and gross margins, economic risks and weather-related variability can be assessed. These data can then be used as an investment decision support tool.

Site-specific farming: Profit maximization may be achieved by managing farms as sets of sub-units and providing the required inputs at the optimum level to match variation in soil properties across the farm. Such an Endeavour is attainable by coupling simulation models with geographic information systems (GIS) to produce maps of predicted yield over the farm. But, one of the prerequisites is a systematic characterization of units that may prove costly.

C. As Policy Analysis Tools

Best management practices: Models having chemical leaching or erosion components can be used to determine the best practices over the long-term. The EPIC model has been used to evaluate erosion risks due to cropping practices and tillage.

Yield forecasting: Yield forecasting for industries over large areas is important to the producer (harvesting and transport), the processing agent (milling period) as well as the marketing agency. The technique uses weather records together with forecast data to estimate yield across the industry.

Introduction of a new crop: Agricultural research is linked to the prevailing cropping system in a particular region. Hence, data concerning the growth and development of a new crop in that region would be lacking. Developing a simulation model based on scientific data collected elsewhere and a few datasets collected in the new environment helps in the assessment of temporal variability in yield using long-term climatic data. Running the simulations with meteorological data in a balanced network of locations also helps in locating the industry.

Global climate change and crop production: Increased levels of $C0_2$ and other greenhouse gases are contributing to global warming with associated changes in rainfall pattern. Assessing the effects of these changes on crop yield is important at the producer as well as at the government level for planning purposes.

ii. Model Limitations

Agricultural systems are characterized by high levels of interaction between the components that are not completely understood. Models are, therefore, crude representations of reality. Wherever knowledge is lacking, the modeler usually adopts a simplified equation to describe an extensive sub-system. Simplifications are adopted according to the model purpose and / or the developer's views and therefore constitute some degree of subjectivity. Models that do not result from strong interdisciplinary collaboration are often good in the area of the developer's expertise but are weak in other areas. Model quality is related to the quality of scientific data used in model development, calibration and validation.

When a model is applied in a new situation (e.g. switching a new variety), the calibration and validation steps are crucial for correct simulations. The need for model verification arises because all processes are not fully understood and even the best mechanistic model still contains some empirism making parameter adjustments vital in a new situation. Model performance is limited to the quality of input data. It is common in cropping systems to have large volumes of data relating to the above-ground crop growth and development, but data relating to root growth and soil characteristics are generally not as extensive. Using approximations may lead to erroneous results.

Most simulation models require that meteorological data be reliable and complete. Meteorological sites may not fully represent the weather at a chosen location. In some cases data may be available for only one (usually rainfall) or a few (rainfall and temperature) Parameters but data for solar radiation, which is important in the estimation of photosynthesis and biomass accumulation, may not be available. In such cases, the user would rely on generated data. At times, records may be incomplete and gaps have to be filled. Using approximations would have an impact on model performance.

Model users need to understand the structure of the chosen model, its assumptions its limitations and its requirements before any application is initiated, e.g. using a model like QCANE, developed for cane growth under non-limiting conditions, would lead to erroneous output and analysis if it is used to simulate under water or nitrogen stress conditions. At times, model developers may raise the expectations of model users beyond mode capabilities. Users, therefore, need to judiciously assess model capabilities and limitations before it is adopted for application and decision-making purposes. Generally, crop models are developed by crop scientists and if interdisciplinary collaboration is not strong, the coding •nay not be well-structured and model documentation may be poor. This makes alteration and adaptation to simulate new situations difficult, specially for users with limited expertise. Finally, using a model for an objective for which it had not been designed or using a model in a situation that is drastically different from that for which it had been developed would lead to model failure.

CHAPTER-8: STCR: APPLICATION FOR PRECISION AGRICULTURE

STCR APPROACH FOR FERTILIZER RECOMMENDATIONS

Earlier work on soil testing in India was based on the approach of correlation between test values of soil with yield, nutrient uptake or response to graded levels of applied nutrient. The approach has many limitations and its validity under field conditions has always been questioned. Currently, the targeted yield approach has become the mainstay of Coordinated Soil Test Crop Response (STCR) correlation work in India as applied to a number of crops both on research farms and at cultivator's fields in different agro-climatic regions of the country.

What is Soil Test Crop Response Approach?

Efficient crop fertilization programme to meet the crop nutrient needs is key to sustainable agriculture. Efficient crop fertilization means optimizing crop yields, while minimizing nutrient losses to the environment, which is important economically and environmentally. Efficient nutrient application necessitates balanced fertilizer use and sound management decisions and practices.

Soil's nutrient supplying capacity (soil fertility) can be easily determined in laboratories. However, soil fertility assessment of specific locations at countrywide scale requires systematic soil sampling, delivery and feedback reporting. Crop responses to added nutrients can be tested in field experiments; nevertheless, results are site-specific and often not applicable to other locations with different soils or climate. Recognizing the lack of correlation between soil tests and crop responses to fertilizer in multi-location fertilizer-rate trials in the past and the frequent need for site-specific refinements of fertilizer prescriptions, a novel and unique field experimentation methodology was designed for soil test crop response (STCR) correlation studies at IARI (Ramamoorthy, 1968).

The STRC approach takes into account nutrient contribution from three measurable sources: (1) Soil fertility (available nutrients, based on chemical soil tests), (2) Added fertilizers and (3) Added organic manure. Over 2,000 demonstration trials in farmers' fields have validated the concept, realizing the yield targets within a 10 per cent deviation. This novel approach has become a useful strategy to increase fertilizer use efficiency and boost food production in India.

Objective of STC is to prescribe (recommend) fertilizer doses for a given crop based on soil test values to achieve the targeted yields in a specific agro-climatic region under irrigation or protective irrigated conditions by using mathematical equations for different crops and different agro-climatic zones separately. This takes into consideration-the efficiency of utilization of soil and added fertilizer nutrient by the crops and its nutrient requirements for a "desired yield level".

Concept of STCR is that this approach aims at obtaining a basis for precise quantitative adjustment of fertilizer doses under varying soil test values and response conditions of the farmers and for targeted levels of crop production. These are tested in follow up verification by field trials to back up soil testing laboratories for their advisory purpose under specific soil, crop

and agro-climatic conditions. Fertilizers can be recommended based on regression analysis for certain per cent of maximum yield. The STCR methodology takes in to account the three factors: nutrient requirement of the produce, percentage contribution from soil available nutrients and percentage contribution from added fertilizers, as indicated above.

The adjustment equation derived from these parameters takes the form:

F (N, P, K) = a (N, P, K) x T- b (N, P, K) x S (N, P, K)

Where,

F = fertilizer nutrients (kg/ha).

S = Soil available nutrients (kg/ha).

T = Target yield (q/ha).

Nutrient requirement (NR), fertilizer efficiency (FE) and soil efficiency (SE) can be calculated from the experimental data as given below:

$$a\ (N, P, K) = \frac{NR}{FE/100}$$

$$b\ (N, P, K) = \frac{SE}{FE}$$

I. Nutrient requirement (NR) for one quintal (q) of grain:

$$NR = \frac{\text{Total nutrient uptake by grain and straw (kg/ha)}}{\text{Grain yield (q/ha)}}$$

II. Fertilizer efficiency (FE %):

$$FE = \frac{\text{Total nutrient uptake (kg/ha)} - (\text{Soil test value in treated plot – kg/ha}) \times \text{Soil nutrient efficiency (\%)}}{\text{Fertilizer dose (kg/ha)}}$$

III. Soil efficiency (SE %):

$$SE = \frac{\text{Total nutrient uptake in control (kg/ha)}}{\text{Soil test value in control (kg/ha)}}$$

Using the above parameters, adjustment equations have been developed for different crops in different agro-climatic regions on various soils as indicated below.

Fertilizer adjustment equations for rice:

F N = 2.83 T -0.32 SN

F P_2O_5 = 2.29 T-2.98 SP

F K_2O= 1.34 T-0.17 SK

Fertilizer adjustment equation for wheat:

F N = 7.54 T- 0.74 SN

F P_2O_5 = 1.90 T-2.88 SP

F K_2O = 4.49 T-0.22 SK

Fertilizer adjustment equation for sorghum:

F N = 4.04 T-0.22 SN

F P_2O_5 = 2.72 T - 8.26 SP

F K_2O = 3.80 T-0.17 SK

Fertilizer adjustment equation for sugarcane:

F N = 5.40 T-1.08 SN

FP_2O_5 = 6.83 T-6.51 SP

FK_2O= 1.90 T-0.15 SK

Based on the fertilizer adjustment equations, ready reckoner of fertilizer doses at varying soil test values for specific yield target have been prepared for different crops under different agro-climatic conditions. As an example, ready reckoner of fertilizer doses for rice at varying soil test values for specific yield target are presented in Table.

Ready reckoner of fertilizer doses at varying soil test values for specific yield target in Nandyal region.

Fertilizer adjustment equations for rice in Nandyal region:

FN = 2.83 T - 0.32 SN, FP_2O_5 = 2.29 T-2.98 SP, FK_2O = 1.34 T - 0.17 SK

Soil available nutrients (kg/ha)			**Fertilizer nutrient required (per ha) for yield target of**					
			50 q/ha			**55 q/ha**		
$KMnO_4$ N	**Olsens' P**	**Amn. Ac K**	**N**	**P_2O_s**	**K_2O**	**N**	**P_2O_s**	**k_2O**
150	10	200	122	108	46	150	131	60
175	15	250	114	93	38	142	116	51
200	20	300	106	78	29	134	101	43
225	25	350	98	63	21	126	86	34
250	30	400	90	48	12	118	71	26
275	35	450	82	33	4	110	56	17
300	40	500	74	18	0	102	41	8
350	50	600	58	—	—	86	11	—

STCR Approach for Precision Agriculture

Agricultural production system is an outcome of a complex interaction of seed, soil, water, fertilizers and other agrochemicals. Therefore, judicious management of all the inputs is essential for sustainability of such a complex system. Focus on enhancement of the productivity during green revolution coupled with total disregard to proper management of inputs and without considering the ecological impacts, has resulted in environmental degradation. The only alternative left to enhance productivity in a sustainable manner from the limited natural resources is by maximizing resource input use efficiency. An integrated crop management system that attempts to match the kind and amount of inputs with the actual crop needs for small areas within the field appears to be precision farming.

In order to collect and utilize information effectively, it is important to be familiar with modem technological tools available indicated below:

- Global positioning system (GPS) receivers.
- Yield monitoring and mapping.
- Grid sampling and variable-rate (VRT) fertilizer.
- Remote sensing.
- Crop scouting.
- Geographic information system (GIS).
- Information management.
- Quantifying on-farm variability.

Important tools, among the above, have been briefly discussed in Chapter 3 Precision Agriculture. Grid sampling and variable-rate fertilizer application for precision agriculture is given below:

Grid Soil Sampling and Variable Rate Technology (VRT) for Fertilizer Application

Under normal conditions, recommended soil sampling procedure is to take samples from portions of fields that are no more than 20 acres in area. Soil cores taken from random locations in the sampling area are combined and sent to a laboratory to be tested. Crop advisors make fertilizer application recommendations from the soil test information for the 20 acre area. Grid soil sampling uses the same principles of soil sampling but increases the intensity of sampling. For example, a 20 acre sampling area would have 10 samples using a 2 acre grid sampling system (samples are spaced 300 feet from each other) compared to one sample in the traditional recommendations. Soil samples collected in a systematic grid also have location information that allows the data to be mapped. The goal of grid soil sampling is to generate a map of nutrient requirement, called an application map. Grid soil samples are analyzed in the laboratory and an interpretation of crop nutrient needs is made for each soil sample. Fertilizer application map is plotted using the entire set of soil samples. Application map is loaded into a computer mounted on a variable-rate fertilizer spreader. Computer uses the application map and a GPS receiver to direct a product-delivery controller that changes the amount and or kind of fertilizer product, according to the application map.

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A
LECTURE NOTE
ON
Agron. 6.9 (1 + 1 = 2)

PRINCIPLES OF ORGANIC FARMING

SIXTH SEMESTER B. SC. (Hons.) Agri. Degree

Prepared by

Prof. M. G. Chaudhary
Associate Professor, C.P. College of Agriculture, SDAU, S. K. Nagar

Dr. V. M. Patel
Associate Professor, College of Agriculture, NAU, Waghai

Dr. P. M. Patel
Associate Professor, B.A. College of Agriculture, AAU, Anand

Dr. S. J. Sindhi
Assistant Professor, College of Agriculture, JAU, Porbandar

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Organic Farming

Theory:

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6.	Plant protection in organic farming	
7.	Weed management in organic farming	
8.	Standards for organic farming	
9.	Certification process	
10.	Marketing	

Reference books

1. Organic farming-Theory and Practice by S.P. Palaniappan and K. Annadurai
2. Principles of organic farming by S. R. Reddy
3. Principles of Agronomy by S. R. Reddy
4. Organic crop production (Principles and practices Vol-I: Principles and General Aspects) by J. P. Sharma
5. Principles and practices of organic farming by R. Balasubramanian, K. Balakrishnan and K. Sivasubramanian

CHAPTER -1

INTRODUCTION, DEFINITION, CONCEPT, IMPORTANCE, ADVANTAGES AND DISADVANTAGES, OBJECTIVES, ESSENTIAL CHARACTERISTICS OF ORGANIC FARMING

1.1 Introduction:

Green revolution technologies such as greater use of synthetic agro chemicals like fertilizers and pesticides, adoption of nutrient responsive, high-yielding varieties of crops, greater exploitation of irrigation potentials etc… has boosted the production out put in most of cases. Without proper choice and continues use of these high energy inputs is leading to decline in production and productivity of various crops as well as deterioration of soil health and environments. The most unfortunate impact on Green Revaluation Technology (GRT) on Indian Agriculture is as follows:

1. Change in soil reaction
2. Development of nutrient imbalance /deficiencies
3. Damage the soil flora and fauna
4. Reduce the earth worm activity
5. Reduction in soil humus / organic matter
6. Change in atmospheric composition
7. Reduction in productivity
8. Reduction in quality of the produce
9. Destruction of soil structure, aeration and water holding capacity
10. Breeding more powerful and resistant pests and diseases

All these problems of GRT lead to not only reduction in productivity but also deterioration of soil health as well as natural eco-system. Moreover, to day the rural economy is now facing a challenge of over dependence on synthetic inputs and day by day it change in price of these inputs. Further, Indian Agriculture will face the market competition due to globalization of trade as per World Trade Organization (WTO). Thus apart from quantity, quality will be the important factor. Agriculture gave birth to various new concepts of farming such as organic farming, natural farming, bio-dynamic Agriculture, do-nothing agriculture, eco-farming etc.

The essential concept of these practices is “Give back to nature”, where the philosophy is to feed the soil rather them the crop to maintain the soil health. Therefore, for sustaining healthy ecosystem, there is need for adoption of an alternatives farming system like organic farming.

1.2 Definition of organic farming

Many scientists at different levels have elaborated the concept of organic farming; the important descriptions are as follows;

Lampkin (1990) Organic farming is a production system which avoids or largely excludes the use of synthetic compounded fertilizers, pesticides, growth regulators and live stock feed additives.

Koferi (1992) (Korean organic farming environment Research Institute) It is the farming method by which we never use compound chemical fertilizers, agricultural chemicals, pesticides, growth hormones and uses natural sources such as organic matters, minerals, and microbes.

According to national organic standards board of the U.S. defines organic farming as an ecological production management system that promotes and enhances bio diversity, biological cycles and soil biological activity.

Organic farming refers to organically grown crops which are not exposed to any chemicals right from the stage of seed treatments to the final post harvest handling and processing (Pathak & Ram, 2003).

Organic farming relies on crop rotation, crop residues, animal manures, legumes, green manures, off-farming organic wastes, agricultural cultivation, mineral bearing rocks and aspect of biological pest control to maintain soil productivity and tilth to supply plant nutrients and also to control insects, weeds and other pests (Lamkin-1990). In a broader sense it includes biofertilizers, bio diversity and biotechnology.

1.3 Concept of organic farming

The basic concepts behind organic farming are:

1. It concentrates on building up the biological fertility of the soil so that the crops take the nutrients they need from steady turnover within the soil nutrients produced in this way and are released in harmony with the need of the plants.
2. Control of pests, diseases and weeds is achieved largely by the development of an ecological balance within the system and by the use of bio-pesticides and various cultural techniques such as crop rotation, mixed cropping and cultivation.
3. Organic farmers recycle all wastes and manures within a farm, but the export of the products from the farm results in a steady drain of nutrients.
4. Enhancement of the environment in such a way that wild life flourishes.

In a situation where conservation of energy and resources is considered to be important community or country would make every effort to recycles to all urban and industrial wastes back to agriculture and thus the system would be requiring only a small inputs of new resources to “Top Up” soil fertility.

1.4 Importance of Organic Farming

The agriculture today in the country is hampered by erosion of natural resources viz., land, water, biodiversity, fast declining soil fertility and use efficiency of inputs, such as water, fertilizer and energy. Demographic pressure accelerates the former and the faulty agronomic

practices account for the latter problems. The modern agriculture with its potential takes the country out of the food trap and to reach an era of self sufficiency in food grain production.

The present day for self sufficiency in food grain production may not last longer unless we develop a sustainable agricultural system which maintains and /or improves soil fertility and productivity with greater acceptance of biological principles so as to assure adequate/more food production in future. Besides plants are more prone to pest and diseases in intensive agriculture, use of chemicals can have residues on the produce, in the soil and in ground water. With more of purchased inputs cost of production is also mounting up. Pesticides use in paddy, cotton and vegetables which occupy less than 30 per cent of total area account for more than 80 per cent of the chemicals used.

Organic farming practices that reduces the pressure on land, water and bio-diversity without adverse effects on agricultural production and nutritive value of food comprise, judicious use of organic manure, viz. farm yard manure, compost, crop resides, Vermicompost etc. integrated is an efficient nutrient management practices, cropping systems, conjunctive use of rain, tank and under ground water, integrated pest management and conservation of genetic resources. Among them, soil fertility is give top attention due to its dynamic action with various physical, chemical and biological properties. Besides this, following advantages derived from organic farming**:**

1.5 Advantages of organic farming

1. Organic manures produce optimal conditions in the soil for high yields and good quality crops.
2. They supply all the nutrients required by the plant (NPK, secondary and micronutrients).
3. They improve plant growth and physiological activities of plants.
4. They improve the soil physical properties such as granulation and tilth, giving good aeration, easy root penetration and improved water holding capacity. The fibrous portion of the organic matter with its high carbon content promotes soil aggregation to improve the permeability and aeration of clay soils while its ability to absorb moisture helps in the granulation of sandy soils and improves their water holding capacity. The carbon in the organic matter is the source of energy for microbes which helps in aggregation.
5. They improve the soil chemical properties such as supply and retention of soil nutrients and promote favourable chemical reactions.
6. They reduce the need for purchased inputs.
7. Most of the organic manures are wastes or byproducts which on accumulation may lead to pollution. By way of utilizing them for organic farming, pollution is minimized.
8. Organic fertilizers are considered as complete plant food. Organic matter restores the pH of the soil which may become acidic due to continuous application of chemical fertilizers.
9. Organically grown crops are believed to provide healthier and nutritionally superior food for man and animals than those grown with commercial fertilizers.

10. Organically grown plants are more resistant to disease and insects and hence only a few chemical sprays or other protective treatments are required.
11. There is an increasing consumer demand for agricultural produces which are free of toxic chemical residues. In developed countries, consumers are willing to pay more for organic foods.
12. Organic farming helps to avoid chain reaction in the environment from chemical sprays and dusts.
13. Organic farming helps to prevent environmental degradation and can be used to regenerate degraded areas.
14. Since the basic aim is diversification of crops, much more secure income can be obtained than to rely on only one crop or enterprise.

1.6 Disadvantages of organic farming.

1. **Small holding**: The average size of an operational holding is 1.57 ha and further decreasing gradually due to population pressure.
2. **Poor infrastructure facilities**: i.e. lack of sufficient soil testing laboratories.
3. Lack of technological knowledge, lack of knowledge for use of bio-fertilizers, bio-pesticides, bio-control, IPM and INM etc.
4. Organic farming takes four years for a farmer to free his land completely stopping the use of chemical as nutrients & crop savers.
5. The neighbouring farmers do not well co-operate regarding use of fertilizer, pesticides, weedicides etc.
6. Decrease in production of high yielding crops like rice, wheat which needs high fertility status to get potential yield.
7. The competitive uses of organic materials such as dung-cakes for domestic cook fuel in villages and bagasse as fuel in sugar factories & villages.
8. Wheat & rice straws are disposed by burning, instead of return to the soil.
9. Dung, slurry & pig manure and other waste used directly in the field (without compositing), which damage the crop & pollute the ground water.
10. Most of organic material is bulky in nature, hence very difficult to store, carry and use.
11. Sewage, sludge contains pathogens and, some of them survive more than six months, which may hazard the human life and prove fatal for the animal .
12. City garbage contains un-decomposed materials such as metal, plastic, glass, stones, needles etc. which causes many problems,
13. Bio control agents are available only for few selected insect pests.
14. Complicated organic certification process and also high cost of certification.
15. High price expectations, delayed delivery, quality restrictions, lack of certification & marketing net work are the major problems for organic producers.
16. Major Indian and multinational companies are not interested in bio pesticides, also dealer's interest in chemical pesticides.

1.7 Objectives of Organic Farming

The objectives of organic agriculture have been expressed in the standard document of the International Federation of Organic Agriculture Movement (IFOAM) as follows**:**

1. To produce food of high nutritional quality in sufficient quantity.
2. To work with natural systems rather than seeking to dominate them.
3. To encourage and enhance the biological cycles within farming system involving microorganisms, soil flora and fauna, plants and animals.
4. To maintain and increase the long term fertility of soils.
5. To use, as far as possible, renewable resources in locally organized agricultural systems.
6. To work as much as possible, within a closed system with regard to organic matter and nutrient elements.
7. To given all livestock, conditions of life that allow them to perform all aspects of their innate behavior.
8. To avoid all forms of pollution that result from agricultural techniques.
9. To maintain the genetic diversity of the agricultural system and its surroundings, including the protection of plant and wildlife habitats.
10. To allow agricultural producers for adequate return and satisfaction from their work including a safe working environment.
11. To consider the wider, social and ecological impact of the farming system.

1.8 Essential Characteristics of Organic Farming

The most important characteristics are as follows**:**

1. Maximal but sustainable use of local resources.
2. Minimal use of purchased inputs, only as complementary to local resources.
3. Ensuring the basic biological functions of soil-water-nutrients-human continuum.
4. Maintaining a diversity of plant and animal species as a basis for ecological balance and economic stability.
5. Creating an attractive overall landscape which given satisfaction to the local people.
6. Increasing crop and animal intensity in the form of polycultures, agroforestry systems, integrated crop/livestock systems etc to minimize risks.

CHAPTER-2

PRINCIPLES, SCOPE AND COMPONENTS OF ORGANIC FARMING

1. Principles of Organic Farming

To understand the motivation of organic farmers, the practices they use and what they want to achieve, it is important to understand the guiding principles of organic agriculture. These principles encompass the fundamental goals and caveats that are considered important for producing high quality food, fiber and other goods in an environmentally sustainable way. Principles of organic agriculture have changed with the evolution of the movement and are now codified. The principles apply to agriculture in the broadest sense, including the way people tend soils, water, plants and animals in order to produce, prepare and distribute food and other goods. They concern the way people interact with living landscapes, relate to one another and shape the legacy of future generations. The principles of organic agriculture serve to inspire the organic movement in its full diversity. They are the roots from which organic agriculture grows and develops. They express the contribution that organic agriculture can make to the world and a vision to improve all agriculture in a global context. **Principles of organic agriculture** serve to inspire the organic movement in its full diversity.

The **International Federation for Organic Agriculture Movement's (IFOAM)** definition of organic farming is based on:

1. The Principle of Health.
2. The Principle of Ecology.
3. The Principle of Fairness.
4. The Principle of Care.

Each principle is articulated through a statement followed by an explanation. The principles are to be used as a whole. They are ethical principles to inspire action.

1.1: The principle of health

Organic agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible. This principle points out that the health of indivisibles and communities cannot be separated from the health of ecosystems – healthy soils produce healthy crops that foster the health of animals and people.

Health is the wholeness and integrity of living systems. It is not simply the absence of illness, but the maintenance of physical, mental, social and ecological well-being. Immunity, resilience and regeneration are key characteristics of health. The role of organic agriculture, whether in farming, processing, distribution or consumption, is to sustain and enhance the health of **ecosystems** and organisms from the smallest in the soil to human beings. In particular, organic agriculture is intended to produce high quality, nutritious food that contributes to preventive health care and well-being. In view of this it should avoid the use of fertilizers, pesticides, animal drugs and food additives that may have adverse health effects.

1.2: The principle of ecology

Organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.

This principle roots organic agriculture within living ecological systems. It states that production is to be based on ecological processes and recycling. Nourishment and well-being are achieved through the ecology of the specific production environment. For example, in the case of crops this is the living soil; for animals it is the farm ecosystem; for fish and marine organisms, the aquatic environment.

Organic farming, pastoral and wild harvest systems should fit the cycles and **ecological balances** in nature. These cycles are universal but their operation is site-specific. Organic management must be adapted to local conditions, ecology, culture and scale. Inputs should be reduced by reuse, recycling and efficient management of materials and energy in order to maintain or improve **environmental quality** and conserve resources.

Organic agriculture should attain ecological balance through the design of **farming systems**, establishment of habitats and maintenance of genetic and agriculture diversity. Those who produce, process, trade, or consume organic products should protect and benefit the common environment including landscapes, climate, habitats, bio-diversity, air and water.

1.3: The principle of fairness

Organic agriculture should build up relationship that ensures fairness with regard to the common environment and life opportunities.

Fairness is characterized by equity, respect, justice and stewardship of the shared world; both among people and in their relations to other living beings.

This principle emphasizes that those involved in organic agriculture should conduct human relationships in a manner that ensures fairness at all levels and to all parties – farmers, workers, processors, distributors, traders and consumers. Organic agriculture should provide everyone involved with a good quality of life and contribute to food sovereignty and reduction of poverty. It aims to produce sufficient supply of good quality food and other products.

This principle insists that animals should be provided with the conditions and opportunities of life that accord with their physiology, natural behavior and well-being.

Natural and environmental resources that are used for production and consumption should be managed in a way that is socially and ecologically just and should be held in trust for future generation. Fairness requires systems of production, distribution and trade that are open and equitable and account for real environmental and social costs.

1.4: The principle of care

Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment. Organic agriculture is a living and dynamic system that responds to internal and external demands and conditions. Practitioners of organic agriculture can enhance efficiency and increase productivity,

but this should not be at the risk of jeopardizing health and well-being. Consequently, new technologies need to be assessed and existing methods reviewed. Given the incomplete understanding of ecosystems and agriculture, must be taken.

This principle states that precaution and responsibilities are the key concerns in management, development and technology choices in organic agriculture. Science is necessary to ensure that organic agriculture is healthy, safe and ecologically sound. However, scientific knowledge alone is not sufficient. Practical experience, accumulated wisdom and traditional and indigenous knowledge offer valid solutions, tested by time. Organic agriculture should prevent significant risks by adoption appropriate technologies and rejecting unpredictable ones, such as **genetic engineering**. Decisions should reflect the values and needs of all who might be affected, through transparent and participatory processes.

2.0 SCOPE OF ORGANIC FARMING

The movement started with developed world is gradually picking up in developing countries. But demand is still concentrated in developed and most affluent countries. Local demand for organic food is growing. Success of organic movement in India depends upon the growth of its own domestic markets. India has traditionally been a country of organic agriculture, but the growth of modern scientific, input **intensive agriculture** has pushed it to wall. But with the increasing awareness about the safety and quality of foods, long-term sustainability of the system and accumulating evidences of being equally productive, the organic farming may emerge as an alternative system of farming which addresses the quality and sustainability concerns.

Large-scale use of inputs both organic and inorganic has been a common sight in many of the farming situations in the past several decades. However, in recent times the concept of organic farming is being forcefully projected as the method for sustaining the agricultural production in the country.

Organic farming is a form of agriculture which avoids or largely excluded the use of synthetic fertilisers and pesticides, plant growth regulators and livestock feed additives. Organic farming relies on **crop rotation, crop residues,** animal manures, **bio-fertilisers** and mechanical cultivation to maintain **soil productivity**, to supply plant nutrients and to control weeds, insects, disease and other pests.

Before jumping into organic farming bandwagon, we need to have answers to the following: What level of crop yield/productivity is acceptable? Is it suitable for country like India with a large population to feed? Whether available organic sources of plant nutrients sufficient for pure organic farming? And, are organic farming technologies sustainable in long run?

Whether organic farming can address the multitude of problems faced by Indian agriculture at present is a major issue. Further, the virtues attributed to organic farming need to be rechecked before coming to any conclusions.

2.1: Issues of concern

Major issues to be considered for a decision on conventional agriculture or organic agriculture are:

- Organic farming and nutrient supply.
- Organic farming and plant protection.
- Organic farming and crop productivity.
- Organic farming and certification processes.
- Organic farming and heterogeneity of inputs.
- Organic farming and food quality.
- Organic farming products and marketing.
- Organic farming and switch over period.

2.1.1 Organic Farming and Nutrient Supply

At present, there is a gap of nearly 10 M t between annual addition and removal of nutrient by crops which are met by mining nutrients from the soil. A negative balance of about 8 M t NPK is foreseen in 2020, even if we continue to use chemical fertilizers, maintaining present growth rates of production and consumption. The most optimistic estimates at present showed that only about 25-30 per cent nutrient needs of Indian agriculture can be met by utilising various organic sources. These organic sources are agriculture wastes, animal manure etc.

2.1.2 Organic Farming and Plant Protection

Plant protection against the ravages of pests, diseases and weeds is an important issue if any modern high production system. Exclusion of pesticides for plant protection poses greater risk of yield losses. Options available under organic production systems are very few and crop specific. Often they are very slow and the success rate depends on the prevailing weather conditions leading to low to moderate effectiveness even in the recommended crops and situations. Thus, they limit the realisation of full potential of crop yields. Any sudden outbreak of insect pests or plant disease can completely destroy the crops, unless requisite chemical pesticides are used.

2.1.3 Organic Farming and Crop Productivity

In general, it is observed that the crop productivity declines under organic farming. The extent of decline depends on the crop type, farming systems practices followed at present etc. The decline is more in high yielding and high nutrient drawing cereals as compared to legumes and vegetables and in irrigated systems as compared to rainfed and dryland farming systems. Without using fertilisers, the requirement of area to merely sustain the present level of food grain production will be more than the geographical area of India! This is simple neither possible nor sustainable.

2.1.4 Organic Farming and Certification Processes

There are no standard certification processes uniformly applicable across different agro-climatic conditions. Both process and product certification procedures are still evolutionary stage and need further progress they can be effectively adopted. Due to biological nature of both processes and products, there is always an element of dynamism subject to temporal and spatial conditions. Presently available certification procedures are very cumbersome and expensive and out of reach for the common farmer. Due to highly fragmented holdings of the farmers, there is possibility of "contamination" from the neighbouring farms-besides the temptation to use chemical inputs to boost yields.

2.1.5 Organic Farming and Heterogeneity of Inputs

There is large variability in the inputs used in organic farming. Due to biological nature of the inputs, prescribing uniform standards and maintaining them in different agro-climatic conditions is beyond ones control. Thus leads to arbitrariness on the part of organic farmers as far as input management is concerned.

2.1.6 Organic Farming and Food Quality

It is often opined that the quality of the organically produced food is superior to that of conventionally produced food. However, there is no such conclusive proof to justify the nutritional superiority of the organically produced food over conventionally produced food. If the conventionally produced foods are blamed to contain traces of chemical residues, the organically produced foods are equally to be blamed for their contamination with harmful bacteria and other organism inimical to the health of the consumers.

2.1.7 Organic Farming Products and Marketing

There are no diagnostic techniques available as of now to distinguish products from different farming systems. The perceived belief that organic products are good for health is fetching them premium prices. However, unscrupulous hawkers may sell anything and everything as organically produced to unsuspecting buyer at higher prices resulting in outright cheating.

2.1.8 Organic Farming and Switch over Period

A transition period of 3-4 years is generally required to convert a conventional farm into an organic farm. In this period, the produce is not considered as organically produced. The reduced yield and lack of benefits of premium for the produces is a double blow for the farmers leading to financial losses which are substantial for the small to medium farmers.

2.2: THE POSSIBLE OPTIONS

With all the above concern, *organic farming is not feasible as* ***an alternative to conventional farming*** *under all circumstances in Indian context*. The shortfall in inorganic nutrient supply, uneconomic returns to inorganic inputs under dry land and **rainfed farming** systems, inherent better response to organic farming in crops like vegetables, legumes and

millets under traditional farming systems paves way for integration of conventional farming with organic farming. Such integration on sound scientific basis will be effective in addressing the problems of micronutrients deficiencies, recycling of crop residues, farm wastes, rural and urban waste, besides effectively meeting growing food demands of rising populations. There will also be scope for practicing organic farming on case basis in traditional strongholds like hilly areas, rainfed and dryland farming system to cater to the demands of organic produces in urban areas that would pay premium prices for such commodities.

Organic farming should be considered for lesser endowed region of the country. It should be started with low volume high value crops like spices and medicinal and aromatic crops. A holistic approach involving integrated nutrient management, integrated pest management, enhanced input use efficiency and adoption of region-specific promising cropping systems would be the best farming strategy for India.

Organic foods are a matter of choice of the individuals or enterprises. If somebody wants to go for organic farming, primarily on commercial consideration/profits motive, to take advantage of the unusually higher prices of organic food, they are free to do so. Organic farming is essentially a marking tool and cannot replace conventional farming for food security, quality and quantity of crop outputs. With a growing population and precarious food situation, India may not afford to take risk with organic farming alone as of now.

3.0 COMPONENTS OF ORGANIC FARMING

The components of organic farming are discussed in this section:

3.1: Organic Manures

Organic materials such as farm yard manure, biogas slurry, compost, straw or other crop residues, biofertilisers, green manures and cover crops can substitute for inorganic fertilisers to maintain the environmental quality. In addition, the organic farmers can also use sea weeds and fish manures and some permitted fertilisers like basic-slag and rock phosphate. Crop rotation with legumes as well as green manuring also provides nutrients and improves the soil fertility.

3.2: Non-chemical weed control measures

Compared to conventional farmers, the organic farmers use more of mechanical cultivation of row crops to reduce the weed menace. No herbicides are applied as they lead to environmental pollution.

3.3: Biological pest management

The control of insect pests and pathogens is one of the most challenging jobs in tropical and sub-tropical agriculture. Here again non-chemical, biological pest management is encouraged. The conservation of natural enemies of pests is important for minimising the use of chemical pesticides and for avoiding multiplication of insecticide-resistant pests. Botanical pesticides such as those derived from neem could be used. Selective microbial pesticides offer particular promise, of which strains of *Bacillis thuringiensis* is an example.

Chapter-3. Initiatives for Promoting Organic Farming

In ability of Indian agriculture to meet the demand for food in the country during the two and a half decades immediately after independence had been a matter of concern at those times. The system of our agriculture based on traditional knowledge and practices handed down from generation to generation could not produce enough to feed the increasing population. The ignominy of our dependence for food on the western developed nations and the politics of food aid practiced by them added to our determination to be self-sufficient in food production by modernising agriculture. The **"Green Revolution"** fulfilled our aspirations by changing India from a Food importing to a food exporting nation.

However, the achievement was at the expense of **ecology** and environment and to the determent and of the well-being of the people. Agriculture system adopted from the west has started showing increasing unsustainability and once again the need for appropriate method suitable to our requirements is being felt.

The practice of organic farming, said to the best known alternative to the conventional method, also originated in the west, which suffered from the ill – effects of chemical agriculture. However, organic farming is based on the similar principles underlying our traditional agriculture. **Organic agriculture** aims at the human welfare without any harm to the environment which is the foundation of human life itself.

Conventional farming had helped India not only to produce enough food for own consumption but also generated surpluses for exports. However, the increasing population and income will lead to further increase in demand for food and also for raw materials for industry. The modern system Of farming, it is increasingly felt, is becoming unsustainable as evidenced by declining crop productivities, damage to environment, chemical contaminations etc. The necessity of having an **alternative agriculture** method which can function in friendly ecosystem while sustaining and increasing the crop productivity is realized now Organic farming is recognised as the best known alternative to the conventional agriculture.

The first conference of NGOs on organic farming in India was organized by the Association for Propagation of Indigenous Genetic Resource (APIGR) in October 1984 at Wardha. Several other meetings on organic farming were held at different places in the country towards the end of 1980s. Here, mention must be made of the **Bordi Conference** in Maharashtra, the state which was the focal point for the organic farming movement in India. The Rajasthan College of Agriculture with the support of the state government organized a meeting on organic agriculture in 1992. The United Planters' Association of South India **(UPASI)** organized two national level conference on organic farming in 1993 and 1995. Then **ARISE** (Agricultural Renewal in India for a Sustainable Environment) is a major organization in the country engaged in the Promotion of organic farming. The ARISE comprises of a supporting network of regional groups aiming at sustainable environment by protecting **bio – diversity** and promoting organic agriculture practices. The selection of Auroville for the conference was apt as

it housed the Arabindo Ashram and pioneering work under its auspices on building technology, alternative energy research, wasteland development, afforestation and organic agriculture.

By 1980, three groups of Indians had taken to Organic farming. The first one consisted of urban educated technocrats for peripheral interest, which did not last long. Educated farmers consisted of the second group whose farming practices were based on scientific knowledge. The third group practiced organic farming through trail and error. Successful organic farmers in India are those who have access to sufficient natural resources like, water and other organic inputs mostly on their own farms. These farms Produce crops like sugarcane, areca, cocoa, coconut, pepper, and spices. Many of them have shown that switch over to organic farming to do not affect yields and income and more importantly, knowledge/expertise is available for successful adoption of organic farming in the country.

The International Federation of Organic Agriculture Movements (IFOAM) estimates that an area of about 42,000 has in India is under organic farming representing about 0.18 per cent of the world organic acreage as in the year 2015. Non – Governmental Organisations (NGOs) are spearheading organic farming in India. About 15,000 tonnes of organic products have been raised in India. They include tea, coffee, rice, wheat, pulses, fruits, spices and vegetables. India exports organic agricultural products to European Union, USA, Canada, Saudi Arabia, UAE, Japan, Singapore and Australia, among others.

The international conference on "Indian Organic Product-Global Markets" at the end of 2002 was the first to be held in India. IFOAM predicts that India and China have great potential to be organic farm produce exporters in the future. An important event in the history of the modern organic farming in India was the unveiling of the National Programme for Organic Production **(NPOP)** on 8th May, 2000 and the subsequent **Accreditation** and **Certification Programme** in October, 2001. The logo "Indian Organic" was released on 26th July 2002 to support the NPOP.

3.1 INDIA ADVANTAGE

India is endowed with various types of naturally available organic form of nutrients in different parts of the country and it will help for organic cultivation of crops substantially. There is diversity in climates: 100 – 10,000 mm rainfall, hill, desert, strong traditional farming stem – crop – tree animal, innovative farmers, vast dry lands (60% agriculture land), least use of chemicals. In fact, the rainfed, tribal, north – east and hilly regions of the country where negligible chemicals used are practicing subsistent agriculture for a long period.

These areas are organic by default. As regards the availability of major organic nutritional inputs (NPK) in India, the estimate of National Centre of Organic Farming, Ghaziabad is as follows:

- **Crop residue = 3.865 million tonnes.**
- **Animal dung = 3.854 million tonnes.**
- **Green manure = 0.223 million tonnes.**
- **Bio – fertilizer = 0.370 million tonnes.**

Besides, there is enough scope of using **bio –dynamic** preparation, vermicompost, Amrit pani etc. on on-farm production basis.

An appropriate national agriculture policy, giving a prominent place to organic farming addressing the issues related to its coverage, financial support during the **conversion period**, creation of linkages among the farmers, processors, traders and consumers, inspection and certification and organic products and increasing the public awareness of the benefits of organic agriculture along with the ill effects of the conventional system, should be designed. This must be followed by concrete action on the ground if we do not want to miss the far reaching changes all over the world heralded by the organic farming movement.

3.2 GOVERNMENT POLICY ON PROMOTING ORGANIC FARMING

Organic farming appears to be one of the options for sustainability. Starting of organic agriculture in India in 1900 by Sir Albert Howard, a British agronomist in North India, Development of Indore Method of **aerobic compost** (Howard 1929), Bengaluru method of **anaerobic compost** (Archarya 1934), NADEP Compost (ND Pandari Panda, Yeotmal 1980) initiated organic agriculture in India.

The year 2000 is very important year for India from organic point of view. The four major happenings were made during the year 2000. These are:

1. The Planning Commissions constituted (2000) a steering group on agriculture who identified organic farming as national challenge and suggested that it should be taken in the form of a project as major thrust area for 10^{th} Plan. The group recommended organic farming in NE region, rainfed areas and in the areas where the consumption of agrochemical is low or negligible.
2. The National Agricultural Policy (2000) recommended promotion of tradition knowledge of agriculture relating to organic farming and its scientific up gradation.
3. The Department of Agriculture and Cooperation (DAC), Ministry of Agriculture constituted (2000) a Taskforce on Organic farming under the chairmanship of Shri Kunwar ji Bhai Yadav and this task force recommended promotion of organic farming.
4. The Ministry of Commerce launched the National Organic Programme in 2000 and Agricultural and Processed Food Products Export Development Author **(APEDA)** is implementing the National Programme for Organic Production (NPOP) Under the NPOP, documents like national standards, accreditation criteria accrediting inspection and certification agencies, accreditation producer, inspect and certification procedures have been prepared and approved by National Steen Committee (NSC).

The policy of Ministry of Agriculture seeks to promote technically sound, economical viable, environmentally non-degrading and socially acceptable use of natural resources favour of organic agriculture. The policy seeks to actualize the area and crop potential strengthening rural economy, promoting value addition, accelerating growth of agribusiness and securing a fair standard of living for the farmers and agricultural and their families.

3.2.1 NATIONAL PROJECTS ON ORGANIC FARMING

The Department of Agriculture and Cooperation (DAC), Ministry of Agriculture, Government of India has launched a new Central sector scheme ‘ National Project on Organic

Farming' (NPOF) with an outlay of ₹ 57.05 crore for production, promotion and market development of organic farming in the country during 10th Plan on pilot basis. The project is operation since 1st October, 2004. Its Headquarter is NPOF, Ghaziabad which has six regional centers (RCOFs) at Bengaluru, Bhubneshawar, Hisar, Jabalpur, Imphal and Nagpur.

The unique feature of this scheme is to promote group certification by capacity build through service provider where the service provider will help organic farmers by providing training, educating on record management, supervising internal control system, assisting certification and market access. One Service provider will be registered with 1500 farmer working in identical geographical condition with similar type of crop. The group certification will reduce cost of certification.

3.2.2 FAO-DAC PROJECT ON ORGANIC FARMING

The Ministry of agriculture has taken up the Technical Cooperation Program (TCP) of FAO (TCP/IND/3003 – Development of Technical capacity Base for the Promotion of Organic Agriculture in India) to overcome the knowledge gap by quickly production basic information tailored to various ecological zones of the country on the current state knowledge on organic crop productivity packages, input production and utilization and certification issue including legal and institution aspects. The project is operational since April, 2005.

3.2.3 CONSTITUTION OF ORGANIC EXPERT PANEL BY DAC

There are many issues on crop productivity and input use under organic farming which have been raised by various concerns. To address all these issues, the Ministry Of Agriculture constituted (July, 2005) an organic expert's panel under the chairmanship Of Dr. H.P. Singh, Dean, G.B. Pant Agricultural University. Based on the recommendation of this panel, the approach towards organic farming could be reviewed.

3.2.4 ORGANIC FARMING APPROACH BY NAAS

The National Academy of Agriculture Science (NAAS) has issued a Policy Paper on Organic Farming, Which concludes that while synthetic pesticides can be avoided, complete exclusion of fertilizers may not be advisable under all situations. The NAAS recommends that a "holistic approach Involving Integrated Nutrient Management **(INM)**, Integrated Pest Management **(IPM)**, enhanced input use efficiency and adoption of region-specific promising **cropping system** would be the best organic farming strategy for India". To begin with, the practice of organic farming should be foe low volume, high value crops like spices, medicinal plants, fruits and vegetables. The NAAS has also emphasized the need for intensive research on **soil fertility** and plant health management and on issues relating to microbial contamination of food arising from the use of **farm yard manures**.

3.3 GLOBAL SCENARIO OF ORGNIC FARMING

The negative effects of modern chemical based farming system were first experienced by those countries, which introduce it initially. So, naturally, it was in those countries organic farming was adopted in relatively large scales. There are very large organizations promoting the

organic farming movement in European countries, America, Australia etc. These organizations, for example, the International Federation of Organic Agriculture Movements **(IFOAM)** and Greenpeace have studied the problems of the chemical farming methods and compared the benefits accruing to the organic farming with the former. Organic farming movements have since spread to Asia and Africa too.

3.3.1 PRE – WORLD WAR II

Organic Agriculture (as opposed to conventional) began more or less simultaneously in Central Europe and India. The British botanist **Sir Albert Howard** is often referred to as the **father of modern organic agriculture.** From 1905 to 1924, he worked as an agricultural adviser in Pusa, Bengal, where he documented traditional Indian farming practices and came to regard then as superior to his conventional agriculture science. His research and further development of these methods is recorded in his writings, notably, his 1940 book, An Agricultural Testament, which influenced many scientist and farmers of the day.

In Germany, **Rudolf Steiner's** development, **bio-dynamic agriculture**, was probably the first comprehensive organic farming system. This began with a lecture series Steiner presented at a farm in Koberwitz (now in Poland) in 1924.

In 1909, American agronomist **FH King** toured China, Korea and Japan, studying traditional fertilization, tillage and general farming practice. He published his findings in Farmers of Forty Centuries (1911, Courier Dover Publication). King foresaw a "World movement for the introduction of new and improved methods" of agriculture and in late years his book became an important organic reference.

The term **organic farming** was coined by **Lord Northbourne** in his book Look to the Land (written in 1939, published 1940). From his conception of "the farm as organism", described a holistic, ecologically balanced approach to farming.

In 1939, influenced by Sir Albert Howard's work, Lady Eve Balfour launched Haughley Experiment on farmland in England. It was the first scientific, side – by – side comparison of organic and conventional farming. Four years later, she published The soil, based on the initial findings of the Haughley Experiment.

In Japan, **Masanobu Fukuoka,** a microbiologist working in soil science and plant pathology, began to doubt the modern agricultural movement. In 1937, he quit his job as research scientist, returned to his family's farm in 1938 and devoted the next 60 years developing a radical no-till organic method for growing grain and many other crops, no known as **Nature Farming** (Natural Farming), 'do-nothing' farming or **Fukuoka Farming**.

3.3.2 POST – WORLD WAR II

Technological advance during World War II accelerated post – war innovation in aspect of agriculture. At the same time, increasingly powerful and sophisticated farming machinery allowed a single farmer to work larger areas of land and fields grew bigger.

In 1944, an international campaign called **green revolution** was launched in Mexico with private funding from the US. It encouraged the development of hybrid plants, Chemical controls, large-scale irrigation and heavy mechanization in agriculture around the world.

During the 1950s, **sustainable agriculture** was a topic of scientific interest, but research tended to concentrate on developing the new chemical approaches. In the US, began to popularize the term and methods of **organic growing** particularly to consumed through promotion of organic gardening.

In 1962, **Rachel Carson,** a prominent scientist and neutralist, published Silent spring chronicling the effects of DDT and other pesticides on the environment.

In the 1970s, global movements concerned with pollution and the environment increase their focus on organic farming. As the distinction between organic and conventional food became clearer, one goal of the organic movement was to encourage consumption of local grown food.

In 1975, Fukuoka released his first book, The One-Straw Revolution, with a strong impact in certain areas of agricultural world. His approach to small – scale grain production emphasized meticulous balance of the local farming ecosystem and a minimum of human and labor.

In the 1980s, around the world, farming and consumer groups began seriously pressuring government regulation of organic production. This led to legislation and certification being enacted through the 1990s and to date.

Since the early 1990s, the retail market for organic farming in developed economies has growing by about 20 per cent annually due to increasing consumer demand. Concern the quality and safety of food and the potential for environmental damages from conventional culture are apparently responsible for this trend.

In approximately 150 countries of the world, organic farming is being practiced and the under organic management is continuously growing.

TABLE 3.1 Land area of major countries under organic management (2017)

(FiBL Survey – 2019)

No.	**Name of country**	**Area under organic (m ha)**	**No.**	**Name of country**	**Area under organic (m ha)**
1.	Australia	35.65	7.	China	3.01
2.	Argentina	3.39	8.	Japan	0.009
3	USA	2.03	9.	India	1.7
4.	UK	0.49	10.	Pakistan	0.05
5.	Germany	1.37	11.	Sri Lanka	0.17
6.	South Africa	0.41	12.		
	All World	**69.85**			

Standard

Globally there are more than 60 standards which include IFOAM basic standard CODEX Alimentations Commission guidelines, **EU Regulation** 2029/91, **NOP** of USA.

SOME FACTS ON INTERNATIONAL STANDARDS

1 IFOAQM	• Established in 1972 • Headquarters in Germany • Umbrella for organization Organic Agricultural Association • Developed internal basic standards of organic agriculture • Set up International Organic Accreditation Service (IOAS) July 2001
2 CODEX	• Codex Alimentarious Commission – A joint FAO/WHO • Intergovernmental body • Established in 1962 • Produce a set of guidelines for organic production
3 EU REGULATION	• Laid out a basic regulation for European Union organic standard in counsel Regulation No 2092/91 (June 1991)
4 DEMETER	• Demeter internationals is worldwide network of 19 International certification Bodies in Africa, Australia, Europe • Developed guidelines for biodynamic preparation
5 JAS	• A set of guidelines Japan Agricultural Standards For organic Farming

Certification

As per Organic Certification Dictionary, 2003 as published by Grolink, there are 3 certification bodies across the world, but they are unevenly spread. Around 300 of them located in European Union, USA, JAPAN, Canada and Brazil. There is IFOAM accreditation programme, launched in 1992, by initiating International Group accreditation Service **(IOAS)**

CHAPTER-4. ORGANIC PRODUCTION REQUIREMENT

4.1. ORGANIC ECOSYSTEM AND THEIR CONCEPTS

Organic agriculture is often described as a natural farming system. It is characterized by refraining from chemical-synthetic inputs, like chemical fertilizer and pesticides. It controls undesirable quantities of crop associated by stimulating the self-regulatory capacity of the agro-ecosystem as much as possible, for example by using **agro-bio-diversity** at different level of management (farm level, crop species level, variety level) within the organic farming system (IFOAM 2002).

The concept of 'naturalness' as used in the context of organic agriculture not only refers to the avoidance of chemical inputs and the application of agro-ecological principles, but also implies the acknowledgement and appreciation of ' integrity of life'. To be able further optimize the organic farming system, there is need for varieties that are better adapted to the organic system and that are in compliance with the concept of naturalness. Currently, organic farmers largely depend on varieties supplied by conventional plant breeders, who use conventional breeding and seed production techniques and develop varieties for farming systems in which inorganic fertilizer and agro-chemical are widely used. Organic agriculture is not merely a product oriented farming system and thus requiring certain variety traits related to productivity, but it is also a production-controlled system that takes the breeding and propagation techniques and strategies into account; these are partly related to the concept of integrity of life.

This chapter will describe the kind of variety characteristics required to fit and support a self-regulatory, organic farming system from a non-chemical and agro-ecological point of view.

4.1.1. SELF-REGULATORY ABILITY OF THE ORGANIC FARM-ECOSYSTEM: SYSTEM STABILITY AND YIELD STABILITY

Although organic agriculture is now days known for its avoidance of the use of agro-chemicals and its consequent striving for environmental benefits, organic agriculture is more than merely replacing chemical by natural compounds (IFOAM, 2002). In organic agriculture, one does not want to rely on (phytosanitary) agro-chemical intervention because of the application of the concept of the integrity of life at the level of the ecosystem. Production, however, remains very important for an organic farmer, but equally or even more important than productivity per se is the sustainability of the system. This implies that one appeals more to the ecological, self-regulatory and self-supporting ability of the agro-ecosystem (natural pest control and biotic regulation of soil fertility) through low input and preventive, ecological practice than through high external inputs.

System Stability

The self-regulatory ability of organic agro-ecosystems can be defined as the capacity to either resist the effect of small and large perturbations or shoe enough resilience to counter them without high input (chemical protectants) from outside the farm-ecosystem. Such system stability or resilience can often be found in multi-species agro-ecosystem and is important for

risk reduction and yield increase, but also reducing population densities of harmful organisms and increasing densities of beneficial organisms, both in the short and the long run.

Organic agriculture bases its sustainable, self-regulatory production system on the concept of a farm as an agro-ecosystem. An agro-ecosystem, defined as an ecological system within the agriculture context (with inputs, withdrawal of products and interference by the farmer) is shaped by the strong interaction between the (variations in) abiotic and biotic environment, the genetic composition of species involved and the management resource available to the farmer. Among the biotic diversity, there are associated organisms that are harmful for crops, others that are beneficial for crop development and also predators of damaging insects the together contribute to the self-regulating capacity of the agro-ecosystem through balancing and feedback mechanisms.

Yield Stability

The reliability of an organic farming system depends not only on (high) yield levels with low inputs, but also largely on yield stability. Although organic farmers may gain relatively more system stability after their conversation period and several years of good farming practices, they still have few external inputs to quickly control or correct farm conditions during the growing season against undesired heterogeneous environmental conditions in time (weather, climate) and space (soil, topography). Reduce system stability can result in yield reductions and lower yield stability. In humid and temperate sea climate areas, like in the Netherlands, yield reductions are mostly due to infection of crops (varieties) by fungal diseases. In years with dry weather conditions, organic farming system can profit from the higher soil aggregate stability and can in some cases yield higher than the conventional system where organic matter content of the soil is often lower due to the use of minerals fertilizers. The fact that yields fluctuate much more in organic agriculture than in conventional systems, has become one of the most important factors that limit the growth of the organic market share.

4.1.2 SOIL MANAGEMENT

Soil management for organic agriculture stresses the need for efficient soil management in terms of physical, chemical and biological properties of the soil.

Description of Soil Management in Organic Farming

For organic agriculture, the basis of sound organic crop production is the care taken to build up comparison of average yields, standard deviations and coefficient of variation over five successive years for the crops, soil fertility, based on three, inextricably interrelated components of soil management: the physical (water holding capacity, structure etc), chemical (nutrient dynamics, pH) and biological (soil biota) component. The concept of soil fertility in organic farming means: well-managed soil organic matter in the soil, good soil structure, diverse soil biota and high nutrient and water holding capacity by using compost and stable manure. The idea of an organically well-managed soil is that one can build up over time buffering capacity and

resistance to an imbalance in growing conditions as part of the strategy to enhance the self-regulatory capacity of the farm-ecosystem.

Consequence of Organic Soil Management for Variety Requirements

consequence of the above –described organic soil fertility management is that in such farming systems, plants have to form and maintain a larger and more active root system for nutrient uptake (have to be efficient in acquiring nutrients) and are more dependent on interaction with beneficial soil micro-organisms that promote nutrient uptake . Therefore, organic farmers require varieties that are adapted to such specific lower input soil management and that are efficient in nutrient and water uptake under organic farming conditions that have adequate root system architecture and can interact with beneficial soil micro – organisms. Moreover, such varieties need to be efficient in the use of nutrients i.e. producer relatively large amounts of desired products per unit of nutrient and water taken up by the plant. These varieties are directly related to higher yield levels, but indirectly also through optimal growing dynamics – to lower disease, pests and weed population levels.

1. Organic varieties need adaption to low(er) and organic input conditions.
2. Organic varieties need adequate root system architecture.
3. Organic varieties need large capacity to interact with beneficial soil micro-organisms.

4.1.3. WEED MANAGEMENT

In organic farming, weed management is directed at preventive measures and timing of cultural weed management practice beside crop rotation and smothering intercrops.

Description of Weed Management in organic Farming

Weeds are often cited as the most significant problem is organic farming systems and they are certainly the problem the most concern the farmers, who are considering converting their farm from a conventional one into an organic one. The concept of weed management in organic agriculture is : because herbicides are not allowed in organic farming systems, emphasis is on prevention, decision – making (timing) and control technology. control on organic farms of yield and quality – limiting weed population dynamics of weeds over a rotation and about the seed setting of weeds. If weeds are not suppressed in time, they may become very aggressive (competitive) and complete their life cycle thus producing a seed bank for the coming years and the subsequent crops in the rotation. Weeds that cause the biggest problems are annual species in the plant row that can produce seeds in short time and throughout the year.

Consequence of Organic Weed Management for Variety Requirements

Weed suppressive ability of varieties can contributed to the self-regulation principle of the organic farming system, especially when under wet weather conditions the mechanical weed control cannot be done in time or is not effective enough, causing an increase in the labour needed for hand weeding. Thus, Organic farmers require varieties that have a rapid juvenile growth and the ability to cover or shade the soil an early stage of crop development to outcompete weeds for light. This is important for those crops that grow during winter and early

spring when mineralization is low and weeds grow (more) easily under conditions where the soil is poorly covered by crops, as with winter cereals. In general, a denser crop canopy, as influenced by canopy architecture, improves the crop's ability to compete with weeds.

4.1.4 DESCRIPTION OF PLANT HEALTH, DISEASE AND PEST MANAGEMENT IN ORGANIC FARMING

The consequences of losses due to pests and diseases in organic farming systems differ considerably, depending on region, crop, farm structure or market demands. In general, yields in Organic agriculture are 20 per cents lower due to a lower nitrogen- input and in some cases due to pests and diseases. Further, growth of the organic sector can be supported if the yield stability can be raised by a better control of diseases and pets. As in weed management, disease and pests. As in weed management, disease and pest management in organic farming systems is interwoven with the total ecological lay-out of the farming system and the sophisticated use of agro-ecological knowledge and aims at enhancing the self-regulatory capacity and building up high tolerance to pests and disease instead of regulation with chemical protectants. The central concept of plant health in organic farming is: good growing conditions and avoidance of stress will enhance the natural tolerance of plants against plant competitors. Occurrence of much plant disease can, therefore, be seen not as the cause of inferior growth but as a result of an imbalance between plant and growing conditions, causing an imbalance in metabolism which attracts insects, fungi and bacteria.

Soil-Borne Diseases

The concept is that in organic agriculture most soil-borne diseases and pests can be controlled by simulating bio-diversity in and above the soil, by feeding soil life with organic soil amendments and good soil managements and by choosing site-specific crops in a balanced rotation. Although, the power of disease suppressive ability of (organic) soils and soil life is known, more research is needed to be able to use soil life management tool to increase the power of soil defense in a more controlled way. More research has been carried out on and more experience gained with rotations. Although, the need for crop rotation is also being recognized in conventional farming, organic farming is simply not possible without adequate crop rotation. Success is intimately related to the choice of the right crops in the right sequence and in the right frequency suppressing not only population of soil-borne pests and diseases, but also of weeds and creating a diverse soil life where beneficial organisms also flourish. Most soil-borne, immobile pests and diseases, such as wheat and cereal cyst nematodes and Sclerotium cepivorum in onion, can be prevented in such organic farming systems and do not require specific resistance traits in varities grown by organic farmers. Only in cases where rotation and soil management do not have desired effect, as I know during conversion periods and with less or non-specific disease and pests, resistant varieties can offer an additional alternative. Examples of such, needed by organic farmers are sugarbeet varieties resistant to cyst nematodes and Fusarium – resistant rootstock for tomato

Air – Borne Diseases

In organic or reduced-input farms, root diseases and pets are, generally, less server than or just as severe as some specific foliar diseases. foliar disease are more difficult to control by biological or cultural measures than root diseases, because foliar disease development is much more determined by climatic factors than by antagonistic or parasitic interaction on the leaf surface, while the reverse is true for root disease development. Many foliar diseases and pests are air-borne, so that rotation (diversification in time) plays limited role, although spatial crop diversification in combination with varietal disease resistance has an effect at a regional scale. The concept is that for most air-borne disease good crop management will improve the tolerance of a crop. Shortage as well as an Overdose of nutrient reduces the tolerance of the crop. Essential in organic farming system is gaining and maintaining soil fertility (concerning biotic as well as abiotic components), as described before with an active soil life (micro- and macrobiota), good soil structure and crop specific manuring for buffering and resistance to unbalance plant growth. Another diversification strategy to reduce spreading of air-borne diseases, such as rusts and powdery mildew in cereals and pests, is through mixed cropping and variety mixtures, creating more within – field genetic variation (or the strategy of under-sowing legumes in non-nitrogen fixing crops). Other diversification for enlarging the self-regulatory ability of the farm ecosystem related to crop health includes biological control using natural predators. Therefore a farmer has to manage an ecological infrastructure (the total of more or less deliberately introduced non-productive elements) on the farm for shelter and food web, like potato late blight (Phytophthora infestans) or apple scab (Venturia inaequalis). Such diseases stress the need for non-chemical, natural fungicides or pesticides in the short run. Availability of 'natural' sprays on the basis of e.g. Bacillus thuringiensis, pyrethrum and sulphur, permitted in the organic sector, is very limited and not the main focus of organic farming systems.

Seed-Borne Diseases

The EU – regulations on organic farming require the use of organically produced seeds and will no longer allow further derogations for the use of conventionally produced seeds by the end of 2003. This encourages even more conventional seed producers to begin seed production under organic conditions and confronts them with the problems of controlling seed-borne diseases without chemical seed and soil treatments. Organic seeds have to fulfill the regular phytosanitary requirements for seeds, so that production of seeds with or without chemical seeds, so that the production of seeds with or without low levels of seed-borne disease requires more knowledge and experience than is currently available.

Although the organic farming system is designed to reduce the disease pressure, an organic farmer expected to start with seeds that are free from harmful disease, especially when these have not yet occurred on his farm and he therefore has high demands on seed quality. Particularly when growing conditions during germination are not optimal, as in spring, plants can suffer from germination fungi, such as *Fusarium sp* on cereals and grass. Other seed-borne disease that have proved to be difficult to control in organic crop and seed production are instance *Alternaria radicini* and *A dauci* on carrot seeds, A *brassicicola* on cabbage species and

Rhizoctonia solani on seed potato. For organic seed production, more attention to developing varieties that not only prove to be sufficiently resistant or tolerant during ware production but also during seed production is required.

Consequences of organic Diseases and Pest Management for Variety Requirements

A part from the question which crop(s) suit(s) best in the given farm context and in which sequence and in what frequency, a farmer makes use of the possibility of choosing among available varieties. Availability of resistant and otherwise organically adapted varieties is an important factor in designing a possible composition of the rotation. Because an organic farmer has hardly any curative means he, in contrast to his conventional colleague, will have to give more priority to varietal disease resistance, even if this is associated with a lower productivity Because in many cases, organic farmers can keep the disease pressure low with ample rotation and low nitrogen input, the focus is not merely on absolute resistance; in many cases tolerant or field resistant varieties can be sufficient. The priorities go more in the direction of resistance against fungal, air-borne disease and not of soil-borne disease and pests. For air-borne, non crop-specific pets, like aphids and disease like botrytis, adequate soil and water management is required varietal characteristic can be instrumental for better adaptation to organic soil and water management in order to improve a steadier and more balanced plant growth and therefore improving the tolerance of the plant against such non-specific pests and diseases. For crop specific air-borne and see-borne pests and disease special cultural practice in combination with resistant or tolerant varieties are required.

Plant architecture is very important focus for farmers wishing to reduce mostly the fungal diseases. For instance, a longer peduncle and less compact ear for cereal crops or a less compact growth habit and more planophyl-oriented leaves instead of leaves instead of leaves hanging close to the stem for greenhouse tomato. There is need to refer several other different avoidance and defense mechanisms in plants to be explored to diversify the breeding strategies for durable resistance in plants. For some crops such a focus is even more important if there is too little knowledge or there are no adequate tools yet available in organic agriculture to control complex disease, like late blight in potato or Alternative in carrot. As there are no varieties available that are fully resistant against these diseases they specifically challenge researchers to look multi factorial solutions and require interdisciplinary research including genetic, epidemiological and agronomic strategies. The strategies in this case focus on crop and farm sanitary measures, different cultural practice and avoidance strategies with early bulking varieties, higher disease tolerance and exploiting difference in resistance components to delay the infection and sporulation rate.

General variety Characteristic as discussed before on the basis of the agro-ecological approach to enhance the self-regulatory ability for the main components of organic farming strategies are summarized in table 10.2

That organic farmers use modern varieties does not mean that these are optimal for their farming system. The current modern varieties are adapted to conventional agriculture that has put

in a lot of effort to minimize or simply over-rule diversity in the cultivation environment and breeding has mainly been focused on such relatively standardized farming systems. In this contribution, it is explained how organic agriculture substantially differs from conventional agriculture farming systems. Although organic farming systems aim at enhancing the self – regulatory ability and resilience in the farm-ecosystem, they have nevertheless few possibilities to quickly react and interfere when correction are needed. This explains why for further optimization of the self-regulation principle of organic farming system new varieties are needed, requiring traits that make varieties flexible and robust with adequate buffering capacity.

Table 4.1 General criteria for desired variety characteristic for organic farming system derived from the agro-ecological approach

Verity characteristic	criteria
Adaptation to organic soil fertility management	Adaption to lower and organic inputs, ability to cope with fluctuating N – dynamics (growth stability), efficient in capturing water nutrients, deep, intensive root architecture, ability to interact with beneficial soil microbes, efficient nutrient up take, high nutrient use efficiency .
Weed suppressiveness	Plant architecture for early soil cover and more light compensation, allelochemical ability, allowing and resisting mechanical/physical control
Crop health	Monofactorial and polyfactorial, durable resistance, field tolerance, plant morphology, combining ability for crop variety mixtures, capable of interaction with beneficial microbes that enhance plant growth and suppress disease susceptibility
Seed health	Resistance/ tolerance against disease during seed production, including seed-borne disease, high germination percentage, high seeding vigour
Crop quality	Early maturity/ripening, high processing/baking quality, good taste, high storage potential
Yield and Yield Stability	Maximum yield level and yield stability under low input conditions.

Organic farmers do not require varieties with higher yielding capacity in the first place because of the risk of losing such profit by (increased) disease susceptibility, but require varieties that show higher yield stability through improved adaption to organic farming systems and by that less yield reduction. Referring to the current State of available inputs (practical and scientific

knowledge, agronomic tools) the conclusion is that there is great need and that there are enough arguments and perspective to improve and adapt varieties to organic farming systems. Such new varieties will out perform the best conventional varieties foe organic agriculture.

4.2 Choice of crops and varieties

4.2.1 Organic varieties need large capacity of interact with beneficial soil microorganisms

Modern wheat cultivars are less responsive to mycorrhizal Symbiosis (Hetrick et al., 1993) this can be attributed to selection of breeding material under high input conditions although it is known that molecular interaction between microorganism plant roots and genetically determined varieties have not yet been bred for beneficial action with micorrhizae or other beneficial microorganisms. In the interaction between legumes and rhizobia the presence of modulating mutants is one of the strongest indication that breeding for more intense interactive with beneficial plant associated microbae is possible (Jacobsen, 1984). Learning more about the genes involved in this beneficial plant microbae interaction will yield an orginacally managed soils harbor more beneficial microorganisms than conventionally managed soils, it is obvious the breeding appropriate varieties for such farming system will require selection under organic soil conditions.

4.2.2 Crop Ideotypes in Organic Farming

The organic farming system differs fundamentally in management of crop nutrition, soil, Fertility, weeds, diseases and pests. The system has higher emphasis on ecology along with product quality and yield stability compared with conventional farming. Organic farming system aim resilience and buffering capacity in the farm-ecosystem, by stimulating internal self - regulation through functional agro-biodiversity in and above the soil, instead of external regulation through chemical Protectants. For Further optimization of organic product quality yield stability new varieties are required that are adapted to organic farming systems.

The desired variety traits include adaptation to organic soil fertility environment implying good returns with less requirement of organic inputs, better root system and ability to interact with beneficial soil microorganism, ability to suppress weeds, contributing to soil, crop and seed health, good product quality, high yield level and high yield stability in the short, organic crop ideotypes can help to select the best varieties available among existing working gene collections. However, until now many of desired traits have not received sufficiently priority in conventional breeding programs. Traits such adaption to organic soil fertility management requires selection under organic soil conditions for optimal results.

Organic farmers by and large depend on varieties developed by bye conventional plant breeders who use conventional breeding and seed production techniques and develop varieties for farming system in which artificial fertilizers and Agro Chemicals are widely used to be able to to further optimise the organic farming system there is a need for varieties that are better adapted to the organic production system and that are in compliance with the concept of naturalness of organic agriculture.

The self regulatory ability organic Agro ecosystems can be defined as the capacity to either resist the effect of small and large alteration or show enough resilience to counter them without high input (chemical protectants) from outside the farm ecosystem such system stability or resilience can often be found in multi-species agro-ecosystems and is important for risk reduction and yield increase (Vandermeer et al., 1998). Each organic farmer has to find his own way in managing site-specific diversity and identifying the correct assemblages of species (in time and space) that will be realize through their biological synergism the self-regulatory capacity of his individual farm-ecosystem . This speaks identification of species competency to exist in and promote multi-spices biodiversity

Next to given difference in Environmental condition and social economics context of each farm, difference in cultural practices, and the knowledge, skills and motivation of each farmer result in specific farm styles. Organic farmers may gain relatively more system stability after their conversation period and several years of good farming practices. They still have few external inputs, compared chemical supported agriculture, to quickly control or correct farm conditions during the growing season against undesired heterogeneous environmental condition in the time (weather, climate) and space (soil, topography). Reduce system ability can result in able to crop with unfavorable weather soil conditions are better the choice. Thus, selection of the proper variety can contribute to yield stability through different genetic traits are highly desired in any organic crop management system. Moreover development of varieties adapted to such environment and production conditions are the target of organic breeders

4.2.3 Organic wheat ideotype

Considering type non-chemical and agro-ecological approach aimed at gaining progress in the improvement of wheat varieties for organic farming systems, the main ideotypes features are:

- The competitive ability to establish faster (fast germination, rapid root system proliferation and fast early vegetative growth)
- Suppressive competency against weeds
- Yield stability under organic management
- Better nitrogen uptake and assimilation
- Resistance rusts
- Grain quality meets organic standards
- Tolerance to droughts at intermittent and terminal stages

4.2.4 Organic ideotypes

Desired characteristics for varieties potato developed for organic cultivation are:

- Respond to organic fertilization (animal manures, green manures, composts and biofertilizers)
- Take roots very rapidly, also under cold circumstances
- develop an adequate root system architecture

- Are efficient in mineral uptake and use
- Have a rapid juvenal development
- Resistance to late blight
- Resistance to viruses
- Short growing period
- Bulky early
- Ripen early
- Give a stable yield under organic environment
- Reach a good quality in a short growing period (high dry matter, good cooking and baking quality, good storability)
- Appearing external appearance

CHAPTER -5. ORGANIC NUTRIENT MANAGEMENT

INTRODUCTION

In order to realize the potential of production systems on a sustained basis, efficient management of resources is crucial (essential). A successful farming system relies on the management of organic matter to enhance physico-chemical and biological properties of the soil. The effects of soil organic matter are dynamic as it is a source of gradual release of essential plant nutrients; improves soil structure, its drainage, aeration and water holding capacity (WHC); improves soil buffer capacity; influence the solubility of minerals and serves as a source of energy for the development of micro-organisms.

The use of biological inputs such as N-fixing bacteria , mycorrhiza or soil fauna as a means of enhancing the endemic biological activities are the means of biological soil management. Direct management is also achieved by the use of organic matter inputs, for the purpose of providing feeding materials to biological populations. Management techniques such as tillage and fertilization also influence the activity of the biota by improving the physical and chemical environment of the soil.

According to a conservative estimate, around 600 to 700 mt of agricultural waste is available in the country but it is not managed properly. We must convert waste into wealth by converting this biomass into energy, nutrient to starved soil and fuel to farmers. India produces about 1800 mt of animal dung per annum. Even if ⅔ of the dung is used for biogas generation, it is expected to yield about 440 mt/ annum of manure, which is equivalent to 2.90 mt N, 2.75 mt P_2O_5 and 1.89 mt K_2O.

CONCEPT AND DEFINITION OF BIOLOGICAL INM

The concept of biological INM is the continuous improvement of soil productivity on long-term basis through appropriate use of organic manures, green manures, BGA, biofertilizers and other biological derived materials and their scientific management for optimum growth, yield and quality of crops and intensive cropping systems in specific agro-ecological situations.

Definition of Biological INM

According to Sanchaz (1994). We should relay on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient, cycling to minimize external inputs and maximize the efficiency of their use.

It can also be defined as “a system for approaching of soil nutrient management which maintain soil health, soil fertility, sustaining agricultural productivity and improving farmers profitability through effective, judicious and intensive use of biological based nutrient management resources”. The resources are biofertilizers, organic manures green manuring crop rotation, N-fixing organisms, mycorrhizae, PSM etc.

ROLE OF DIFFERENT SOURCES FOR BIOLOGICAL INM

5.1 ORGANIC MANURES

Term 'manure' was used originally for denoting materials like cattle manure and other bulky natural substances that were applied to land, with the object of increasing the production of crops. Therefore, manures are defined as the plant and animal wastes which are used as sources of plant nutrients.

Urine is normally low in phosphorus and high in potash, where as about equal parts of nitrogen may be excreted in faeces and urine of the cattle. Hence the manure in which the proportion of the urine was allowed to drain away would be relatively low in N and K. Poultry manure is very important for organic farming due to there will be no loss of urine, since both liquid & solid portions are excreted together.

Fresh poultry manure creates local alkalinity, it may hamper the standing crop. Therefore, it is recommended to preserve the excreta at least for six months with suitable amendments and appropriate microbes.

ADVANTAGES OF MANURING

- ⇒ Manures supply plant nutrients including micro nutrients
- ⇒ They improve soil physical properties
- ⇒ Increase nutrient availability
- ⇒ Provide food for soil micro organisms
- ⇒ Provide buffering action in soil reaction
- ⇒ Improve soil tilth, aeration and WHC of the soil

On the basis of concentration of nutrients, manures can be grouped into two categories-

5.1 (A) ***Bulky organic manures***

Contain small percentage of nutrients and they applied in large quantities like FYM, compost, green manure, biogas slurry, night soil, sewage and sludge, poultry manure, sheep & goat manure, animal waste, crop residue etc.

A.1 FARM YARD MANURE (FYM)

Most commonly used organic manure in India. It refers to the decomposed mixture of dung and urine of farm animals along with litter and left over materials from roughages or fodder fed to the animals. It contains 0.5% N, 0.2% P_2O_5 and 0.5% K_2O. Urine contains 1% N and 1.35% K_2O. *Litter is the straw, peat, sawdust and dry leaves used as bedding material for farm animals and birds.* The N present in urine is mostly in the form of urea which is subjected to volatilization losses. Chemical preservatives are used to reduce losses and enrich FYM e.g. gypsum, kainite and super phosphate. These preservatives absorb urine and prevent volatilization loss of urea and also add nutrients.

A.2 COMPOST

Compost means 'a product obtained by the controlled decomposition of organic wastes (*composting*), finally used as organic manure'. Composting is the process of reducing animal and vegetable refuse (except dung) to a quickly utilizable condition for improving and maintaining soil fertility. The final well decomposed manure having lower C: N ratio is termed as 'compost'. The recycling of organic materials by biological decomposition as manure is very important for organic farming as it kills weed seeds, pathogenic organisms, and dispose off agricultural / industrial wastes to produce a uniform, slow release organic fertilizer which stimulates soils life, improve soil structure and control insect-pests and diseases. Compost contains 0.5-0.15-0.5 N,P,K, respectively.

A.3 BIOGAS SLURRY

Instead of directly using the animal dung for composting it can be used for production of biogas by feeding through Biogas Plants. It contains (1–1.8% N, 0.4–0.9% P_2O_5 and 0.6-1% K_2O) due to low volatilization losses of ammonia.

A.4 NIGHT SOIL (Poudrette)

Night soil is human excreta, both solid and liquid. It contains 5.5% N, 4% P_2O_5 and 2% K_2O. The dehydration of night soil, as such or after admixture with absorbing materials like soil, ash, charcoal and sawdust produces a poudrette that can be used easily as manure. Poudrette contains about 1.32% N, 2.8% P_2O_5 and 4.1% K_2O.

A.5 SEWAGE AND SLUDGE

1.1.1 The solid portion in the sewage (human excreta + water) is called *sludge* and liquid portion is *sewage water*. It can be recycled for crop fertilization, irrigation to the crop, aquaculture production, application to forest land, biogas production and land reclamation. It was estimated that total waste generated by 217 million people in urban areas is 39 mt/ year (2001). The total NPK content of this would be 2.5 lac tone of N, 2.6 lac tone of P and 2.6 lac tone of K. Both the components are separated and are given a preliminary fermentation and oxidation treatments to reduce bacterial contamination and offensive smell, otherwise soil quickly becomes "**sewage sick"** owing to the mechanical clogging by colloidal matter in the sewage and the development of anaerobic organisms which not only reduce the nitrate already present in the soil but also produce alkalinity. These defects can be removed by thoroughly aerating the sewage in the settling tank by blowing air through it. The sludge that settles at the bottom in this process is called "**activated sludge"** (3.6% N, 2% P_2O_5 & 1% K_2O).

A.6 SHEEP & GOAT MANURE

The droppings of sheep and goat contain higher nutrients than FYM and compost. On an average, the manure contains 3% N, 1% P_2O_5 & 2%K_2O). It is applied to the field in two ways- i) Sweeping of sheep and goat sheds are placed in pits for decomposition and it is applied later to the field. ii) Sheep penning- wherein sheep and goats are allowed to stay over night in the field and urine and faecal matter is added to soil.

A.7 POULTRY MANURE

Poultry manure can supply higher N and P to the soil than other bulky organic manures. The average nutrient content is 2.87% N, 2.93% P_2O_5 & 2.35% K_2O.

A.8 GREEN MANURING

Green un-decomposed plant material used as manure is called green manure. By growing green manure crops (usually leguminous crops) are grown in the field and incorporating it in its green stage in the same field is called green manuring. It adds organic matter and nitrogen to the soil. On an average green manuring gives 60-80 kg N/ha.

5.1 (B) Concentrated organic manures

These have required in small quantities and contain higher nutrients as compared to bulky organic manures. The most commonly used are oil cakes, fish meal, meat meal, blood meal, horn & hoof meal, bird guano, raw bone meal etc. which act a good source of organic manures for organic farming system.

B.1 OIL CAKES

Oil cakes are generally grouped into two groups, viz., *edible* oil cakes suitable for feeding the cattle and other domestic animals and *non-edible* oil cakes exclusively used as manure due to their higher content of plant nutrients. It has been estimated that India produced about 2.5 million tones of oil cakes annually

Non-edible oil cakes are used as manure especially for horticultural crops. Nutrient present in oil cakes, after mineralization, are made available to crops 7-10 days after application. Oil seed cakes need to be well powdered before application for even distribution and quicker decomposition. **Neem cake** acts as **Nitrification Inhibitor**.

Average nutrient content of different oil cakes

Oil cakes	**Per cent composition**		
	N%	**P%**	**K%**
Edible oil cakes (feed for livestock)			
Safflower (decorticated)	7.9	2.20	1.9
Groundnut	7.3	1.5	1.3
Cotton seed (decorticated)	6.5	2.9	2.2
Non-edible oil cakes (not fed to livestock)			
Safflower (un-decorticated)	4.9	1.4	1.2
Cotton seed (un-decorticated)	3.9	1.8	1.6
Caster	4.3	1.8	1.3
Neem	5.2	1.0	1.4

B.2 FISH MEAL

Sea food canning industries are present in almost all coastal states of India, Fishes which is not preferred for table purposes due to their small size, bonny nature and poor taste can be converted into very good organic manure. The fish is dried, powdered and filled in bags. It contains average nutrients are 4-10, 3-9 & 0.3-1.5 NPK. These manures are highly suitable for fruit orchards and plantation crops.

B.3 MEAT MEAL

An adult animal can provide 35 to 45 kg of meat after slaughter or death. It contains 8-9% N and 7% P_2O_5.

B.4 BLOOD MEAL

Blood manure contain about **13-20%N**, rich in **Iron** and its application gives a deep rich colour to foliage,.

B.5 HORN & HOOF MEAL

A healthy animal can give about 3 to 4 kg of horn and hoof. These materials are dried, powdered, bagged and marketed as manure. It contains 13% N.

B.6 GUANO (Bird / Fish)

The excreta and dead remains of the bird is called *bird guano* (11-14% N & 2-3% P_2O_5) and the refuse left over after the extraction of oil from the fish in factories, dried in cemented yards and used as manure is called as *fish guano* (7% N & 8% P_2O_5).

B.7 RAW BONE MEAL - An excellent source of organic phosphorus. It contains 3 to 4% N and 20 to 25% P_2O_5.

5.2 VERMICOMPOSTING

Definition: The process of composting organic wastes through domesticated earthworms under controlled conditions is vermicomposting.

Earthworms have tremendous ability to compost all biodegradable materials. Waste subjected to earthworm consumption decompose 2 to 5 times faster than in conventional composting. During composting the wastes are deodorized, pathogenic micro-organisms are destroyed and 40 to 60 % volume reduction in organic wastes take place. It is estimated that the earthworms feed about 4 to 5 time their own weight of material daily.

Earthworms bears both male and female reproductive organs. However, two worms are needed for successful copulation. The self fertilization does not occur generally in the earthworms. Fertilization take place in the egg case or cocoon.

Earthworm species such as Eisenia foetida, Eudrilus eugeniae, lumbricus rubellus, L. mauritee and perionix excavatus have been recommended for vermiculture technology. Vermicompost is the compost which is prepared by earthworms. It is a mixture of worm casting (faecal excretions) organic materials including humus, live earthworms, their cocoons and other micro organisms.

Vermiculture : It is the process of rearing and breeding of earthworms in controlled condition and presently it is known as earthworm biotechnology. It is estimated that 1800 worms which is an ideal population for one sq. meter can feed on 80 tonnes of humus per year. Faecal matter or excretions of earthworms is known as vermin cast. Vermi wash is a liquid fertilizer collected after the passage of water through a column of worm activation, which is useful for foliar spray. It may be diluted with water before use. It can also be diluted with 10% urine of cow. The average nutrient content of vermicompost is about 0.5 to 0.9- 0.1 to 0.2- 0.67 % N,P,K respectively.

5.2.1 TYPES OF EARTHWORMS

There are about 3000 species of earthworms reported in the world. Among them 509 species are available in India. Some of the important species used for vermicomposting are *Eisenia foetida, Eudrilus Eugenia, Lampito mauritii, Pherionyx excavatus, Octochaetoma serrata,* etc. These earthworms are mainly divided into two groups viz., i) ***Epigeic*** (Surface feeder) - which feeds at or near the soil surface, mainly on plant litter, dead roots and other plant debris. For example *Eisenia foetida, Eudrilus Eugenia, Lampito mauritii, Pherionyx excavatus, Octochaetoma serrata* etc. are very important for vermicomposting.

ii) ***Endogeic*** (Geophagus/humus feeder) – which feeds deeper beneath the soil surface, ingesting large quantity of organically rich soil. Not suitable for vermicomposting.

5.2.2 CHARACTERISTICS OF COMPOST WORMS

The following are the basic characteristics of earthworm species suitable for vermicomposting:

i) The worms should have feeding preference and adaptability to wide range of organic materials.
ii) It should be efficient converter of plant/animal biomass to body proteins.
iii) It should be tolerant to diseases, wide adaptability to environmental factors and have least inactivity period.
iv) It should have high consumption, digestion and assimilation rates
v) The worms should produce large number of cocoons.
vi) Growth rate, maturity from young one to adult stage should be fast.
vii) The worms should feed near the surface of organic matter.

***5.2.3. VERMIWASH* – A liquid manure**: It is a transparent pale yellow coloured fluid collected after the passage of water through a column of worm action **or** it a collection of excretory products and mucus secretions of earthworm along with nutrients from the soil organic molecules. It is very useful as a foliar spray to enhance the plant growth and yield and to check development of diseases.

5.2.4 BENEFITS OF VERMICOMPOST

1. When added to clay soil, loosens the soil and provides the passage for the entry of air.
2. The mucus associated with it being hygroscopic, absorbs water and prevents water logging and improves water holding capacity.

3. In the vermicompost, some of the secretions of worms and the associated microbes act as growth promoter along with other nutrients.
4. It improves physical, chemecal and biological properties of soil in the long run on repeated application
5. The organic carbon in vermicompost releases the nutrients slowly and steadily into the system and enables the plant to absorb these nutrients.
6. The multifarious effects of vermicompost influence the growth and yield of crops.
7. Earthworm can minimize the pollution hazards caused by organic waste by enhancing waste degradation.

5.2.5 APPLICATION OF VERMICOMPOST

In orchards the dose depends on the age of the tree. It can be used @ 500 g in small fruit plants and 3 – 4 kg/tree whereas for vegetable crops @ 3 kg/10 m^2 area. For general use in agriculture, vermicompost should be applied @ 5 t/ha. Vermicompost is mixed with equal quantity of dried cow dung and used as broadcast when seedlings are 12-15 cm height and water should be sprinkled.

5.3 GREEN MANURING

5.3.1 DEFINITION

Crops grown for the purpose of restoring or increasing the organic matter content in the soil are called *green manure crops* while there green undecomposed plant material used as manure is called *green manure*. Their use in cropping system is generally referred as *green manuring*. It is obtained in two ways-either by grown *in situ* or brought from out site. In both ways, the organic material should be worked into the soil while they are fairly young for easy and rapid decomposition.

i) *In situ green manuring* : Growing of green manure crops in the field and incorporating it in its green stage in the same field (i.e. *in situ*) is termed as *green manuring*.

ii) *Green leaf manuring*: is the application of green leaves and twigs of trees, shrubs and herbs collected from nearby location and adding to the soil. Forest tree leaves are the main source of green leaf manuring. Legumes are usually utilized as green manure crops as they fix atmospheric nitrogen in the root/stem nodules through symbiotic association.

5.3.2 ADVANTAGES OF GREEN MANURING

1. It adds organic matter to the soil. This stimulates the activity of soil micro organisms
2. Green manuring concentrates plant nutrient in the surface layer of the soil
3. It improve the structure of soil by deep rooting system
4. It facilitates the penetration of rain water, thus decreasing run off & soil erosion.
5. It holds plant nutrients that would other wise be lost by leaching (eg.N)
6. It increases the availability of certain plant nutrients like P,Ca,K,Mg & Fe.
7. It checks weed growth by quick initial growth
8. It aid in reclamation of sodic soils by release of organic acids.

5.3.3 DESIRABLE CHARACTERISTICS FOR GREEN MANURE CROPS

The criteria for which green manure crops are selected should have following characters,

It should be high biomass production

It should be deep rooting system

It should be leguminous family

It should be fast initial growth

It should be more leafy than woody

It should be low C/N ratio

It should be non-host for crop related pathogens

It should be easy and abundant seed producer

It should be useful for 'by-products'

5.4 RECYCLING OF ORGANIC RESIDUES

A variety of organic residues include crop residues in the form of straw, husk, forest litter; animal wastes like dung urine, bones etc., guano, city or household residues, oil cakes, bye products of food and sugar industries, pond silt, marine wastes, sea weeds and human habitation wastes. There are two major components of crop residues available, i. e. *harvest refuse* (straw, stubbles, haulm of different crops) and *process wastes* (nut shell, oilcakes and cobs of maize, bajra and sorghum). *Crop residues* are defined as 'the non-economic plant parts that are left in the field after harvest and remains that are generated from packing sheds or that are discarded during crop processing'. The *benefits* of proper organic residue recycling are that they supply essential plant nutrients, improve soil properties, protect the soil from erosion hazards, reducing residue accumulation at the sites they produced, providing employment as well as income to many, enhancing environmental qualities and illustrate that man is not a waste generator but also its wise utiliser/ manager.

5.4.1 METHODS OF RECYCLING

Organic residues can be recycled in soil by different methods like incorporation, burning, surface mulching, composting etc.

a. ***Incorporation*** - The crop residues like maize, rice, sorghum, wheat straw can be directly applied to the field and ploughed in the soil before the rainy season has beneficial effect on soil properties. Farm wastes can be ploughed in the soil ((0-20 cm layer). After harvesting of cotton, sugarcane, sorghum etc. can be incorporated into the soil by use of rotavator implements which directly adding small pieces of crop residues in the soil.

b. Burning - A large quantity of sugarcane trash, cotton stalks, caster stalks etc are available and many farmers burn them in the field. It is not advisable practice as burning kills the soil fauna and flora, increases losses of N, C, S and possibly some other nutrients in volatilization and

results in unfavorable soil conditions. Although burning releases Ca, Mg and k from crop residues but increases the potential loss due to leaching and erosion.

c. ***Surface mulching*** – One unique and simple way of profitable recycling the crop residues is their use as surface mulching materials. Mulches are thermo insulators, have smother effect on weeds, protect the soil from rain drop impact, reduce salinisation and barriers to vapour transfer thus conserve soil moisture. It is also beneficial for soil micro organisms and on degradation adds organic matter to the soil.

d. Composting – As discussed earlier compost is the stabilized and sanitized product of composting which is beneficial to soil health and plant growth. A huge quantity of crop wastes/residues and animal wastes are always available on a farm. Properly recycled, these residues form excellent compost in one to six months, depending upon the composting process used. The important methods of composting are NADEP compost, vermicompost, sugarcane trash compost, obnoxious weed compost and recycling of pond silt accumulation alone or by enriching composting units.

5.5 BIO-FERTILIZERS (*Microbial inoculants*)

The atmosphere over an hectare of land consists of 80,000 tones of N. Though atmospheric N is present in sufficient quantity (80%), it is not available to plants since it exists in inert form. Biological nitrogen fixation is the conversion of atmospheric N by living organisms into forms that plants can use. This process is carried out by a group of bacteria and algae which fix atmospheric Nitrogen (N_2) in to assimilable forms of nitrogen (NH_3)

It can be defined as bio-fertilizers or microbial inoculants are preparations containing live or latent cell of efficient strain of N-fixing or P-solubilizing micro organisms used for seed or soil application with the objectives of increasing the numbers of such micro organisms in the soil or rhizosphere and consequently improve the extent of microbiologically fixed N for plant growth.

5.5:1 **Use of bio-fertilizers**

Azospirilum is applied as seed treatment or soil application in crop like rice, sugarcane, pulses, soybean and vegetables. It increase in root length, top dry weight, root dry weight, total leaf area and yield were reported. The inoculants like nitroplus (legume inoculants) and VAM (*Vesicular Arbuscular Micorrhizae*) are also effective for crop yield improvement. The *Bacillus* sp. and *pseudomonas* sp. are help full in synthesizing the insoluble form of phosphorus. The combined application of phosphobacteria, rock phosphate and FYM to commercial crops have greatly enhanced biomass production, uptake of nutrients and yield .

5.5.2 Enrichment of compost with microbial inoculants.

Compost prepared by traditional method is usually low in nutrients and there is need to improved its quality. Enrichment of compost using low cost nitrogen fixing and phosphate solubilizing microbes is one of the possible way of improving nutrient status of the soil. It could be achieved by introducing microbial inoculants, which are more efficient than the native strains associated with substrate materials. Both the nitrogen fixing and phosphate solubilizing

microbes are more exacting in their physiological and ecological requirements. The only alternative is to enhance their inoculum potential in the composting mass.

5.5.3 Benefits of bio- fertilizers in organic farming

- Bio-fertilizers are eco-friendly and do not have any ill effect on soil health and environment.
- They reduce the pressure on non-renewable nutrient sources/fertilizer.
- Their formulations are cheap and have easy application methods.
- They also stimulate plant growth due to excretion of various growth hormones.
- They reduce the incidence of certain disease, pathogen and increase disease resistance.
- The economic benefits to cost ratio of bio-fertilizers is always higher.
- They improve the productivity of waste land and low land by enriching the soil.

5.5.4 Types of Bio-fertilizers

a. Biological N fixing micro organisms
b. Phosphate solubilizing and mobilizing micro-organisms
c. Potash solubilizing micro-organisms
d. Sulphur mobilizing micro-organisms
e. Arbuscular mycorrhizal fungi
f. Growth promoting substance excreting micro-organisms

a. Biological N-fixing micro-organisms

Biological N-fixing micro-organisms heps in reduction of atmospheric N_2 to NH_3. The N-fixing organisms such as Rhizobium spp. which live in symbiotic association with roots of leguminous vegetables, forming nodules and free living fixers Azotobacter spp. and Azospirillum spp. Which live in association with root system of crop plants. There are two types of rhizobia; (i) the slow growing Bradyrhizobium and (ii) the fast growing Rhizobium. Azospirillum fix N from 10 to 40 kg/ha and saves N fertilizer inputs by 25 to 30%. Azotobacter inoculation saves N fertilizer by 10 to 20%

a.1: Rhizobium and bradyrhizobium

They symbiolically fix N with leguminous plants increasing the amount of available N for uptake by plants. The quantum of N fixation ranges from 50-300 kg N/ha/crop under most optimum conditions. i.e. cow pea 80-85 kg/ha, Red gram 168-200 kg/ha, G.nut 50-60 kg/ha & lucerne 100-300 kg/ha can fix symbiotically N by legume crop root nodules. An increase in yield about 10-20 % has been observed in pulses treated with Rhizobium.

a.2: Azola

Azola symbiotically can fix 30-100 kg N /ha & increase in yield up to 10-25% and also survive at high temperature in flooded rice crop.

a.3: Azotobacter

Azotobacter us a free living aerobic N-fixing bacteria can fix 10-25 kg N/ha/season in cereals. 50% of N requirement of crop can be reduced through Azotobacter inoculation along with FYM. A. *chroococcum* is the dominant spices in arable soils. Vegetable crop such as tomato, brinjal and cabbage responded better to Azotobacter inoculation than other crops.

a.4: Azospirillum

Azospirillum inoculation helps to fix nitrogen from 15 to 40 kg/ha. It is useful in cereals for better vegetative growth and also saving inputs of nitrogenous fertilizers by 25-30 %

A:5 Beijerinckia :

Its production is high in acidic soils. B. idica is a common species. It is generally present in the rhizosphere of plantation crops such as coconut, arecanut, cashewnut, cocoa and pepper.

b. Phosphate solubilizing and mobilizing micro-organism.

Several soil bacteria particularly pseudomonas straita and Bacillus polymixa and fungi Aspergillus awamori and penicilium spp. poses the ability to bring insoluble phosphates into soluble forms by secreting organic acids. Arbuscular mycorrhizal fungi (AMF) are also responsible for converting fixed Phosphorus into available phosphorus through inoculation of efficient strains of AMF, 25 to 50 % of P fertilizer can be saved.

c. Potash solubilizing micro-organisms

The bacterium, *Frateuria aurantia* was isolated from banana plant from Orissa soil. These bacteria have solubilizing power of 90% within 22 days when the mineral source of K is in fixed form. These bacteria were tested on banana and paddy which increased the yield by 20 & 25%, respectively. It can be used as soil application for all types of crops @ 2.5 kg/ha. It can be mixed with @ 200-500 kg FYM in furrows before sowing. The bacterium can save up to 50-60 % of cost of K fertilizer.

d. Sulphur mobilizing micro organisms.

Sulphur present as insoluble sulphur form at 30-35 cm deep in soil and are associated with oxides of iron and aluminium. *Acetobacter pasteurianus* helps in converting this non-usable form to usable form. The use of 625 g/ha of A. pasteurianus influenced the levels of sulphur in crops like vegetables, cabbage, turnip, onion etc.

e. Arbuscular mycorrhizal fungi (AMF)

AMF improve plant growth through better uptake of nutrient like P, Zn, Cu etc. and make the plant root more resistant to pathogens, improve soil texture, WHC, disease resistance and better plant growth. AMF saves 25-50 kg P/ha in addition increase the yield up to 10-12%.

f. Growth promoting substance erecting micro organisms.

The specific strain of plant growth promoting *rhizobacteria* (PGPR) could colonize roots of crops like potato, beet root, apple and legumes. They enhance plant growth indirectly by depriving the harmful micro organisms. PGPR belong to many genera including *Agrobacterium, Arthrobacter, Azotobacter, bacillus, Pseudomonas, cellublomonas, Rhizobium* etc.

5.6 RESTRICTIONS TO NUTRIENT USE IN ORGANIC FARMING

In organic agriculture , maintenance of **soil fertility** may be achieved through the recycaling of organic material whose nutrients are made available to crops through the action of soil micro-organisms and bacteria. Many nutrient supplying inputs are restricted for use in organic production.In this appendix "restricted" means that the conditions and the procedure for use shall be set by the certification programme.Factors such as contamination,risk of nutritional imbalances and depletion of natural resources shall be taken into consideration. Restrictions to nutrient use In organic production are given in Appendix 1, **Annexure 1.**

Product for Use in fertilizing and Soil Conditioning

Inputs	**Condition for use**
Matter produced on an organic farm Unit	
Farm yard & Poultry manure, slurry, cow urine	Permitted
Crop residue and green manure	Permitted
Straw and other mulches	Permitted
Matter produced on an organic farm Unit	
Blood meal, meat meal, bone meal and feather meal without preservatives	Restricted
Compost made from any carbon based residue (animal excrement including poultry)	Restricted
Farmyard manure, slurry, cow urine (preferably after control fermentation and/or appropriate dilution) " factory"c farming Sources not permitted	Restricted
Fish and Fish products without preservatives	Restricted
Guano	Restricted
Human excrement	Prohibited
By-product from the food and textile industries of biodegradable material of microbial, plant or animal origin without any synthetic additives	Restricted
Peat without synthetic additives	Prohibited for soil conditioning
Sawdust, wood shaving, wood provided it comes from untreated wood	Permitted
Seaweed and seaweed products obtained by physical process extraction with water or aqueous acid/or alkaline solution	Restricted
Sewage sludge and urban compost from separated sources which are monitored for contamination	Restricted
Straw	Restricted
Vermicasts	Restricted
Animal Charcoal	Restricted
Compost and spent mushroom and vermiculate substance	Restricted

Compost from organic household reference	Restricted
Compost from Plant residues	Permitted
By product from oil palm, coconut and coca (including empty fruit bunch, palm oil mill effluent (pome), coca peat and empty cocoa pods)	Restricted
By products of industries processing ingredient from organic agriculture	Restricted
Minerals	
Basic slag	Restricted
Calcareous and magnesium rock	Restricted
Calcified seaweed	Permitted
Calcium chloride	Permitted
Calcium carbonate of natural origin (Chalk, limestone, gypsum and phosphate chalk)	Permitted
Mineral Potassium with low chlorine content (e.g. sulphate of potash, Kainite, sylvinite, patenkali)	Restricted
Natural phosphate (e.g. rock phosphate)	Restricted
Pulverised rock	Restricted
Sodium chloride	Permitted
Trace elements (boron, ferrous, manganese, molybdenum, zinc)	Restricted
Wood ash from untreated wood	Restricted
Potassium sulphate	Restricted
Magnesium sulphate (Epson salt)	Permitted
Gypsum (calcium sulphate)	Permitted
Silage and silage extract	Permitted, excluding Ammonium silage
Aluminum calcium phosphate	Restricted
Sulphur	Restricted
Stone meal	Restricted
Clay (bentonite, prelate, zeolite)	Permitted
Microbiological preparation	
Bacterial preparation (bio-fertilisers)	Permitted
Biodynamic preparation	Permitted
Plant preparations and botanical extracts	Permitted
Vermiculate	Permitted
Peat	Permitted

"Factory" farming refers industrial management systems that are heavily reliant on veterinary and feed inputs not permitted in organic culture

CHAPTER-8: FUNDAMENTALS OF INSECT PEST AND DISEASE MANAGEMENT

Introduction:-

The use of synthetic chemicals to manage pests has number of disadvantages which cause environmental pollution, phytotoxicity, ground water contamination and adversely affect the soil and its biotic environment. Indiscriminate use of synthetic pesticides resulted in insecticide resistance, resurgence and accumulation of pesticide residues in food, fruits and vegetables.

Integrated pest management measures are either preventive or curative. Control of insect pest relies on understanding of the pest life cycle, behavior and ecology. It involves natural enemies, host resistance and cultural practices.

A. CULTURAL METHODS

Cultural control is just a modification or manipulation of the environment to the disfavor the pests by disrupting their reproductive cycle, eliminating their foods, destroying their weed hosts or making the environment more favorable for predators, parasitoids and antagonists. The important cultural practices suitable for organic production to reduce the severity of insects, pests and diseases are as follows.

1. **Tillage operation :-**

   Plowing or hoeing helps to expose stages of soil inhabiting insects to sun or predatory birds. Earthing up of soil in sugarcane reduces early shoot borer infestation.

2. **Field and plant sanitation: -**

   Regular removal of weeds, pest-affected plant parts, crop stubbles and their destruction will eliminate the sources of infestation of the diseases and pests. Distraction of bored shoots and fruits of brinjal, okra prevents further build up of the pest population. Many viral diseases like leaf curl, bud and stem rot of tomato, groundnut and sun flower can be minimized by uprooting the infected plants.

3. **Crop rotation :**

   Growing of a non host crop after a host crop of the pest will break the breeding cycle of pest species and reduce their population. Like wise, crop rotation prevents the buildup of plant pathogen in soil.

   Main inoculum source of *Fusarium* head blight (FHB) are crop residues of preceding diseased crops. The best documented example is the high risk of FHB when wheat is grown after maize. Maize stubble are often colonized by the same *Fusarium* sp. affecting wheat and such *Fusarium* sp can survive and multiply on maize stubble for several years. Avoiding growth of maize in rotation with wheat will substantially reduce risks of FHB epidemics. Rotation schemes with cereals grown should, generally, be avoided. In the perennial apple production, crop rotation is no issue.

4. **Growing of pest resistant varieties** :

   Certain varieties of crops are less damage or less infested than other by insects. The resistant varieties have physical and physiological features, which enable to avoid pest attacks. i.e.

Crop	Tolerant / Resistant variety	Pest/Disease
Cotton	L.K.861, Kanchana	White fly
	L-603, L-604,	Jassids
	Narsimha	*Helicoverpa*
Groundnut	Vemana, Tirupathi, ICGS-11	Bud rot
	Kadiri, ICGS-10	Leaf spot
	ICGV-86325	Multiple resistant to pests & diseases
Red gram	ICPL-332 (Abhaya)	Pod borer
Castor	JI-144	Capsule borer

5. **Trap cropping**

Some crops are more preferred by the pests for feeding and egg laying are grown as trap crops on the bunds of the main crop or 1 row after 10 rows. Removal and destruction of egg masses and small larvae from trap crop reduce the pest population.

Crop	Pest	Trap crop
Cotton, Groundnut	*Spodoptera*	Castor, sunflower
Cotton, chickpea, pigeonpea	*Helicoverpa*	Merigold
Sesamum	Red hairy cater pillar	Cowpea
Green gram	Red hairy cater pillar	Sunn hemp

6. **Water management** :

Flooding of field whenever possible; kills root grubs, termites and soil borne plant pathogens. Draining of water for a few days in paddy fields suppress brown plant hopper population.

7. **Adjusting time of sowing** :

The simultaneous sowing of crops in a locality helps in reducing pest damage. Many a times early sown crops escape pest attack i.e. jowar crop sown before the end of June month usually escapes attack by shoot fly.

Maize sown late suffers little borer damage, as by then the egg parasite. *Trichogramma* is able to keep down the population of the pest. Rice may suffer less from borer attack if planted early (early June). Early maturing cotton cultivars have become popular in Punjab and Haryana as they escape pink bollworm.

B. MECHANICAL METHODS:

Hand picking of egg masses, gregarious larvae and sluggish/ lazy adults and their destruction helps in reducing of pest population.

1. **Use of phenomones and light traps** :

Sex pheromones are mostly emitted by female insects to attract the male insect for mating. Such chemical compounds can be prepared in the laboratory and make available

as lures for use in traps. These pheromones and also light traps attract the insects in large numbers, where they get trapped and killed. Pheromones are non toxic, species specific, safe to other organisms, plants and environment. Generally at least 5 traps/ha are recommended for monitoring for each pest species.

2. **Use of yellow sticky traps** :

   It is used to monitor aphids and white fly (sucking pests).

3. **Erecting bird perches** :

   Bird perches helps in attracting birds, keep water in small bowl and spread cooked yellow rice to attract insectivorous birds.

4. **Soil solarization** :

   Soil solarization by mulching the soil with polyethylene cover for 3-4 weeks during summer months results in killing of soil borne pathogens and weed seeds.

5. **Use of nylon net**

   Growing of vegetable nursery under nylon net drastically reduces pest population and virus/ mycoplasma diseases by preventing the entry of vectors.

6. **Hot water treatment** :

   For the control of nematode problem in planting stock of banana suckers soaked in hot water for 25 minutes at 55 ^{0}C temperature.

BIOLOGICAL METHODS

Biological control means "the utilization of any living organisms for the control of insect-pests, diseases and weeds. This means use of any biotic agent for minimizing the pest population either directly or indirectly. Conservation of these biotic agents in the field or multiplying in the laboratory and releasing in the fields is called biological control.

ADVANTAGES OF BIOLOGICAL CONTROL

1. Bio-control is exercised in a wide range of area and it is safe for human as well as animal health.
2. Application of biotic agent is easy and possible even in inaccessible areas like forests, tall trees, ponds, rivers, lakes, ravines etc.
3. The bio agents survive in nature till the pests are prevalent and self perpetuating in nature.
4. There is no need for any special equipments like sprayer, duster except for some microbial preparation
5. No waiting period is required for harvesting of the crops.
6. Biological agents like parasitoids and predators, etc may be multiplied at farmer's level.
7. This method is economical.

Some of the important bio-control agents are,

1. **Predators:** The predators are feeding several of the insect-pests during their life cycle and hold a key role in minimizing pest population under field conditions. The common predators

are birds, spiders, dragonflies, ladybird beetles, ground beetles, ants, chrysoperla *etc* helps to control sucking pests, pod borer eggs and larvae.

Sr. No.	**Predators**	**Pest controlled**
1.	Chrysoperla	Soft body insects like aphids, white fly, leaf hoppers, thrips etc.
2.	Lady bird beetle	Aphid, mealy bug
3.	Spiders	Insects

Parasitoids: These insects are always require passing at least one stage of their life cycle inside the host. The tiny adults of parasitoids search for the host eggs and parasitize them, i.e. they lay their own eggs within the egg of the pests. On hatching, the parasitoid larva feed on the embryonic content of egg. Thus kill only one host insect during their life. However, due to their high multiplication rate they are of vital importance in the bio-control agents. Insect parasitoids (parasites thriving on insects): insect parasitoids include:

Trichogramma – Egg parasitoids against egg of gram pod borer, rice stem borer, castor semi-looper, Cabbage diamond back moth etc.

Bracon hebetor- Against insect-pest of coconut and sugarcane.

Brachymeria - Against the pupae of several pests of plantation crops.

Others such as *Elasmus, Eribor, Trichopilus, Gonlozus, Tetrastichus* and *Chelonus* are also known for their effectiveness in IPM at several situations.

Crop	**Pest**	**Parasitoids**	**Dosage/ha**
Cotton	Bollworms	*Trichograma chilonis*	1,50,000
Sugarcane	Early shoot borer, stock borer	*Trichograma chilonis*	50,000
Paddy, Maize	stem borer	*T. japonicum*	50,000

2. **Botanicals:** The pesticides derived from living organisms are bio-pesticides. These products are more selective, eco-friendly and leave no toxic residues in the environment. The identification of natural chemicals open new era of pest control. These chemicals do not kill the insects, but either attract, repel or modify their usual behavior. Behavior modifying chemicals which reduce mating frequency or release large numbers of sterile insects, control pests biologically by reducing their numbers.

Botanicals	Pests	Action
1. Neem oil	Grass hopper, leaf minor, white flies, scales, mealy bugs pod borer, moth *etc*.	Azadiractin acts as a repellent and antifeedent (*Azadirachta indica*)
2. Nicotine sulphate	White flies, Aphids, Jassids, *Helicoverpa*	Nicotine sulphate acts as a contact poison and fumigant
3.Pyrethrum/	Ants, aphids, flies, ticks	The trade name pyrenone is a contact poison

pyrethrins		
4. Limonene	Pests of pet animals such as fleas, lice, mites, ticks etc.	Trade name d-limonene and linalool extracted from orange or citrus fruit- peels act as contact and fumigant

3. **Microbial insecticides**: These are micro organisms such as bacterium, soil borne actinomytes and fungal pathogens. The insecticidal crystal protein produced by the bacterium, *Bacillus thuringiensis kurstaki* is effective against lepidopterous pest species. These toxins are highly specific in their action, biodegradable and being stomach poison, safe for non-target organisms they are as follows.

No.	Bio control agent	Crop	Pest/ disease	Remarks
1.	*Trichoderma harzianum, Trichoderma viride*	Tomato, chilli, Brinjal, G.nut	Root rot, stem rot, blight, damping-off, wilt, nematodes	Fungal antagonists, soil treatment
2.	*Pseudomonas fluorescens*	Banana, Tomato, Potato, Chilli	Wilt, white rot Tuber rot Fruit rot Die back	Sucker Treatment Soil treatment Seed treatment Seed & Seedling treatment
3.	*Bacillus thuringiensis*	Cotton Cabbage, Tomato, Gram etc.	Lepidopterous pests	Foliar application
4.	*Lecanicillium lecanii*	Cotton, Vegetable crops	Aphid, whitefly	--"--
5.	*Beauveria bassiana*	Gram, Tobacco, Cotton, Tomato	Pod borer, cater pillar, thrips, aphids, mealybugs	Spray application
6.	Nuclear polyhedrosis viruses (NPV) Granulosis Viruses (GV)	Chickpea, Maize, Sunflower, Pigeon pea	*Heliothis, Spodoptera*	Spray the extraction of 250 crushed larve/ha

5. **Mineral Insecticides:** Sulphur is the oldest known pesticide and currently it is being used. It can be used as dust, wettable powder, paste or liquid for the management of powdery mildews, rusts, leaf blight etc. Sulphur damages the plants, when it is applied in hot (above 32 - 33^{0}C) and dry weather. Do not use sulphur where recently oil compound have been sprayed, it reacts with the oils to make a more phytotoxic combination.

CHAPTER-9: FUNDAMENTALS OF WEED MANAGEMENT

Introduction:

Increased use of herbicides has resulted many problems. The environment safety has been doubted with increased pollution hazards. That apart, weed species are developing resistance to chemical toxicants. In India, continuous use of isoproturan in wheat crop has resulted in the development of resistance in *Phalaris minor*. More over there is also problem of resurgence of weeds. In organic farming weeds can be managed by the following methods;

A: Preventive methods:

Preventive method of weed control include use of weed free crop seeds, weed free manure, clear equipments and elimination of weed infestation in and around irrigation channels and cultivated fields.

B: Cultural methods:

Smother crops are highly competitive with the weed species infesting an area for light, nutrients and moisture. The crops such as barley, millet, sorghum, alfalfa, clover, cowpea, sesbania, sunflower etc. Other cultural methods are sowing of cover crops, crop rotation, line sowing, maintaining optimum plant population, drip irrigation etc. which reduces weed problems.

C: Mechanical methods:

This method includes practices like hand weeding, hoeing, mowing, flooding, mulching, burning and tilling the soil for the reduction of weeds.

D: Soil solarization:

This is an eco-friendly technology used to kill weed seeds in soil. It involves mulching of soil with clear plastic films so as to trap the solar heat in the surface soil. The resultant temperature increase would be lethal to soil pathogens, nematodes and weeds. This method can be use where air temperature goes up to 45 ^{0}C during summer months. It is efficient where bright sun light is available for about 4-6 weeks.

E: Biological methods

This method involves utilization of natural enemies for the control of certain weeds. This can be achieved by direct or indirect action of biological control agents. In direct action, firstly the bio control agent bores into plant, weakens its structure which leading to its collapse and consumes as food and destroys the vital plant parts. In indirect action the bio control agent reserves the competitive ability of weed over other plants and enhances the condition favorable for plant pathogens.

E_1: INSECTS:

For bio-control of weeds, the insect selected should specifically attack on the targeted weed without harming the other plants.

S.N.	Weed species	Bio-agent	Remarks
1.	Prickly pear cactus	*Cactoblastis cactorum*	By leaf feeding beetle
2.	Water hyacinth	*Neochetina bruchi*	By leaf eating weevil

		Alternaria eichhornia	& fungus
3.	Parasitic weed *Orobanche* sp.	*Fusarium oxysporum* and fly (*Sipha maidis*)	Fungus & Insects both are used
4.	*Cyperus rotundus*	*Bactra minima* and *Athespacuta cyperi*	By leaf eating insect
5.	*Parthenium hysterophorus*	*Zygograma bicolorata* and *Smicronyx lutulentus*	By leaf eating insect

E $_2$: PLANT PATHOGENS

The active ingredient in a bio-herbicide is a living organism, mostly a micro organism. An herbicide made of mycelia fragments or spore of fungi is called mycoherbicide. This technique holds promise because reduced quantities of spores are needed, when seedlings are small and emerging.

Mycoherbicide	Fungus	Weed controlled
De vine	*Phytophthora palmivora*	Milk weed vine
Velgo	*Colletotrichum coccodes*	Velvet leaf
Collego	*Collego gloeosphoroides f. sp. aeschynomene*	Northern joint vetch

F: Allelopathy:

Inter-weed-competition determined by allelopathy can be manipulated in the natural control of weeds. Natural compounds released by some plants inhibit or prevent the growth of nearby plants. Marigold flowering plant is found to suppress the growth of parthenium. Thistle exudation inhibits the growth of oats. Wheat, oats & peas suppress the growth of *Chenopodium album*. The crop residues from alfalfa, sunflower, wheat, corn and soybean are toxic to weeds.

CHEPTER 10. OPERATIONAL STRUCTURE OF NPOP AND NATIONAL STANDARDS FOR ORGANIC FARMING

To provide a focused and well-directed development of organic agriculture and quality products, Ministry of Commerce and Industry, Government of India, launched a National Program on Organic Production (NPOP) in the year 2000, which was formally notified in October 2001 under the Foreign Trade & Development Act (FTDR Act).

10.1 NATIONAL STRUCTURE OF NPOP

The National Programme for Organic Production (NPOP) proposes to provide an Institutional mechanism for the implementation of **National Standards for Organic Production,** through a National Accreditation Policy and Programme (NAPP). Aims of the National Programme for organic production, inter alia, include the following:

1. To provide the means of evaluation of certification programmes for organic agriculture and products as per the approved criteria.
2. To accredit certification programmes.
3. To facilitate certification of organic products in conformity to the National Standards for Organic Products.
4. To encourage the development of organic farming and organic processing.

The National Programme for Organic Production shall, among others, include:

1. Policies for development and certification of organic products.
2. National standards for organic products and processes.
3. Accreditation of programmes to be operated by Inspection and Certification Agencies.
4. Certification of organic products.

Fig 1: Operational structure of National Programme for Organic Production (NPOP).

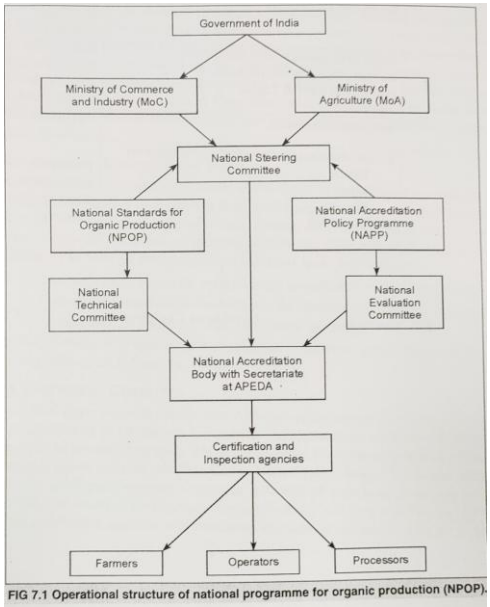


FIG 7.1 Operational structure of national programme for organic production (NPOP).

Operational structure of National Programme for Organic Production is given in Fig.1. The programme will be developed and implemented by the Government of India through its Ministry of Commerce and Industry as the apex body. The Ministry will constitute a National Steering Committee for National Programme for Organic Production, whose members will be drawn from Ministry of Commerce and Industry, Ministry of Agriculture, Agricultural and Processed Food Products Export Development Authority (APEDA), Coffee Board, Spices Board and Tea Board and other government and private organizations associated with the organic movement. To advise the National Steering Committee on relevant issues pertaining to National Standards and Accreditation, sub-committees will be appointed. The National Steering Committee for National Programme for Organic Production will formulate a National Accreditation Policy and Programme and draw up National Standards for Organic Products, which will include standards for organic production and processes as well as the regulations for use of the National Organic Certification Mark. National Accreditation Policy and Programme will be administered by the National Accreditation Body, which will define the overall objectives for the Accreditation programmes and operations. The National Steering Committee may amend the Accreditation procedures whenever it deems fit. The National Accreditation Policy and Programme is subject to periodic internal review, which will be conducted by the Technical Committee, which will advise the National Steering Committee about the need and content of such amendments in the National Programme for Organic Production.

10.1.1 National Accreditation Body

National Steering Committee would also function as the National Accreditation Body. Members of the National Accreditation Body shall comprise of representatives form Ministry of Agriculture, Ministry of Commerce and Industry, APEDA, Coffee Board, Spices Board and Tea Board. The Chairman of the Body shall be the Chairman of the National Steering Committee. The work of the National Accreditation Body will include:

1. Drawing up procedures for evaluation and accreditation of certification programmes.
2. Formulating procedures for evaluation of the agencies implementing the programmes.
3. Accreditation of inspection and certification agencies.

Every certifier will implement a certification programme and a programme cannot be accredited without accrediting the certifier.

10.1.2 Evaluation Committee

Eligible Inspection and Certification Agencies implementing certification programmes will be evaluated by an **Evaluation Committee.** The Evaluation Committee will be appointed by the National Accreditation Body. The members of the Evaluation Committee will comprise of members drawn from the APEDA, Coffee Board, Spices Board, Tea Board, Ministry of Agriculture and Export Inspection Council of India (EIC)/Export Inspection Agencies (EIAs). The APEDA, on behalf of the National Accreditation Body will receive and screen applications from the certification agencies, will coordinate and arrange evaluation visits etc. to ascertain the

credentials of certification programmes of the applicants. The Evaluation Committee will submit its recommendations to the National Accreditation Body for considering accreditation.

10.1.3 Accredited Inspection and Certification Agencies

Based on the recommendations of the Evaluation Committee, eligible Inspection and Certification Agencies will be accredited by the National Accreditation Body. These agencies should be well versed with the operating procedures, the **NSOP** and the international standards. Their programmes should have been in operation for at least one year and they should be able to provide the supporting documents.

10.1.4 Inspectors

The inspectors, appointed by the accredited Inspection and Certification Agencies will carry out inspection of the operations through records maintained by the operators as per specified formats and also by periodic site inspection. Based on compliance with the standards and certification programmes, accredited Inspection and Certification Agencies will certify the organic status of products and operations, specifying their conditions and recommendations.

10.2 NATIONAL STANDARDS FOR ORGANIC FARMING

Under NPOP Programme, the Govt. of India has developed National Standard for organic export. The Ministry of Agriculture, in principle, has accepted this standard for domestic purpose also. The scopes of these standards are:

1. Lay down policies for development and certification of organic products.
2. Facilitate certification of organic products confirming to the National Programme containing the standards for organic production.
3. Institute a logo and prescribe its award by accrediting bodies on products qualifying for bearing India organic label.

A National Steering Committee (NSC) comprising Ministry of Commerce, Ministry of Agriculture, APEDA, Spices Board, Coffee Board, Tea Board and various other Government and private organisations associated with the organic movement is monitoring the overall organic activities under the National Programme for Organic production (NPOP).

10.2.1 Conversion Requirements

Conversion period is the time between the start of organic management and the certification of crops as organic:

General Principles

Organic agriculture means a process of developing a viable and sustainable agro-ecosystem. The time between the start of organic management and certification of crops and/or animal husbandry is known as the **conversion period.** The whole farm, including livestock, should be converted according to the standards over a period of three years.

Recommendations

For a sustainable agro-ecosystem to function optimally, diversity in crop production and animal husbandry must be arranged in such a way that there is interplay of all the elements of the farming management. Conversion may be accomplished over a period of time. A farm may be converted step by step. The totality of the crop production and all animal husbandry should be converted to organic management. There should be a clear plan of how to proceed with the conversion. This plan shall be updated if necessary and should cover all aspects relevant to these standards. The **Certification Programme** should set standards for different farming systems so that they can be clearly separated in production as well as in documentation and the standards should determine norms to prevent a mix up of input factors and products.

Standards

- The standards requirements shall be met during the conversion period. All the standards requirement shall be applied on relevant aspects from the beginning of conversion period itself.
- If the whole farm is not converted, the certification programme shall ensure that the organic and conventional parts of the farm are separate and inspectable.
- Before products from a farm/project can be certified as organic, inspection shall have been carried out during the conversion period. The start of conversion period may be calculated from the date of application of the certification programme or from the date of last application of unapproved farm inputs provided it can demonstrate that standards requirements have been met form that date of implementation.
- Simultaneous production of conventional, organic in conversion and/or organic crops or animal products which cannot be clearly distinguished for each other, will not be allowed.
- To ensure a clear separation between organic and conventional production, a buffer zone or a natural barrier should be maintained. The certification programme shall ensure that the requirements are met.
- A full conversion period is not required where de facto full standards requirements have been met for several years and where this can be verified through several means and sources. In such cases, inspection shall be carried out with a reasonable time interval before the first harvest.

10.2.2 Maintenance of Organic Management

Standards

- Converted land and animals shall not get switched back and forth between organic and conventional management.

10.2.3 Landscape

The certification programme shall set standards for a minimum percentage of the farm area to facilitate bio-diversity and nature conservation.

Standards

- The certification programme shall develop landscape and bio-diversity standards.

CHAPTER 11. CERTIFICATION PROCESS

Certification for organic farm is an essential pre-requisite for marketing their produce, especially in the international markets. This is done mainly to ensure genuineness of organically farm products reaching the market and consumer. The certificate issued by an accredited agency is the attestation of the organic method of production of the products.

"Certified organic refers to agricultural products that have been grown and processed according to uniform standards, verified by independent state or private organizations accredited by the standard setting organization." Certification includes inspection of farm, fields and processing facilities. Farm practices inspected such as long-term soil management, buffering between organic farms and any neighbouring conventional farms, product labelling and record keeping are being followed.

A certification committee decides whether certification may be granted or not and then the agency issues approval of denial or certificate. Certificate is given for current years harvest only and hence annual certification is required.

Types of certification

Worldwide, inspection and certifications of organic foods is carried out by two sets of guidelines and norms namely (i) Statutory certification norms & (ii) Voluntary/ Civil certification norms.

(i) Statutory certification norms: It includes legal guidelines set by Government, which is related to certification of organic produce, regulatory governing import of organic foods, rules regarding equivalence between countries etc.

(ii) Voluntary/ Civil certification Norms: The Norms are stricter then statutory certification norms. It includes National and International agency and association such as Soil Association of U.K., Organic Growers Association in various countries etc.

The most highly accepted voluntary certifications are from agencies like CODEX, IFOAM, Natural land, Demeter and Soil association etc.

Organic certification is a certification process for producers of organic food and other organic agricultural products. In general, any business directly involved in food production can be certified, including seed suppliers, farmers, food processors, retailers and restaurants. Requirements vary from country to country and generally involve a set of production standards for growing, storage, processing, packaging and shipping that include:

1. Avoidance of most synthetic chemical inputs (fertilizer, pesticide, antibiotics, food additive etc.), genetically modified organisms, irradiation and the use of sewage sludge.
2. Use of farmland that has been free from synthetic chemicals for a number of years (often, three or more.)
3. Keeping details written production and sales of records (audit trail)
4. Maintaining strict physical separation of organic products from non-certified products.
5. Undergoing periodic on-site inspections.

In some counties, certification is overseen by the government and commercials use of the term organic is legally restricted. Certified organic producers are also subject to the same agricultural food safety and other government regulations that apply to non-certified producers.

Purpose of certification

It is intended to assure quality and prevent fraud. For organic producers, certification identifies suppliers of products approved for use in certified operations. For consumers, certified organic serves as a product assurance.

Certification is essentially aimed at regulating and facilitating the sales of organic products to consumers. Individual certification bodies have their own service marks, which can act as branding to consumers. Most certification bodies operate organic standard that meet the National government's minimum requirements. Some certification bodies certify to higher standards.

8.1 THIRD PARTY CERTIFICATION PROCESS

To certify a farm, the farmer is typically required to engage in number of new activities, in addition to normal farming operations. In addition, short-notice or surprise inspections can be made and specific tests (soil, water, plant tissue) may be requested.

For first-time certification, the soil must meet basic requirements of being free from use of prohibited substances (synthetic chemicals etc) for number of years. A conventional farm must adhere to organic standards for this period, often, two to three years. This is known as being in transition. Transitional crops are not considered fully organic.

Certification for operations other than farms is similar. The focus is on ingredients and other inputs and processing and handling conditions. A transport company would be required to details the use and maintenance of its vehicles, storage facilities, containers and so forth. A restaurant would have its premises inspected and its suppliers verified as certified organics.

8.2 PARTICIPATORY CERTIFICATION

"*Participatory guarantee systems are locally focused quality assurance systems. They certify producers based on active participation of stakeholders and are built on a foundation of trust, social networks and knowledge exchange*" (IFOAM 2008).

Participatory guarantee systems (PGS) represent an alternative to third party certification, especially adapted to local markets and short supply chains. They can also complement third party certification with a private label that brings additional guarantees and transparency. The PGS enable the direct participation of producers, consumers and other stakeholders in:

1. The choice and definition of the standards.
2. The development and implementation of certification procedures
3. The certification decisions.

Participatory guarantee systems are also referred to as participatory certification.

In India, APEDA regulates the certification of organic products as per National Standards for Organic Production. "The NPOP standards for production and accreditation systems have been recognised by European Commission and Switzerland as equivalent to their country

standards, Similarly, USDA has recognised NPOP conformity assessment procedures of accreditation as equivalent to that of US.

With these recognitions, Indian organic products duly certified by the accredited certification bodies of India are accepted by the importing countries." In March 2000, the Ministry of Commerce launched NPOP (National Programme for Organic Production) designed to establishment national standards for organic products which could then be sold under the logo Indian Organics. For proper implementation of NPOP, NAPP (National Accreditation Policy and Programme) has been formulated with Accreditation Regulations announced in May2001. These make it mandatory that all certification bodies whether internal or foreign operating in the country must be accredited by an Accreditation Agency. The regulations make provision for exports, import and local trade of organic products. However, currently only the exports of organic products come under government regulations.

Thus, an agricultural product can only be exported as an organic product if it is certified by a certification body duly accredited by APEDA. Organic crop production, organic animal production, organic operations, forestry and wild products are the categories of products covered under accreditation.

8.3 ACCREDITATION

Accreditation is a process in which certification of competency, authority or credibility is presented. Organisations that issue credentials or certify third parties against official standards are themselves formally credited by accreditation bodies (such as UKAS); hence they are sometimes known as "accredited certification bodies". Accreditation process ensures that their certification practices are acceptable, typically meaning that they are competent to test and certify third parties, behave ethically and employ suitable quality assurance.

In India, as per the National Programme for Organic Production (NPOP), an accreditation refers registration by the accreditation agency for certifying agency for certifying organic farms, products and processes as per the guidelines of the National Accreditation Policy and Programme for Organic Product.

The NPOP programme in context of Indian accreditation scenario, defined the function of accreditation agencies like:

1. Prescribe the package of practices for organic products in their respective schedule.
2. Undertake accreditation of inspection and certifying agencies who will conduct inspection and certify products as having been produced in accordance with NPOP.
3. Monitor inspection made by the accredited inspection agencies.
4. Lay down inspection procedures.
5. Advise the National steering Committee on organic Production.
6. Accept accredited certification programme if such programme confirm to National Standard.
7. Accreditation agencies shall evolve accreditation criteria for inspection and /or certifying agencies and programme drawn up by such agencies for their respective area of operation and products.

8. Accreditation agencies shall prepare an operating manual to assist accredited agencies to abide by such a manual must contain appropriate directions, documentation formats and basic agency and farm records for monitoring and authentication of adherence to the organic production programme.
9. Eligible inspection and certification agencies implementing certification programmes will be identified by the Accreditation Agency.

In the year 2000, Ministry of Commerce, GoI has launched the NPOP. The following accreditation agencies are designated vide trade Notice (No ORG/004/2001) dated June13, 2001.

1. Agricultural and Processed Food Product Export Development Authority (APEDA)
2. Coffee Board
3. Spice Board
4. Tea Board

8.4 CERTIFICATION PROCESS

Organic certification is intended to assure quality and prevent fraud. For organic producers, certification identifies suppliers of products approved for the use in certified operations. Certification is essentially aimed at regulating and facilitating the sale of organic products to consumers.

8.4.1 Responsible body and Certification Decisions

1. Certification decisions are not only limited to initial approval of Licensed Operators, but also approval of products, change in production, disciplinary measures etc.

2. Authorised Inspection and Certification Agencies shall ensure that each decision on certification is taken by persons differently from those who carried out the inspection or assessment.

3. Agency responsible for certification decisions shall reflect a diversity of stakeholders without any single interest predominating.

4. Where certification decisions are delegated to a small committee or officers, the Authorized inspection and Certification Agencies shall demonstrate reporting and review functions that enable the agency responsible for certification to exercise ultimate control and responsibility for such decisions.

Exceptions

If exceptions are granted, clear criteria and procedures for granting exceptions shall be evolved.

Exceptions shall be clearly limited in time.

The rationale for any exception shall be properly recorded.

8.4.2 ACTUAL CERTIFICATION PROCESS

The certification policies and procedures shall be well documented and, include:

1. All procedural steps in processing the application until final certification.
2. That the certification status of all Licensed Operators and their production be indicated throughout the certification process.

3. The procedures for extension and updating certification, including certification of individual products.
4. That the certification decisions be recorded and clearly communicated to the Licensed Operator.
5. If certification is denied, the reasons shall be clearly stated.
6. Authorised Inspection and Certification Agency shall be able to impose conditions and restrictions. Mechanisms for monitoring compliance with such conditions and restrictions shall be in place.
7. The criteria for the acceptance of applicants, formerly certified by other certification system shall be documented. Relevant records from the other certification system must be requested.
8. That, when asked for by the licensed operator, relevant records are released to another Authorised Inspection and Certification Agency.
9. That processing of inspection reports and certification decision shall be done in a timely manner.
10. That processing of any issue related to violations shall be done with highest priority.

The following certification records and reports are necessary for grant of certification:

1. Licensed operators.
2. Inspection and certification of all stages in handling.
3. Inspection and certification of wild product.
4. Inspection and certification of input manufacturing.

8.4.3 GRANT OF CERTIFICATION

After preliminary inquiry and thorough inspection is satisfied that the applicant having regard to requisite skill, resources, production, processing previous performance and antecedents relevant to the issuance of the License is to fit to use the Certification Mark, the authorised inspection and Certification Agency shall grant a License in prescribed form authorising the use of the certification mark in respect of the product or class of products manufactured by the applicant, subject to such terms and conditions as specified in these rules. The Authorised Inspection and Certification Agency shall intimate the applicant about grant of License.

PROCESSING METHOD

Standards

- The following kinds of processes are approved:
  - Mechanical and physical
  - Biological
  - Smoking
  - Extraction
  - Precipitation
  - Filtration

- Extraction shall only take place with water, ethanol, plant and animal oils, vinegar, carbon dioxide, nitrogen or carboxylic acids. These shall be of food grade quality appropriate for the purpose.
- Irradiation for the purpose
- Filtration substances shall not be made of asbestos nor may they be permeated with substances which may negatively affect the product.

PACKAGING

Standards

The materials used must not affect the organoleptic character of the product or transmit to it any substances in quantities that may be harmful to human health.

LABELLING

Standards

- The person or company legally responsible for the production or processing of the product shall be identifiable.
- Single ingredient product may be labeled as producer of organic agriculture or a similar description when all standards requirements have been met.
- Mixed products where not all ingredients, including additives are of organic origin may be labeled in the following way

- Where a minimum of 95 per cent of the ingredients are of certified organic origin, products may be labelled “Certified organic”.
- Where less than 95 per cent but not less than 70 per cent of the ingredients are of certified organic origin, products may not be called organic. The word organic may be used on the principal display in statements like “made with organic ingredients” provided there is a clear statement of the proportion of the organic ingredients.
- Where less than 70 per cent of the ingredients are of certified origin, the indication that an ingredient is organic may appear in the ingredients list. Such product may not be called organic.

- Added water and salt shall not be included in the percentage calculations of organic ingredients.
- The label for in conversion products shall be clearly distinguishable from the label for organic products.
- All raw materials of a multi ingredient product shall be listed on the products label in order of their weight percentage. It shall be apparent which raw material are of organic certified origin and which are not. All additives shall be listed with their full name. If herbs and /or spices constitute less than 2 per cent of the total weight of the product, they may be listed as spices or herbs without stating the percentage.
- Organic products shall not be labeled as GE (genetic engineering) or GM (genetic modified) free in order to avoid potentially misleading claims about the end product. Any reference to genetic engineering on product labels shall be limited to the production method.

Chapter 10. ECONOMIC CONSIDERATIONS, MARKETING AND EXPORT POTENTIAL OF ORGANIC FARMING

Farming in India was fundamentally organic till the middle of the twentieth but industrial revolution; desire to make quick and more money and to get rid pests and disease brought in the concept of **chemical farming** after independence. Farmers started using chemical fertilizers to increase the yield and to meet the demand of growing population. Though, initially it looked extensively amazing, its adverse effects started to appear in 1980s. Extensive use of fertilizers and pesticides resulted in pests and diseases resistance of the cultivars and polluted the crop growing environment including groundwater. It appears that health conscious people are looking for healthy options and shifting towards organic products.

10.1 ECONOMIC SONSIDERATIONS

Productivity of organic farming may be less in initial years, but the yield increases progressively under organic farming, equating the yield under inorganic farming by sixth year. A long -term experiment conducted by ICRISAT also sustains the view that yield of different crop in low cost sustainable sytems,the annul productivity (rain + post rainy season yield), in particular, is comparable to that in the conventional system.

In areas of **intensive farming** system, shifting to organic agriculture decrease yield; the range depends on the intensity of external input use before conversion. In the so-called **green revolution** era (irrigated lands), conversion to organic usually leads to almost identical yields. In traditional **rainfed agriculture** (with low external inputs), organic agriculture has shown the potential to increase the yield.

Replacement of external inputs farm-derived **organic resources** normally leads to a reduction in variable input costs under organic management. Expenditure on fertilizers and plant protection inputs is substantially lower than in conventional systems in almost all the cases. In a few cases, higher inputs costs due to purchase of compost and other organic manures have been reported. Studies have shown that the common organic agricultural combination of lower input costs and favorable premiums can offset reduced yields and did not include organic farms equally and often more profitable than conventional farms. Farms that did not include organic price premiums have given mixed results on profitability. Economics of organic cotton cultivation over a period of six years indicated that there is a reduction in cost of cultivation and increased gross and net returns compared to conventional cotton cultivation in India.

10.2 VIABILITY OF ORGANIC FARMING

Farmers will only be able to convert to organic farming if their livelihood is secured during the transition phase and if their farming is economically viable in the long run. Crop yield play an important -though not the only- role in this. It is therefore important to minimize the initial drop in yield to the best possible extent and to ensure that yield achieve a satisfying level after the **conversion period.** At the same time, production costs need to be kept low. By

providing appropriate extension services, projects can support farmers in identifying and implementing suitable management practice to achieve these goals. In order to be able to manage the farm in an optimum way, farmers not only need to learn organic farming methods, but also to develop and understanding on the interrelations between the different components of an agro-ecosystem: soil fertility, nutrition and water household, **biodiversity, ecological balance** etc. Conducting suitable training for farmers interested in converting to organic farming can help build a basis on which farmers can further develop their management capacity. Equally important is that farmers can obtain practical can obtain practical advice to fine-tune their management practices in the field.

Extension staff must be able to create awareness among farmers for the core principles of organic farming, such as the ecosystem approach, the central role of **soil fertility,** closed nutrient cycles and **ecological balance** .If the manage to convey the philosophy of organic agriculture, it is more likely that farmers whole heartedly stick to organic farming about is potential benefits and persuade farmers to join the initiative. They should openly address the difficulties that farmers are likely to face during the **conversion process** and provide a realistic picture own the limitations of the project. In this, they need to take into consideration the different resource bases and degrees of vulnerability of marginal and wealthier farmers. It is important to create an atmosphere in which problems and short- comings are openly addressed by all stakeholders, so that the team and the management can work on improvements. Most probably the farmers are technically more familiar with cotton farming practice than the extension staff and after some time they will also be more experienced in the practical implication of organic farming methods. The role of extension staff should, therefore, change to being facilities or coaches who farmers in developing suitable solutions to problems and in sharing their experience and expertise with other members of the group. The focus might shift to creating platforms for and moderating processes of farmer-to farmer exchange.

Application of adequate of organic manures increases soil **organic matter** content leading to increasing cotton yields. Especially in fields where synthetic fertilizers were extensively used before conversion, it is a necessary to apply sufficient amounts of organic material in order to build up soil organic matter and to stimulate soil life. Projects, therefore, should advise farmers about producing organic manure from farm-own sources, such as farmyard manure, compost and liquid manures, Support could also be rendered for purchasing additional cattle or for building simple infrastructure for efficient collection of cattle dung and urine and for preparing compost. As farm-own sources of manure might not be sufficient to achieve satisfying yield levels, projects could further facilitate the supply of manures and natural mineral fertilizers from off-farm sources (de-oiled castor, sugarcane press mud, rock phosphate). Increased input of manure, however, is not the only way to increase soil organic matter and nutrient supply. Appropriate **crop rotation** patterns that involve legumes, the cultivation of green manures and intercrop and the recycling of crop residues can be equally effective.

Results of investigation have shown that small holder organic farming systems can produce similar yield as in conventional farming after completing a **transitional period** of 3-4

years. This challenges the argument that conversion to organic farming is not a suitable option for developing countries as it puts food security at risk. Crop yield are- without a doubt-an important factor in farming. However, if innovation in farming is to really improve rural livelihoods, the focus needs to shift away from yields, to a broader perspective that includes sustainability of the management of the production base, economic viability of the farm operations (the relation of costs and revenues) and livelihood security. It is in the field where organic farming offers the most promising potentials. Replacing agro-chemicals with natural means and management practices has positive impacts on **soil fertility** environment and human health. Lower dependency of organic farms on external inputs not only decreases production costs, thus contributing to improved incomes, but also reduces the risk of farming in context of insecure climatic and market conditions. While this could to some extent -also be achieved with integrated farming approaches, organic farming offers in additional the opportunity to link production with a growing market demand for environmentally and socially better products.

Organic farming seems to be a particularly suitable option for smallholders and marginal farmers, who could not benefit from adopting green **revolution** practices. Their lack of production means and capital is counter balanced with the availability of under-utilized family labour and the ability to produce inputs on the farm itself. Once production costs are intensifying their production and opening up off-farm income sources. However, small and marginal farmers are also the ones who find conversion to organic farming most difficult, as yield and incomes in usually in the initial year, thus putting their fragile livelihoods at risk. The challenge in utilizing the potential of organic farming for achieving development goals, therefore, lies in enabling poor farms to overcome the obstacles of **conversion period** so that they can benefit in the long term, appropriate extension approaches that facilitate conversion and mechanisms for bridging the initial income gap are thus needed. The experience of successful organic cotton initiatives in several developing countries provides ample material to study how project support could be further improved.

For successful extension, certification and marketing, **organic cotton** farming with small- holders requires a group approach. Only if the involved farmers develop emotional ownership for the project and identify as a group, can free-riding b prevented and the long term sustainability of the project be ensured. Due to its holistic approach that relates to societal dimensions of rural livelihoods, the organic farming systems seems to be particularly suitable to create this identify and solidarity among framers. The need to form strong farmers based project entities poses a considerable challenge to utilizing organic farming in development work. At the same time -if successful - the group approach allows implementing a range of joint activities in other fields e.g. in micro-credit community development and off-farm income generation.

Although our research has shed some ligh on crucial regarding the potential of organic farming in developing countries, it also opened up a range of new questions. In some aspects-such as water management, gender aspects and the interface between farmers and project

organisers - we could only touch the surface,leaving a more in-depth investigation to other researches. It will also be necessary to put the finding on a broader base of investigated case studies in different countries. Therefore, a lot remains to be done to fully utilize the potential of organic farming in development work.

MARKETING AND EXPORT POTENTIAL OF ORGANIC PRODUCTS

Organic farming has a place where there is a market to accept the produce at a higher price as the growing interest in organic farming practice is due to an expectation of higher premium for organically produced farm commodities. The basic focus of organic farming should be first to produce farm products for the home (domestic) market and second for the export market.

Marketing of Organic Products

Major organic produces in India are given **in Table.** There is no organic production of meat products like poultry, livestock and fisheries in India as yet. There are three types of organic producers in India- Traditional organic growers who grow for their subsistence needs, commercial farmers who have surplus and export their produce through different channels and private companies which either have their own farms or organize large conversion programmes with growers.

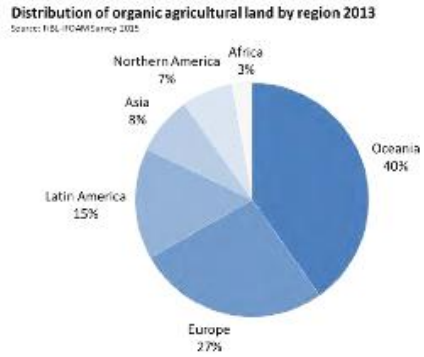
Table: Major products produced in India by Organic Farming

Type of Product	Products
Commodity	Tea, coffee, rice, wheat
Spices	Cardamom, black pepper, white pepper, ginger, turmeric, vanilla, tamarind, clove, cinnamon, nutmeg, mace, chili
Pulses	Pigeonpea, blackgram
Fruits	Mango, banana, pineapple, passion fruit, orange, cashewnut, walnut
Vegetables	Okra, brinjal, garlic, onion, tomato, potato
Oilseeds	Mustard, sesame, castor, sunflower
Others	Cotton, sugarcane, herbal extracts

Organic products available in the domestic market are rice, wheat, tea, coffee, pulses and vegetables. On the other hand, products available for export market, besides, these, include cashewnuts, cotton, oilseeds, various fruits and medicinal herbs. Whereas wholesalers and traders, super markets and own shops are the major channels in the domestic market which is mainly in metropolitan cities and accounts for only 8.0 per cent of the total organic production, the market channel for export of organic products is export companies with the exception of tea which is produced and exported by tea estates. Major markets for Indian organic products are the EU, USA, Canada, Australia and the Middle East Asian countries. Quality production with traditional methods, low use of chemical inputs in mountain and tribal areas, easy availability of cheap labour, NGO interventions and various types of support provided by the governments as the main advantages of Indian organic products. High price expectations, delayed delivery, quality restrictions, lack of certification and marketing networks are some of the constraints in

marketing organic products internationally. On the other hand, in home market, there are no separate markets for organic products in many commodities like wheat in Rajasthan. Thus, the market does not offer any incentive for the production of organic produce. But more recently, some agencies have tried to create separate market outlets for organic produce like the Maharashtra Cotton Marketing Federation purchased organic cotton from growers separately for export.

Global organic market-A brief review.



1. Organic market share=1% of total food sales
2. Global market 2000=17 billion USD 2003=25 billion USD 2004= 26 billion USD 2005=31 billion USD
3. Value of organic food sales USA = 80000 million USD Germany= 2100 million USD UK = 1000 million USD Italy = 1000 million USD France = 850 million USD Switzerland = 450 million USD
4. Organic export in India = 15.5 million USD (2003)=710 million rupees
Export Potential of organic products • 170 countries • 69.85 million ha certified organic (1.6%) • 2 million producers Oceania – 17.3 mha, Europe – 11.5 m ha, Latin America - 6.6 m ha, Asia - 3.4 m ha, North America 3 m ha Africa – 1.2 m ha, 35 m ha wild harvest collection area

Indian organic: An overview **(2017)**

- Total cultivable area 1.70 m ha (15th Rank in the World)
- 4.22 m ha forest and wild area
- MP has largest certified organic area fb HP & Rajsthan
- Produced 1.85 m MT organic products
- Exported 263687 MT organic food; 298 m USD (oilseed, processed food, cereals & millets, tea, pulses, dry fruits etc.)

Export of organic produce from India to EU

Product	Quantity(tonnes)	Product	Quantity(tonnes)
Tea	1997	Cashew nut	126
Pineapple	1320	Walnut	89
Spices	625	Fruit	46
Honey	526	Cotton	26
Rice	432	Pulses	12
Sesame seed	354	Sugarcane	8

1 Rainfed Agriculture: Introduction, Types and History of Rainfed Agriculture in India

1.1 Introduction

Even after the utilization of all our water resources for irrigation, about half of the cultivated area will remain rainfed. As there is hardly any scope for increasing the area under cultivation, it is really a colossal task for meeting the future food needs. It is against this background that the role of dryland agriculture gained importance. Agriculture is the single largest livelihood sources in India with nearly two thirds of people depend on it. Rainfed agriculture is as old as agriculture itself. Growing of crops entirely under rainfed conditions is known as dryland agriculture.

Very often, the words dry farming, dryland agriculture and rainfed agriculture are used synonymously to indicate similar farming situation. Clearly, the two exclude irrigations. **Depending on the amount of rainfall received, it can be grouped into three categories:**

Types of Dryland/Rainfed Agriculture

1.2 Definitions

a) Dry farming: is cultivation of crops in regions with annual rainfall less than 750 mm. Crop failures is most common due to prolonged dry spells during the crop period. These are arid regions with a growing season (period of adequate soil moisture) less than 75 days. Moisture conservation practices are necessary for crop production.

b) Dryland farming: is cultivation of crops in regions with annual rainfall more than 750 mm. In spite of prolonged dry spells crop failure is relatively less frequent. These are semi-arid tracts with a growing period between 75 and 120 days. Moisture conservation practices are necessary for crop production. However, adequate drainage is required especially for vertisols or black soils.

C) Rainfed farming: is crop production in regions with annual rainfall more than 1150 mm. Crops are not subjected to soil moisture stress during the crop period. Emphasis is often on disposal of excess water. These are humid regions with growing period more than 120 days.

In dry farming and dryland farming, emphasis is on soil and water conservation, sustainable crop yields and limited fertilizer use according to soil moisture availability. In rainfed agriculture, emphasis is on disposal of excess water, maximum crop yield, high levels of inputs and control of water erosion.

Sr. No.	Particular	Dry Farming	Dryland Farming	Rainfed farming
1	Rainfall/annum (mm)	< 750	750 – 1150	> 1150
2	Moisture availability	Acute shortage	Shortage	Enough
3	Crop growing season	< 75 days	75 – 120 days	> 120 days
4	Growing region	Arid	Semi-arid	Humid
5	Cropping systems	Single crop/ intercropping	Single crop/ intercropping	Inter/ Multi-cropping

6	Dry spells	Most common	Less frequent	No occurrence
7	Crop failure	More frequent	Less frequent	Rare
8	Constraints	Wind erosion	Wind erosion/ water erosion	Water erosion
9	Measures Required	Moisture conservation practices	Moisture conservation practices & drainage for vertisols	Proper drainage required

United Nations Economic and Social Commission (UNESC) for Asia and the Pacific distinguished dryland agriculture mainly into two categories: dryland and rainfed farming. The distinguishing features of these two types of farming are given below

1.3 Dryland farming v/s Rainfed farming

Constituent	Dryland farming	Rainfed farming
Rainfall (mm)	<750	>750
Moisture availability to the crop	Shortage	Enough
Growing season (days)	<200	>200
Growing regions	Arid and semiarid as well as uplands of sub-humid and humid regions	Humid and sub-humid regions
Cropping system	Single crop or intercropping	Intercropping or double cropping
Constraints	Wind and water erosion	Water erosion

1.4 The Concept:

The concept **of rainfed agriculture** (farming) under which both dry farming and dryland farming **(dryland** agriculture) is included has been changed. Dry farming was the earlier concept for which amount of rainfall (less than 500 mm annually) remained the deciding factor for more than 60 years.

In modem concept, dryland areas are those where the balance of moisture is always deficit side. In other words, annual evapotranspiration exceeds precipitation. In dryland agriculture, there is no consideration of amount of rainfall. It may appear quite strange to a layman that even those areas which receive 1100 mm or more rainfall annually fall in the category of dryland agriculture under this concept. To be more specific, the average annual rainfall of Varanasi is around 1100 mm and the annual potential evapotranspiration is 1500 mm. Thus the average moisture deficit so created comes to 400 mm. This deficit in moisture is bound to affect the crop production under dryland situation, ultimately resulting into total or partial failure of crops. Accordingly, **production is either low or extremely uncertain and unstable which are the real problems of dryland in India**.

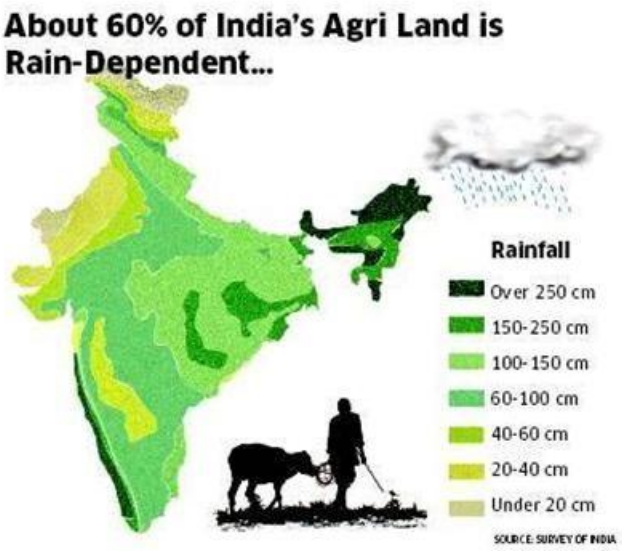
Success of crop production in these areas depends on the amount and distribution of rainfall, as these influences the stored soil moisture and moisture used by crops. Amount of water used by crop and stored in soil is governed by water balance equation:

$$ET = P - (R + S)$$

When balance of the equation shifts towards right, precipitation (P) is higher than ET, so that there may be water logging or it may even lead to runoff (R) and flooding. On the other hand, if the balance shifts to left, ET becomes higher than precipitation, resulting in drought. Taking the country as a whole, as per meteorological report, severe drought in large area is experienced once in 50 years and partial drought once in five years while floods are expected every year in one or other part of the country, especially during rainy season. In fact, the balance of the equation is controlled by weather, season, crops and cropping pattern.

Present Status

- Growing of crops entirely under rainfed conditions is known as dryland agriculture.
- India has about 108 m ha as rainfed area/dryland agriculture of total 143 m ha (67 %)
- Dry farming contribute in total food grains production: 44 %
- Area under oilseeds (groundnut, rapeseed, mustard and soybean): 80 %
- Nearly 67 M ha of rainfed area falls in the mean annual precipitation range of 500 – 1500 mm.
- Average annual rainfall of the country is 1200 mm amounting to 400 M ha-m of rainwater over the country's geographical area (329 M ha).



- However, distribution across the country varies from less than 100 mm in extreme arid areas of western Rajasthan to more than 3600 mm in NE states and 1100 mm from East Coast to 2500-3000 mm in the West Coast.
- Broad area of summer monsoon activity extends from 30^{o} N to 30^{o} S and from 30^{o} W to 16.5^{o} E. Detailed information on rainfall and monsoonal pattern in India has been summarized below.

Rainfall pattern in India

Season/Period	**M ha-m**	**Per cent**
Winter (Jan-Feb)	12	3
Pre-monsoon (March-May)	52	13
S – W monsoon (June – Sept.)	296	74
N – E monsoon (Oct-Dec)	40	10
Total for the Year	**400**	**100**

- India ranks first in rainfed agriculture globally in both area (86 M ha) and the value of produce.
- Rainfed regions in India contribute substantially toward food grain production including 44% of rice, 87% of coarse cereals (sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.), maize (*Zea mays* L.), and 85% of food legumes, 72% of oilseeds, 65% of cotton, and 90% of minor millets (Table 1.2).
- Rainfed agriculture, with nearly 58 per cent of the cultivated area, contributes 40 per cent of the country's food production.
- Even after full irrigation potential of the country is realized, half of the cultivated area will continue to be under rainfed fanning.
- Hence, it is necessary to increase the productivity of major rainfed crops to meet the ever-increasing demand for food and fiber.
  - During the past 25 years, there occurred significant changes in the area and yield of important crops of rainfed areas.
  - Area under coarse cereals decreased by about 10.7 M ha and most of this was under sorghum.
  - Area under oilseeds increased by 9.2 M ha and most of this increase was due to irrigated rapeseed and mustard and soybean.
  - Total area under pulses and cotton remained constant but more of cotton became irrigated and shifts in the area occurred from one agro-ecological region to others. Area under chickpea in northern belt decreased but increase in central belt. This change occurred due to increase in area under rice-wheat cropping system which displaced chickpea and also pearl millet to a great extent and maize to a small extent.

Table 1.2: Area sown under various rainfed crops and percentage of rainfed area

Crop	Area sown (M ha)	Rainfed area (%)
Rice	45.5	42
Coarse cereals	27.5	85
Sorghum	7.5	91
Pearl millet	8.7	91
Maize	8.2	75
Pulses	22.1	83
Pigeonpea	3.4	96
Bengalgram (Chickpea)	7.9	67
Oilseeds	27.6	70
Groundnut	6.2	79
Rapeseed and mustard	6.3	27
Soybean	9.5	99
Sunflower	1.8	69
Cotton	9.4	65

  - Of these 25 districts, covering 18 M ha of net area sown with 10 per cent of irrigation, receives 375-750 mm rainfall annually spread over central Rajasthan, Saurashtra region of Gujarat and rain shadow region of Western Ghats in Maharashtra and Karnataka.

Basic Facts:

- India is home to 18% of world's population, 15% of the world livestock, 4.2% of fresh water resources, 1% of forests, and 0.5% of pasture land, but only has 2.3% of the geographical area.
- India is home to 25% of the world's hungry population of world. 1 billion along with an estimated 43% of children malnourished under the age of five.
- The net sown area in India has remained constant for several years at 141 M ha, but the human and livestock populations have been steadily increasing. Though the Indian population increased from 361 million in 1951 to 1360 million in 2019, the food-grain production has more than quadrupled, but the yield gains are largely from the irrigated agro-eco systems.
- Notwithstanding the increase in average productivity from 0.6 t / ha in the 1980s to 1.1 t/ ha at the present time, large yield gaps exist for rainfed crops in the semiarid regions.
- Even after realizing the full irrigation potential, nearly 40% of the net sown area of 142 M ha will remain totally rainfed.
- The per capita availability of land has fallen drastically from 0.37 ha in 1951 to about 0.19 ha in 2001; and it is projected to decline further to 0.09 ha by 2050. According to the World Bank collection of development indicators arable land (hectares per person) in India was reported at 0.11813 in 2016.

Area Under Irrigated and rainfed conditions in India

Class	Area (m ha)	%age of total Arable
Total Arable	143.8	100
Dryland	34.5	24.0
Rainfed	65.5*	45.5
Irrigated	43.8	30.5
*Includes Flood-prone area of 15 m/ha		

Per Capita Land Availability

Year	Cropped Area (m.ha)	Total Population (m)	Av. Land per capita (ha)
1951	13189	361.1	0.37
1971	165.79	548.2	0.30
1991	185.74	846.3	0.22
2001	190.76	1027	0.19
2050	200.00	1600	0.09

Arable-land-hectares-per-person (tredingeconomics.com)

Principles of Agronomy, Reddy & Reddy, 2016 Food security and SRI, Pradhan *et al*., 2019

- Increasing productivity of rainfed cropping systems is of critical importance to meet the food demands of an ever-increasing population in India.
- The potential productivity of maize (Z. mays) in high rainfall regions under rainfed condition are 8.0 t/ha vis-a-vis the national average yield of 2.1 t/ ha, indicating an unabridged yield gap of 6 t/ ha. Large yield gaps exist in other crops as well which are primarily grown under rainfed conditions.
- Recommended management practices (RMPs) such as improved cultivars, site specific nutrient management (precision agriculture), and water harvesting and recycling can potentially increase the yields in several crops up to 6 t/ ha, indicating the large realizable potential under rainfed conditions.
- There are many districts in India where the actual yields are much lower than the national average, and there is enormous potential for improvement.

- According to the present concept, there are 128 districts in the country which face the problems of dryland.
- Twelve districts have irrigation covering 30-50 per cent of the cropped area and do not pose serious problems.
- Remaining 91 districts covering mainly Madhya Pradesh, Gujarat, Maharashtra, Andhra Pradesh. Karnataka, Uttar Pradesh parts of Haryana, Tamil Nadu etc. represent typical dryland area. Total net sown area in these districts is estimated to be 42 M ha of which 5 M ha are irrigated. Rainfall in these districts varies from 375 to 1125 mm. Therefore, more and more efforts are to be made for enhanced and stable production in these areas so that the recurring droughts do not stand in the way of meeting the growing food demands.

History of Dryland/Rainfed Agriculture:

- First systematic scientific approach to tackle the problems of dry farming areas was initiated by Tamhane in 1923 on a small plot at Manjri Farm near Pune and the work passed on to kanitkar in 1926.
- A comprehensive scheme of research was drawn up by Kanitkar with financial support from the ICAR. Realizing the importance, the 1CAR launched a comprehensive project on dryland farming at five centers: Sholapur and Bijapur in 1933, Hagari and Raichur in 1934 and Rohtak in 1935.
- A decade of work up to 1943-44 mainly on rainfall analysis, physico-chemical properties of soils, physiological studies on millets and on agronomic aspects resulted in a series of dry farming practices commonly known as the Bombay dry farming practices, Hyderabad dry farming practices and Madras dry farming practices.
- These practices stressed the need for contour bunding, deep ploughing, and application of FYM, low seed rate with wide spacing, mixed cropping and crop rotation. These recommendations could not motivate the farmers to adopt them as the yield advantage was about 15-20 per cent over a base yield of 200-400 kg/ ha.
- By the mid-1950s, importance of soil management (soil and moisture conservation) was realized for improving the productivity of dryland and the ICAR established eight Soil Conservation Research Centers in 1954. However, yield improvement was not more than **15-20** per cent over the basic yield of 200-400 kg/ha.
- Importance of short duration cultivars maturing within adequate soil moisture available period (crop growing period) was recognized during 1960s.
- The place of high yielding varieties and hybrids for yield advantage in dryland agriculture was realized in mid-1960s.
- With the establishment of All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in 1970, emphasis was shifted to multi-disciplinary approach to tackle the problem from several angles.
- Similar efforts were initiated at ICR1SAT, Hyderabad in 1972.
- The ICAR selected 25 dryland agricultural centers all over the country on the basis of the moisture deficit, soil type and rainfall characteristics as indicated below :

1. Agra (Uttar Pradesh)
2. Akola (Maharashtra)
3. Anantapur (Anadhra Pradesh)
4. Arjia (Rajasthan)
5. Ballowal Saunkhri (Punjab)
6. Bengaluru (Karnataka)
7. Bijapur (Karnataka)
8. Biswanath Chariali (Assam)
9. Chianki (Jarkhand)
10. Faizabad (Uttar Pradesh)
11. Hisar (Haryana)
12. Indore (Madhya Pradesh)
13. Jagdalpur (Chattisgarh)
14. Kovilpatti (Tamil Nadu)
15. Parbhani (Maharashtra)
16. Phulbani (Odisha)
17. Rajkot (Gujarat)
18. Rakhdhiansar (J & K)
19. Rewa (Madhay Pradesh)
20. Sardarkrushinagar (Gujarat)
21. Solapur (Maharashtra)
22. Varanasi (Uttar Pradesh)
23. Bellary (Karnataka)
24. Jhansi (Uttar Pradesh)
25. Jodhpur (Rajasthan)

The chronology of major events in dryland agricultural research in India is as follows:

1880 The First Famine Commission was appointed by the then British Empire to suggest ways and means to offset the adverse effects of recurring droughts, which country faced from 1860 onwards. An important recommendation of the commission was to set up protective irrigation project.

1920 The Royal Commission on Agriculture stressed the need for scarcity tract development.

1923 Imperial Council of Agricultural Research sanctioned six schemes and established the first Dryland Research Station at Manjari (Pune) by Tamhane.

1933 Bombay Dry Farming Research Schemes at Bijapur and Sholapur the centers of famine tract.

1934 The Madras Dry Fanning Research Scheme at Hagari (near Bellary) and the Hyderabad Dry Farming Research Scheme at Raichur.

1935 The Punjab Dry Farming Research Scheme at Rohtak (Punjab).

1942 Bombay Land Development act passed.

1944 Monograph on dry fanning in India by NV Kanitkar (Bombay, Hyderabad and Madras Dry Farming Practices)

1953 Establishing Central Soil Conservation Board.

1954 The Central Soil and Water Conservation Research and Training Institute at Dehradun.

1954 Soil Conservation Research, Demonstration and Training Center, Ootacamund.

1954 Soil Conservation Research, Demonstration and Training Center, Bellary.

1954 Soil Conservation Research, Demonstration and Training Center, Kota.

1955 Soil Conservation Research, Demonstration and Training Center, Vasad.

1957 Soil Conservation Research, Demonstration and Training Center, Agra.

1957 Soil Conservation Research, Demonstration and Training Center, Chandigarh.

1959 Central Arid Zone Research Institute (CAZRI) was established at Jodhpur to tackle the problems of arid agro-ecosystem.

1962 Soil Conservation Research. Demonstration and Training Center. Ibrahimpatnam.

1962 Launching of Soil Conservation in the Catchments of River Valley Projects.

1970 All India Coordinated Research Project for Dryland Agriculture (AICRPDA) in 23 locations (now 25) with the support from Canadian International Development Agency through an instrument of bilateral collaboration signed between the Governments of India and Canada (up to 1987).

1972 The Consultative Group on International Agricultural Research (CGIAR) established the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad

1976 Establishment of Dryland Operational Research, Projects.

1980 Integrated Watershed Management in the Catchment of Flood prone area

1983 Starting of 47 model watersheds under ICAR.

1984 Initiation of World Bank assisted Watershed Development Programs in four states

1985 **The Central Research Institute for Dryland Agriculture** (CRIDA) **at Hyderabad**

1985 National Wasteland Development Board (NWDB).

1986 Launching of NWDPRA programs by Government of India in 15 states

1989 Integrated Watershed Development Projects (IWDP) by National Watershed Development Board (NWDB)

2006 National Rainfed Area Authority (NRAA).

The ICAR collaborated with Canadian dryland research (Indo-Canadian Dryland Research, from 1970 to 1987. The 1CAR-1CR1SAT collaborative research programs are working in areas of biological nitrogen fixation, agro-forestry, soil and moisture conservation, economics of watershed technology and vegetative barriers in soil and water conservation. The Indo-US collaboration started in 1980. Currently, CRIDA-US collaborative research projects are working on fertilizer use efficiency, germplasm enhancement, evaluation of legumes for high nitrogen fixation, crap simulation modeling and implements for dryland agriculture.

Rainfed Agriculture Research in Gujarat

Agricultural Research Station, JAU, Targadia

Agricultural Research Station, AAU, Arnej

Major constraints and problems in these areas are:

1. Uncertain, erratic and uneven distribution of rainfall
2. Degradation of forests and natural tree cover
3. Low soil fertility and soil depth
4. Shortage of drinking water and assured irrigation for crops
5. Considerable area under wastelands
6. Cultivation of marginal lands due to population and animal pressure
7. Lack of infrastructure and facilities
8. Shortage of fuel wood and fodder
9. Continuance of traditional varieties and management practices
10. Improper management of community lands

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2 Problems and prospects of Rainfed Agriculture in India

2.1 Problems or constraints for crop production in dry farming regions

Most of the cropping in the arid and semi-arid regions continues to be under rainfed conditions. A majority of the farmers are small farmers with meager resources. The poor resource base permits only low input subsistence farming with low and unstable crop yields. The low productivity of agriculture in dry farming regions is due to the cumulative effect of many constraints for crop production.

The problems can be broadly grouped in to

a) Climatic constraints
b) Soil constraints
c) Lack of suitable varieties
d) Traditional cultivation practices
e) Heavy weed infestation
f) Resource constraints
g) Technological constraints
f) Socio economic constraints

2.1.1 Climatic constraints

A) Rainfall characteristics: Among the different climatic parameters, rainfall is an important factor influencing the crop production in dry regions

(i) Variable rainfall: Rainfall varies both in time and space dimension. Annual rainfall varies greatly from year to year and naturally, its coefficient of variation is very high. Generally, higher the rainfall less is the coefficient of variation. In other words, crop failures due to uncertain rains are more frequent in regions with lesser rainfall. The average annual rainfall of India is 1192 mm where as in Gujarat it is 816 mm. Based on the average annual rainfall, the India can be divided into four zones. More than one third of total geographical area in India receives rainfall less than 750 mm (Table. 2.1).

(ii) Intensity and distribution: In general, more than 50 per cent of total rainfall is usually received in 3 to 5 rainy days. Such intensive rainfall results in substantial loss of water due to surface runoff. This process also accelerates soil erosion. Distribution of rainfall during the crop growing season is more important than total rainfall in dryland agriculture.

iii) Aberrations or variations in monsoon behavior

(a) Late onset of monsoon: If the onset of monsoon is delayed, crops/varieties recommended to the region cannot be sown in time. Delayed sowing lead to uneconomical crop yields.

(b) Early withdrawal of monsoon: This situation is equally or more dangerous than late onset of monsoon. Rainy season crops will be subjected to terminal stress leading to poor yields. Similarly, post-rainy season crops fail due to inadequate available soil moisture, especially during reproductive and maturity phases.

(c) Prolonged dry spells: Breaks of monsoon for 7-10 days may not be a serious concern. Break between two consecutive rainfalls for more than 15 days duration especially at critical stages for soil moisture stress, leads to reduction in yield. Drought due to break in monsoon may adversely affect the crops in shallow soils than in deep soils. It also has ill-effect on crop yield in tropical and sun-tropical regions.

Table 2.1 Classification of India into different zones based on rainfall

Zone	Average annual rainfall (mm)	Per cent of geographical area
Zone I (very low rainfall area)	< 350	13
Zone II (low rainfall area)	350 to 750	22
Zone III (Medium rainfall area)	750 to 1125	36
Zone IV (High rainfall area)	> 1125	29

High atmospheric temperature: Because of high atmospheric temperature, the atmospheric demand for moisture increases causing high evapotranspiration losses resulting in moisture stress.

B) Low relative humidity: Low relative humidity results in high ET losses causing moisture stress whenever moisture is limiting.

D) Hot dry winds: Hot dry winds causes desiccation of leaves resulting in moisture stress. High turbulent winds especially during summer months cause soil erosion resulting in dust, storms and loss of fertile soil.

E) High atmospheric water demand: Due to high atmospheric water demand the potential evapotranspiration (PET) exceed the precipitation during most part of the year.

2.1.2 Soil Constraints

The different soil groups encountered in dryland areas are black soils, red soils and alluvial soils. The constraints for crop production are different in different soil groups. The predominant soil group is alluvial where the problems for crop production are not so acute as in red and black soils. The different soil constraints for crop production are

a) Inadequate soil moisture availability: The moisture holding capacity of soils in dry regions is low due to shallow depth especially in alfisols (red soils), low rainfall and low organic matter content.

b) Poor organic matter content: The organic matter content in most of the soils under dryland conditions is very low (< 1 %) due to high temperature and low addition of organic manures. Poor organic matter content adversely affects soil physical properties related to moisture storage.

c) Poor soil fertility: Due to low accumulation of organic matter and loss of fertile top soil-by-soil erosion, the dry land soils are poor in fertility status. Most of the dry land soils are deficient in nitrogen and zinc.

d) **Soil deterioration due to erosion (wind, water):** In India nearly 175 m.ha of land is subjected to different land degradations, among them, the soil erosion is very predominant. The erosion causes loss of top fertile soil leaving poor sub soil for crop cultivation.

e) Soil crust problem: In case of red soils, the formation of hard surface. Soil layer hinders the emergence of seedlings, which ultimately affect the plant population. Crusting of soil

surface after rainfall reduces infiltration and storage of rainfall, resulting in high run off.

f) Presence of hard layers and deep cracks: Presence of hard layers (pans) in soil and deep cracks affect the crop production especially in case of black soils.

2.1.3 Lack of suitable varieties: Most of the crop varieties available for cultivation in dry lands are meant for irrigated agriculture. There are no any special varieties exclusively meant for dryland areas. Hence still more efforts are required to develop varieties in different crops exclusively meant for dryland agriculture.

2.1.4 Traditional Cultivation practices

The existing management practices adopted by the farmers are evolved based on long term experience by the farmers.

The traditional management practices are still followed by farmers leading to low yields.

- Ploughing along the slope
- Broadcasting seeds/ sowing behind the country plough leading to poor as well as uneven plant stand
- Monsoon sowing
- Choice of crops based on rainfall
- Application FYM in limited quantity
- Untimely weeding
- Low productive cropping systems
- Inadequate nutrient supply
- Traditional storage system

3.1.5 Heavy weed infestation: This is the most serious problem in dryland areas. Unfortunately, the environment congenial for crop growth is also congenial for weed growth. Weed seeds germinate earlier than crop seeds and try to suppress the crop growth. The weed problem is high in rainfed areas because of continuous rains and acute shortage of labour. The weed suppression in the early stage of crop growth is required to reduce the decrease in crop yields.

a) Less access to inputs, poor organizational structure for input supply
b) Non availability of credit in time
c) The risk bearing capacity of dryland farmer is very low

3.1.6 Resource constraints

1. Most of the resource for dry land are run under subsistence level of farming
2. There is less intention to adopt new technologies in dry lands among the farmers.
3. Occurrence of frequent drought for flood in dry farming areas
4. Uncertainty and is distributed rainfall and mid-season break in monsoon leading to crop failure
5. Difficulties in adoption of new cropping pattern for cropping systems to suit the monsoon and its behaviour
6. Absence of suitable varieties, non-availability of quality seeds, inadequate nutrient supply and problems of soil salinity and alkalinity aggravate the situation in dry farming areas
7. Resource poor dry land farmers are not able to practice soil conservation practices and other new technology

8. There is a limited recognition of indigenous methods of soil and water conservation
9. Poor land preparation and untimely ploughing, sowing, lake of labour and animal power during peak season
10. Lack of adequate linkages between crop and animal components in dry farming

3.1.7 Technological constraints

1. Lack of suitable Technologies for lesser rainfall areas
2. Lack of varieties capable of yielding higher in adverse condition. Improved varieties for high yielding varieties are found more vulnerable to moisture stress as compared to traditional variety
3. Non-availability of seeds of improved varieties and the demand supply is found to be 80% with groundnut, 50% with Sorghum, 25% with pearl millet and 90% with forest species
4. Problems with prediction of sowing rain
5. Laser utilization of improved machineries/ implement under dry lands leading to poor timeliness in feel operation and crop failure/ reduced yield
6. Poor pest and disease management practices, lack of resources for the purchase, ultimately untimely or delay control measures and lack of water for good quality water for spray in dryland
7. Lesser adoption of alternate land use system agroforestry, alley cropping and dry land horticulture in dry farming region
8. Inadequate extension activities reading to poor Technologies dissemination

3.1.8 Social economic constraints

1. Lack of capital, support prices for the produce, marketing facilities and credited proper time make the farmers hesitant to adopt the technology
2. Most of the dry land farmers are resource poor which tends them to avoid risk
3. Many dry land farmers engage only limited labor , mostly family labor for most of the farm activities
4. Prevailing social system in dry regions prevent the farmers in adopting the improved technology
5. Non-promotion of stakeholders concept in development of dry farming

FUTURE PROSPRECTS FOR RAINFED FARMING

A. Research:

1. Proper agro-meteorological analysis of climate- soil- crop relationship for efficient crop planning and management
2. As water harvesting systems for crop production is uneconomic including cost of runoff and cost of storage; however, this technique is helpful to stabilize crop production in dry land areas. Therefore, there is a great deal of scope for stabilizing production in dry land areas by adopting water harvesting techniques on community basis.
3. Review of contingent crop planning for Major three current weather conditions and improvement in the contingent crop planning for different zone mainly to mitigate drought effects.
4. Importance the development and release of dual conditions high yielding varieties of food and vegetable crops for normal monsoon season and for dryland conditions.

Availability of seeds of these varieties along with the suitable agronomic practices will certainly improve and stabilize the production and productivity of rainfed areas.

5. Identification of improved soil and moisture conservation practices and turn off management suited to the conditions of individual farm holding as well as the watershed as a whole.
6. Emphasis to increase intensity of cropping by developing appropriate inter-cropping and double cropping systems with importance on pulses and oilseeds.
7. Agro-techniques on socially acceptable cropping systems (*viz;* laser leveling, application of organic manures, modified method of sowing i.e. Aqua-fertilizer drill and FIRB system of seed bed preparation) bases are to be developed with a view to increase the FUE/WUE, efficient weed management, tillage system and crop residue management including INM.
8. Emphasis on site-specific research mainly to optimise the use of resources available for conservation and utilisation of moisture under rainfed conditions.
9. Proper adoption of alternate land use system including Agro-forestry, Agro-horticulture and fodder based cropping system in terms of diversification in cropping system is required for saving water and for efficient water management.
10. Completion of incomplete major and minor projects and covering about 69 m ha. cultivated under micro irrigations by 2030 is to be exercised.

B. Policy:

1. Undertake significant shift in investment from irrigated to rainfed areas, with a major emphasis on afforestation and soil conservation project organised on a watershed basis.
2. Investment in soil conservation practices including creation of infrastructure as well as water harvesting system such as farm ponds has to be undertaken on a village-by-village basis.
3. Weather aberrations continue to plague dry land farmers. Since seed is the primary input in the adoption of improved farm technologies, seed bank must be established with Government support in order to help farmers adopt contingent strategies.
4. Draft power is a serious constraint in dry land farming. Individual farmer cannot afford to purchase mechanical implements. In this case, a system of custom hiring in the villages would help farmer to complete their operation timely at an affordable cost.
5. High risk is involved in rainfed farming which does not allow farmers to adopt improved crop production technologies. Therefore, availability of crop insurance for drought protection involving selected dry land crops should be implemented.
6. Since farm holdings are small and excessively fragmented, further division of land should be prevented. This can be done by encouraging the development of small scale, agro-based industries and services in the rainfed region
7. In addition to low productivity in rainfed areas there is also an acute scarcity of fodder. Silvi -pastoral systems on marginal land should be encouraged through liberal financing, and should be established to cope with scarcity during drought years.

- India receives 400 M ha m of rainwater annually (392 M ha m from rainfall and 8 M ha m from other sources).
- Out of 400 M ha m only 105 M ha m (26.25 %) is available for utilization. Out of which 77 M ha m (19.25 %) is available for irrigation and 19 M ha m (4.75 %) for industries and 9 M ha m (2.25 %) for domestic utilization.
- About 160 M ha m falls on agricultural land
- Nearly 24 M ha m is available for harvesting in small scale water harvesting structures
- About 186 M ha m goes to rivers as runoff
- Around one-fourth of the total annual rainfall is received before or after cropping season.

x-x-x-x-x

3 Soil & Climatic Conditions Prevalent in Rainfed Areas

Soil

Soil is the uppermost part of the earth crust containing a mixture of minerals. It is a three-phase system containing solid, liquid and gaseous components existing in certain equilibrium.

Ideal dry land soils

Soil texture has a profound influence on the productivity of soil. In general depth, texture, structure, drainage conditions and soil moisture relationship are very important soil properties, which decide the crop growth. Advantages and disadvantages of coarse and fine textured soils regarding crop cultivation are listed in Table 3.1.

Table 3.1 Suitability of coarse and fine textured soils for dry land agriculture

Character	Course textured soil	Fine textured soil
1. Example	Sandy soil	Clay soil
2. Plant's nutrients	Low	Moderate to high
3. Moisture holding capacity	Less	High
4. Bulk density	High	Low
5. Pore space	Low	High
6. pores	Large and continuous	Minute and discontinuous
7. Infiltration / Percolation	Very rapid	Low
8. Permeability	High	Slow
9. Water Stagnation	Nil	High
10. soil erosion	Less	High (Especially in slopes)
11. dry land agriculture	With uniform distribution of rainfall and sufficient moisture conservation measures	Preferable and possible for double cropping in case of stored up/residual soil moisture

Dry land soils and their characteristics:

In India, dry land occurs in almost all the regions of the country and the major soil types in these dry regions are red soils (Alfisols), black soils (Inceptislos and Vertisols), Laterite soils (Ultisols) and desert soils (Aridisols). The characteristics, features of the major soil groups and the prospects for raising crops in these soils under dry land conditions are described hereunder.

1. Red soils (Alfisols) :

Red soil is an important soil group in India and especially in dry land. These soils are moderately weathered and derived from granites, gneiss and other metamorphic rocks, either in-situ or from these decomposed rock materials washed down to lower level by rain. They are generally red or reddish brown or yellowish brown in colour due to the coating of ferric oxides on soil particles. Morphological types are red loams and red earth with loose topsoil.

Main features of red soils are light texture, friable structure, absence of lime concretions and free calcium carbonates and contents of soluble salts. These soils are slightly acidic to slightly alkaline nature, medium in cation exchange capacities and near base

saturated. Dominant clay mineral is *kaolinite* with an admixture of *illite*. Red soils are well drained with a moderate permeability. Excessive gravel, surface crust formation and susceptibility to erosion in high slopes are some of the problems in these soils. They are low in organic matter content and nutrients like nitrogen and phosphorus. Occasionally, micronutrients like zinc is deficient in red soils. Potassium content in these soils is generally adequate for raising crops and the soil pH range is 6 to 7.

Most of the red soils have been classified in the order alfisols and these type of soils occur widely in the states of Andhra Pradesh, Bihar, Assam, TN, West Bangal, Goa, Daman, Diu and parts of Kerala, Maharastra and Karnataka.

Crop cultivation in red soils under dry land conditions:

Rooting depth of crops is affected in the red soils as it consists of distinct gravel and weathered rock fragments. Crops grown under red soils in dry land conditions are susceptible to drought if the rainfall is poorly distributed during the cropping season. The soil lacks aggregation property leading to surface roughness, rapid seal of the soil surface after rainfall and results in soil crusting on drying. Tilling the soil is easier on wet conditions, but becomes hard and difficult on drying. Tillage with high wetness may lead to compaction and ploughing will be perfect only under limited soil moisture conditions.

Establishment of a good crop is risky and the rapid surface drying due to poor rainfall distribution may affect the crop growth under dry land conditions in the red soils. Cultivation of crops will increase the infiltration initially, but in due course, the rate of infiltration will be reduced. Soil erosion will be less in presence of crops or vegetation in red soils and on denudation or allowing the land, as fallow will lead to high runoff and erosion. Leaching of nutrients is common due to its well-draining capacity, which necessitates adequate and frequent application of nutrients in red soils.

Groundnut, sorghum, pearl millet, fox tail millet, red gram, green gram, cowpea, castor and horse gram are suitable crops for red soils. Groundnut + red gram, Groundnut + castor, sorghum+ red gram are the profitable intercropping systems which help in preventing crop loss during drought years.**Black soil (Vertisol/ inceptisol)**

Black soils are another important group of soils that occur in dry land conditions. They are characterized by dark Grey to black colour, high clay content, neutral to slightly alkaline in soil reaction and developing deep cracks during summer season. These are locally known as black cotton soil. Depth of the soil varies ranges from a low of 50 cm to several metres and in many cases it overlies decompose rocks (parent material) known as *murram*.

Black soil are formed from *Deccan* basalt trap rocks either in-situ or on the transported parent material. In the formation of black soils, presence of a high proportion of alkaline earth in the weathering complex is of great importance. These soils have impeded drainage and low permeability. It occurs in areas under monsoon climate, mostly in semi-arid and sub humid type. High clay content and *montmorillonite* type of clay mineral impart high swelling and shrinkage properties of these soils.

Black soils are low in organic matter content, available nitrogen and phosphorus and sometimes zinc, but reach in base nutrients like calcium, magnesium and potassium. Soil pH

is in the range of 7.5 to 8.5. Soil is highly clayey and the clay content varies from 35 to 60% and sometimes up to 80%.

Table 3.2 : Improved technologies for red soils

Sr. No.	Technology	Aims	Suggestions/ Observations
1	Land & water management	Realigning and strengthening of field or boundary bunds for conservation of soil and water	• Establishment of vegetation cover on bunds • Formation of graded bunds • Growing vegetative filter strips on contours • Summer ploughing • Contour tillage in slope lands • Opening of dead furrows (at 10 feet interval) • Construction of dugout pond • For soil depth more than 20 cm, deep tillage once in three years for better infiltration of rainwater and to reduce pest and weed problems • Mulching with agricultural waste @ 5 t/ha, within 10 days after sowing of crop to prevent evaporation losses. • Water harvesting in farm ponds and subsequent use as supplementary/ lifesaving irrigation to increase yields of rain fed crops.
2	Crop management	Cropping season in coincidence with safe period of rainfall. Double cropping in deep and medium soils	• Depending on amount and distribution of rainfall and retention capacity of soil • Following double cropping / intercropping / sequential cropping • In case of surface crusting, application of sand @ 40 t/ha before sowing to decrease the crust strength, to facilitate better infiltration of water into soil and to improve germination and crop stand • Intercropping with pulses reduce runoff losses, reduce soil erosion, conserve more moisture, add more organic matter in the soil and ultimately improves soil productivity
3	Fertility management	Increasing the crop response to applied nutrients especially phosphorus	• Application of phosphate fertilizers • Application of nitrogen in splits with sufficient moisture • Crop residue addition to improve soil physical properties • Addition of other nutrients as per soil test

These soils are characterized by high swelling and shrinkage, plasticity and stickiness. Black soils are generally calcareous neutral to slightly alkaline in reaction, high base status and high cation exchange capacity. They possess high soil moisture holding capacity. Runoff is severe in black soil and it is prone to erosion and the soil loss is estimated to be in the range of 6 to 8 t/ha per year. Shallow black soils on slopes have been classified in

the order of Entisolsl and Inceptisols, while the deep medium black soils in the order of Vertisols. Black soil occur extensively in the states of Maharashtra, Madhya Pradesh and parts of Andhra Pradesh, Gujarat and Tamilnadu

Table- 3.3 : Improved Technologies for black soil

Sr. No.	Technology	Aims	Suggestions/Observations
1	Land & Water management	• Promotion of intake of water in soil • Improvement of aeration and workability • Reduction in soil erosion and runoff • Facilitation of safe disposal of excess water	• Construction of water storage structures like farm ponds • Following watershed concept • Application of FYM @ 20 tons per hectare for better infiltration of water • Formation of graded Bund • Formation of a channel with a slope of.1-0.25% along the graded Bund and merging this channels into a grassed waterway to drain water without any soil erosion
2	Land configuration	• Reduction in Runoff	• Rough with ridges and furrow to facilitate ponding of water
3	Dry season tillage	• loosening of soil after harvest of post rainy season crop	• Blade harrowing after receipt of Pre-monsoon rain to break clods
4	Pre-monsoon dry seedling	• Utilisation of first rain, ensuring early establishment of crops and reduction in the difficulty in planting in wet and sticky soil	• Placing seeds in 5 cm death • Good results reported in crops of sorghum, cotton, main sunflower iI, green gram, red gram and poor results reported in in pearl millet, soybean and groundnut
5	Improved cropping system	• Increasing the crop productivity and Returns	• Best suited to areas with moderately dependable and favourable rainfall>750 mm
6	Fertility management	• Increasing the crop response to applied nutrients especially nitrogen	• Recommendation as per soil test/ application of nitrogenous fertilizers
7	Pest management	• Low cost and maintenance of environment (pesticides used only at threshold level of pests)	• Following integrated pest management practices

Crop cultivation in black soils and dry land conditions

A large area with Vertisols is under dryland conditions in India. Black soil is more productive than red soil. Important crops grown under the soils are coarse grains, cotton, oilseeds and pulses. Growing of crops is possible during post-rainy season (*rabi* season) with stored up soil moisture in shallow black soils (Entisols). In case of medium and deep black soils (i.e. Vertisols/ Inceptisols), growing crops is possible in season and post rainy season

which stored up soil moisture (double cropping) depending on the quantity and distribution of rainfall. Cotton, Sorghum and other millets, pulses; especially chickpea, chillies, sunflower, safflower and coriander are suitable crops.

Laterite soils (Ultisols)

Laterite soils are well-drained soil with good hydraulic conductivity. They are formed by soil forming process called *laterization*. Laterite is a geological term, which means literally rock. Under high rainfall conditions, silica is released and leached downwards and upper horizons of the soil become rich in oxides of iron and Aluminium. This process is called *laterization* . Laterites are subdivided into high and low level laterites. High level laterites are found capping the summits of hills and plateau of the high lands and they are not useful for agriculture as they are thin and gravely. Low level laterites comprising of clay and loam occur in coastal regions on both sides of the peninsular region and are of considerable agricultural importance. *Laterization* is intensified with increase in rainfall with low intensity.

Texture of a laterite soil is generally loam in top layers and depth of the loamy layer varies and in eroded nature. These soils are Pale, gritty, shallow and poor in plant nutrients in top layer. Soils in lower layers are of fine texture, darker and rich in plant nutrients and organic matter. All laterite soils are very poor in base materials like calcium and magnesium. The pH of the soil is low and acidic in nature. Soil clay type is generally *kaolinite* with traces of *illite*. Most of the laterite soils are classified under the order ultisols. These soils are well developed on the summits of Hills of the *Deccan*, Karnataka, Kerala and Madhya Pradesh, the *Ghat* regions of Orissa, Maharashtra, Kerala, West Bengal, Tamil Nadu and Assam.

Crop cultivation in laterite soils under dry land conditions

At lower elevations, suitable crops for cultivation under dryland conditions are rice (either single or double cropping), minor millets, trees and shrubs. Soil and moisture conservation measures may become necessary in regions of low to medium rainfall. At higher elevation in laterite soil plantation crops like tea, coffee, cinchona, rubber and cashew are grown.

Desert soil (Aridisols)

These soils occur in hot desert region in India. Rainfall of the region is ranging from as low as 50 mm to the highest of 400 mm of which the major portion is received during monsoon season. Potential evapo-transpiration is very high and showing aridity. A major part of the region consists of sand dunes and undulations. A zone of accumulation of lime concretions at a depth of 60 to 120 cm and presence of alkaline earth carbonate are common futures of this type of soils. Clay content is very low ranging between 2 to 8% and presence of sodium clay make the soil susceptible to dispersion and less permeable. The pH of the soil ranges from 8 to 9. Clay type is *illite* with small amounts of *kaolinite*. Desert soils are classified under the order Aridisols. These soils are distributed in the regions of Rajasthan, southern Haryana and Punjab and northern Gujarat.

Crop cultivation in desert soils under dryland conditions

Soils are light textured and the moisture holding capacity and nutrient availability are less. They are generally poor in available nitrogen and phosphorus. Soil salinity is a common problem and effective soil depth is influenced by the presence of calcium and carbonate concretions at various depth. Crop cultivation is possible only in deep soils either during *kharif* or *rabi* season based on the rainfall quantity and its distribution.

Sub-Montane Soils

Sub-montane soils occur in undulating lands of sub *Himalayan* regions under coniferous forest. Regions with sub-montane soils are characterized by high rainfall, accumulation of organic matter, absence of free lime and acidic nature. Landslides and soil erosion arecommon problems associated with sub-montane soils which lead to the leaching of bases.

Crop cultivation in sub-montane soils under dry land conditions

Soil moisture storage varies from 20 to 30 cm per metre soil profile. As the regions are characterized by high rainfall, double cropping is possible in sub-montane soils. Soils are low in available nitrogen and phosphorus and crops respond well to the application of N and P for higher productivity.

Saline and sodic soils

Saline and sodic soils occur mainly in arid and semi-arid regions of the country where the annual temperature are high and rate of evaporation generally exceeds rainfall. The situation leads to accumulation of salts in surface layers of the soil. In India, such soils are spreading over 8.5 million hectare of land and they are found with poor organic carbon, available nitrogen and Zinc.

Saline soils contain excessively soluble salts and the dominant soil type are chlorides and sulphates of sodium, magnesium and Calcium. Total salt concentration as expressed by soil EC is generally more than 4 dS/ m. These soils are associated with water logging, saline groundwater and aridity.

Sodic soils generally contain salts of carbonates and bicarbonates of sodium where the soil EC will be less than 4 dS/m and exchangeable sodium percentage more than 15%. These soils can be observed with stagnation of muddy water after rain for many days and they are very hard when dry and very soft when wet. Sodic soils contain insoluble calcium carbonate at high pH level (>9.5).

Crop cultivation in saline sodic soils under dry farming conditions

Reclamation Technologies for growing crops in Salt affected soil differ depending upon the availability of source of water. For areas which depend only on rainfall as the source of moisture, cultivation of salt tolerant plants species and planting techniques are recommended. Crops have been identified to salt stress conditions and few such crops which are sensitive and tolerant to soil salinity and sodicity under dry land conditions are given in table 3.4.

Table 3.4 : Sensitive and tolerant to soil salinity and sodicity under dry land conditions

Saline soils		**Alkaline/ sodic soil**
Sensitive	**Tolerant**	**Tolerant**
Highly sensitive Legumes like green gram, black gram, lentil, gram and peas **Moderate sensitive** Major and minor millets	**Highly tolerant** Direct sown rice, wheat, pearl millet, barley, oats, mustard **Medium Tolerant** Sunflower, cotton, kernel grass, Trees like acacia, tamarind, ber	Beans, rice, grasses like Rhodes grass, barley, wheat, cotton, trees like Amla, ber, Eucalyptus hybrid, *Dalbergia sissoo, Terminalia arjuna*

Climate

The behaviour of atmospheric phenomenon at a given place and time is defined as **weather** and the composite day-to-day weather elements for a given place or region over a period is referred as **climate**.

Dry climate

A dry climate is one in which the average annual precipitation is definition in relation to evaporation. It can be divided into arid and semi-arid climate.

Arid climate

It can be defined as an extreme dry climate where the average annual precipitation is less than 500 mm and usually in the range of 250 82500 mm. Generally, the rainfall is well short of evapotranspiration demand of the atmosphere. The precipitation is insufficient for crop production.

Semi-arid climate

It can be defined as a climate where the average annual precipitation is greater than 500 mm and generally, crop production is possible with dry farming methods or with supplemental irrigation.

The tropical retreat and semi-arid climate I have many features in common the distinct character of this climate is lake of sufficient rainfall to sustain crop production. They are centre on the latitudes from 20 to 25 degree north and South.

Climate largely limits crop and animal production, ensures the human comfort, influences on health determine clothing and housing etc. Its influence on agriculture is enormous throughout the world and in a country like India where agriculture is the backbone of development, importance is manifold. The success of failure of farming is closely related to the prevailing weather condition. However, there are possibilities to optimise farm production by existing cropping pattern and agronomic practices to suit the climate of a locality. Weather resumes significance in nearly every phase of Agricultural activity from the preparatory tillage to harvesting and storage. Therefore, a sound knowledge of climate factors and an understanding of the complex processes of interaction between the climate and the biological processes of the plants are essential to a scientific approach on farming. The principal climatic factors limiting crop production in the order of priority under dryland conditions are precipitation temperature, sunlight, wind length of growing season etc.

1. **Effect of precipitation in dryland**

The common forms of precipitation are drizzle, rain, snow, sleet and hail. In dry lands rainfall limitation is the greatest factor in influencing the crop growth and yield. Rainfall plays a major role in determining the real potential of a crop and the region. It also has an influence on deciding the sequence and timing of farming operation and farming system

General advantages of precipitation

- Recharge of groundwater
- Decision on various agricultural operations
- Decision on pattern of land utilisation
- Selection of crops, varieties, cropping and farming system
- Storage in reservoirs
- Decision on vegetation
- Development of irrigation sources
- Hydro power generation..

Forms of precipitation and their effect on crop growth.

General forms of precipitation are rainfall, snow and hail. Their common characteristics in dry regions and its effects on crop growth are discussed as under.

Table 3.5 Rainfall and its characteristics in dry lands

Characteristics			Effects on crop growth	
General	**In dry region**	**General effects**	**If excess**	**If deficient**
1. Seasonal distribution 2. Dependability 3. Frequency 4. Intensity	1. Highly unreliable 2. Frequency less 1. Intensity more 3. Highly seasonal (maximum in winter) 4. Often insufficient	**1. High intensity and heavy rainfall** a. Denudation and soil erosion b. Run off and floods c. Destruction of soil crumbs d. Loss of soil fertility e. Loss of soil fertility f. Poor germination, pollination and flowering 2**. Wet weather due to rainfall leading to pest spread** **3. Failure or poor rainfall** a. Soil salinity/alkalinity b. Crop loss/ damage	1. Run off 2. Leaching of plant nutrients 3. Reduction in germination 4. Crop lodging 5. Impair in pollination 6. Crops affected by anaerobic conditions	1. Drought 2. Yield loss 3. Problem soils 4. Famine 5. Crop damage

Table 3.6 Hail and its characteristics in dry lands

Characteristics		General effects	Effects in crop growth
General	**In dry regions**		
1. Rare occurrence in tropics 2. Rare occurrence in high latitudes 3. Common in warm season	1. Common in sub-montane areas in India 2. Rare occurrence in southwest monsoon season	1. Floods under high temperature/storms 2. Road or path closure 3. Mechanical damage to trees 4. Hazards to air crafts	1. Mechanical damage to plants 2. Shredding of leaves 3. Shattering of flower and seed heads

2. Effect of solar radiation in dry lands

Sun is a primary source of heat and light on the earth and radiant energy striking the earth is called as insolation. The insolation consists of the sunlight and temperature, which act as the important factors of weather and climate. Distribution of insolation is closely related to latitude and it is greater at equator and decrease towards poles regularly. Influence of solar radiation decides the rate at which plants develop at various stages of growth. Every crop has limitations in their temperature and sun light requirements.

Table 3.7 Snow and its characteristics in dry lands

Characteristics		General effects	Effects in crop growth
General	**In dry regions**		
1. Present in mountainous regions in mid-latitudes 2. Release by rising temperature 3. Ground water recharge 4. Generally more on leeward side of mountains and uplands from oceans	Significant to water users in arid lands adjacent to snow-capped mountains	1. Floods under high temperature/ storms 2. Road or path closure 3. Mechanical damage to trees 4. Problems in housing 5. Sheet or reel type of erosion	1. Run off 2. Soil erosion 3. Suffocation to crop plants

Table 3.8. Sunlight and its characteristics in dry lands

Duration (Relative length of day and light	Intensity	Quality (Wave length)
1.General Characteristics a. Varies with latitude and season b. Equal day and night at equator c. Day light ranging from zero (winter to 24 hours (summer) at polar regions d. Crops flowering behaviour depends on duration of light e. Division as short day, long day and day neutral plants **2. Effects on crop growth in arid region** a. Arid and semi-arid crops are mostly short day plants (< 10 hours) and they require long nights for flowering b. Most sun shine in dry areas (20-30^0 latitude on both sides). c. More dry matter production (if moisture is not a limiting factor).	**1. General Characteristics** a. Energy source for whole plant process b. Extreme low (< 500 candles) and extreme high intensities inhibit photosynthesis. **2. Effect on crop growth** a. Light intensity indirectly affect productivity by its effect on leaf temperature	**1. General Characteristics** a. Wave length ranging from 0 to 0.25 micron is harmful to plants b. Wave length ranging from 0.30 to 0.55 micron has photoperiodic effect c. Wave length ranging from 0.40 to 0.79 micron is good for photosynthesis d. Wave length more than 0.79 micron has no effect on photosynthesis

Table 3.9 Effect of temperature and its characteristics in dry lands

General Characteristics	Characteristics in arid regions	Effects on crop growth
1. Decrease from equator to poles 2. Wind direction and movement influence mean temperature in a locality 3. Mountains act as barriers on horizontal temperature distribution 4. Temperature reduction by 3.3^0F for every 1000 feet elevation.	1. Seasonal higher 2. Diurnal variation more 3. Highest in arid and semi-arid tropical climates 4. Occasionally below freezing temperature in tropical deserts 5. Lesser at higher attitudes in arid and semi-arid climates.	1. Temperature limit for each stage of every crop 2. High temperature is not a serious problem if soil moisture is adequate 3. Slow or stop in growth rate at very high temperature 4. Premature fall of leaves and fruits 5. Prolonged chilling or freezing reduce water flow in plants leading to retardation or killing 6. Disastrous dry and hot conditions 7. Increases evapo-transpiration and water requirements of the crops 8. Influences multiplication of insects and pathogens

3. Effect of wind in dry lands

General effects of wind

- ❖ Favours cross pollination
- ❖ Affects pollination by insects
- ❖ Causes mechanical damage to plants
- ❖ Leading to shattering of flowers and seeds
- ❖ Stripping of fruits and nuts
- ❖ Dispersal of weed seed
- ❖ Wind erosion and removal of soil fertility
- ❖ Increase evapo-transpiration
- ❖ Reduces germination (by covering seeds)
- ❖ Prevention of frost (on occasions)
- ❖ Dispersal of pollen and seeds
- ❖ Decides monsoon pattern
- ❖ Desiccation of plants
- ❖ Blow from desert may have reduction in photosynthesis and translocation of food materials
- ❖ Influence migration of insects and pathogens

Various types of wind are gale, storm and hurricane and their sub types. They have differential effects on crop growth.

Table 3.10 Gale and its effects

Types of Gale	Speed (km/hour)	General effects
1. Moderate gale	56 to 60	1. Swaying to uprooting of trees
2. Fresh gale	61 to 74	2. Slight to heavy structural damage
3. Strong gale	75 to 88	3. Causing obstructions to traffic
4. Whole gale	89 to 102	

Table 3.11 Storm and its effect

Type of storm	General Characteristics	General effects
1. Thunder storms (89 to 102 km/hr)	1. Unknown polar regions 2. Diameter from 5 to 35 miles 3. Heavy rainfall with large drops 4. Chances of hail/snow/snow pellets 5. Thunder storm followed by lighting	1. Severe damage to air planes in flight 2. Run off and severe soil erosion
3. Tornadoes (102 to 117 km/hr)	1. Violent storms 2. Maximum width of one to two miles 3. Accompanied by thunder storms, rain, hail and lighting 4. Funnel shaped column from the base of the cloud 5. Funnel diameter of 50 m or more	1. Unbelievable destruction in its pathways including explosion of buildings

Table 3.12 Hurricane and its effects

General Characteristics	General Effects
1. Speed in the range of 117 to 132 km/hr. 2. Energy depends on moisture content in warm air 3. Diameter from 100 to 6000 miles/hr (minimum of 25 miles/hr) 4. Eye diameter from 5 to 30 miles 5. Also called cyclones, typhoons and tropical storms	1. Structural destruction 2. Flooding 3. Shipping affected

4. Effect of other climatic factors

a. Humidity

Humidity refers the measure of moisture content in atmosphere and it plays a significant role in climate and weather. Air can hold a certain quantity of water vapour at a given temperature and several expressions are used for denoting the humidity. They are…

1. **Specific humidity** : It can be defined as the ratio of the mass of water vapour actually in the air to unit mass of air

2. **Dew point or Saturated Vapour Pressure** :It is all the water vapour that can be held by the air at a given temperature and pressure.

3. **Absolute humidity** : It is defined as the actual amount of water vapour in the air.

4. **Relative Humidity** ; It is referred as the ratio of water vapour actually present in the atmosphere to the amount of water vapour required for saturating it ay that temperature (expressed in percentage).

Among these expressions, the best known and mostly used reference to water vapour is relative humidity (RH%) and it is found to be maximum during early morning hours and the minimum is afternoon.

Table 3.13 : Humidity and its characteristics in dry lands

General Characteristics	Characteristics in arid region	Effects in crop growth
1. Greater on land surface in winter 2. RH will increase on decreasing temperatures 3. Low specific humidity in polar regions	1. RH low in arid regions (12 to 30 %) 2. High RH may compensate low rainfall in part 3. RH depends on direction of prevailing winds in semi arid regions 4. Absolute humidity will always be low	1. Evaporation will be less under high RH condition 2. Plants can withstand low humidity if soil moisture is adequate 3. Water requirement of crops can be decided with prevailing RH

b. Dew :

Dew formation mostly occurs at night because of its dependence on radiational cooling of leaf and soil surface. Clear sky, low wind speed, high atmospheric humidity and vegetation of low heat capacity are the main factors contributing to dew formation. The absorption of dew by the plants depends on type of plant species, its intensity, duration of dewfall and soil moisture conditions. Under moisture deficit conditions, effect of dew is important as it can accelerate the restoration of turgor pressure at night and delay the stress at day time.

ECO SYSTEMS UNDER ARID AND SEMI ARID CONDITIONS IN INDIA

A. ARID ECOSYSTEM

Agro eco region number 1 (cold arid eco region)

Location: North Western Himalayas covering *Ladakh* and *Gilgit* districts of Jammu and Kashmir and consisting of 15.2 million hectare.

Climate: Mild summer and severe winter with the mean annual rainfall less than 150 mm. Precipitation is always lesser than potential evapotranspiration.

Soil type: skeletal and calcareous soils with alkalinity and low to medium organic matter content.

Rain: Water vapour condenses around condensation nuclei (such as dust) and falls when the droplet is heavy enough.

Sleet: Same formation as rain, but it freezes somewhere along its path from the clouds to the ground. Sleet is a mixture of snow and rain.

Snow: Water droplets form and then freezing occurs slowly, allowing for the development of uniquely designed ice crystals know as **snow**. Snow is formed when water vapour is deposited in the higher reaches of the atmosphere at a temperature less than zero degrees Centigrade, and then falls to the ground. **Snowflakes** are typically symmetrical, hexagonally shaped groups of ice crystals that form while falling in and below clouds. Simply put - Snow forms if the air in a cloud is below freezing. The water vapour then turns to ice instead of rain and the tiny ice crystals stick together until they form snowflakes. When they get heavy enough to fall, they drop out of the clouds. At this point though, we still don't know whether they will end up as rain or remain as snow. This depends on the temperature of the air they travel through on the way down to the ground. If it gets warmer, they turn into rain, but if the air stays close to freezing all the way down, then the snowflakes will make it without melting and so fall as snow. If this occurs in a mountain area, it is possible for snow to be falling on the mountaintop while lower down in the valley the air is warmer and so it is raining instead.

Hail: Water droplets are carried high into the atmosphere by thunderstorm updrafts, which cause them to freeze. Multiple drops tend to freeze together, which is why the diameter of hail can be large.

Dew: Water vapour on the ground condenses on objects such as blades of grass when the surface temperature is equal to the dew point

Frost: Dew forms and then it freezes. This commonly occurs when nigh time. Radiational cooling drops the ground temperature down enough. There are three kinds of frost: Delicate crystallized ice on windowpanes is called **Hoar frost**. **Glazed frost** consists of thick coatings of ice on cold surfaces. **Rime frost** is formed when super-cooled water droplets freeze on contact with cold surfaces. It often occurs when freezing fogs or drizzle blanket the ground.

Freezing rain: Forms and falls as rain. At the surface or near the surface, the temperature is at or below freezing, which causes the rain to freeze on contact.

Fog: A thin cloud of varying size formed at the surface of the earth by condensation of atmospheric vapour.

Mist: A very thin fog.

Drizzle: A light steady rain in fine drops (0.5 mm) and intensity < 1 mm/hr.

Land use: Sparse forest trees. Regular cropping programs include vegetables, millet, wheat, fodder, pulses, barley and fruit crops like apple and apricot.

Livestock: Dominated by mule and followed by sheep, goat and yak rearing.

Constraints:

- Severe climatic conditions limiting crop growth
- Length of growing season is less than 90 days in a year which limits crop production
- Nutrient imbalance due to Sandy and gravelly and moderate to calcareous soil

Potential of the region

- Dry fruit crops apricot and off season vegetables peas

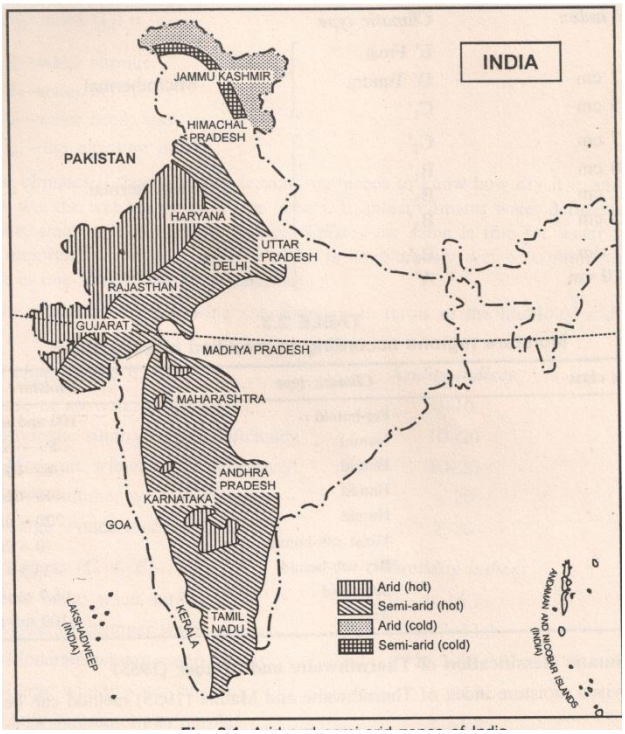

Fig. 3.1 Arid and semiarid zones of India

Agro Eco region number 2 (Hot arid eco region 1)

Location : South western part of Punjab and Haryana, Western parts of Rajasthan, *kutch* and North *kathiyawad* Peninsula in Gujarat. Area under this Zone extends to 31.9 million hectares.

Climate: Hot summer and cold winters with a minimum annual rainfall less than 400 mm. Potential evapotranspiration demand ranges between 1500 and 2000 mm annually. Length of growing season is less than 90 days per year.

Soil type: Desert and Sandy soils with calcareous and alkaline nature

Vegetation and cropping pattern: Drastically reduced, spares and tropical thorn forest. Rainfed mono-cropping with short duration crops like pearl millet and pulses. In irrigated land crops like sugar cane, cotton, mustard, gram and wheat are grown.

Constraints:

- Indiscriminate deforestation
- Scanty and Erratic rainfall pattern leading to draught at critical stages of Crop growth
- Soil salinity and nutrient imbalance

Potential of the zone

- Developing irrigation sources can further increase the productivity
- Dryland Agroforestry and forestry may sustain the productivity

Hot arid eco region 2

Location: *Deccan* Plateau covering the districts of Bellary , Tumkur, North Chitradurga, South west parts of Bijapur, Raichur of Karnataka and Anantapur of Andhra Pradesh. The total spread of the region is 4.9 million hectares.

Climate: Hot and dry summer and mild winters with the mean annual rainfall ranging from 400 to 500 mm. Severe drought prone area throughout the year and length of growing period is less than 90 days in a year.

Soil type: Shadow to medium red loam soil and deep clayey black soil

Vegetation and cropping pattern: Tropical dry deciduous and tropical thorn forests. Irrigated farming includes growing of sugarcane, cotton, safflower and groundnut. Rainfed Mono-cropping is carried out with during rainy season pearl millet or post rainy season with stored residual moisture sorghum or safflower

Constraint:

- Soil erosion during rainy season
- Poor and ill distributed rainfall and occasional crop failure due to prolonged dry spell
- Poor Workability of black soil

SEMI ARID ECOSYSTEM

Agro Eco region number 4 (Hot semi-arid eco region 1)

Location: Parts of Gujarat (5 districts), Haryana (8 districts), Punjab (7 districts), Union Territory of Delhi, Uttar Pradesh (29 districts) and Rajasthan (11 districts). This region extends to 2.2 million hectares.

Climate: Hot and dry summers and cold winters with the mean annual rainfall ranging between 500 to 1000 mm. Length of growing period is 90 to 150 days in a year.

Soil type: Course to fine loam and sand dunes

Vegetation and cropping pattern: Tropical deciduous and tropical thorn forest. Irrigated farming is followed in 65% of the total cultivable area and the crops cultivated are wheat, rice, millet, maize, pulses, berseem, mustard and sugarcane. Rainfed agriculture is followed in 35% of the area with mono-cropping of seasonal crops like sorghum, soybean and pigeon pea and post seasonal crops like ok pulses, lentil and wheat on residual moisture.

Constraints:

- Nature of soil with low water holding capacity
- Lowering water table
- Salinity and sodicity due to in perfect drainage condition

Potential of the region:

- Introduction of irrigation facilities and changes in cropping pattern from low value crops like millets to high value crops like cotton, sugarcane and wheat
- Crop diversification to oil seeds

Agro Eco region number 5 (Hot semi-arid eco region 2)

Location: Western Madhya Pradesh (10 districts), South Eastern parts of Rajasthan (5 districts) and Gujarat (10 districts) and Union Territory of Diu. This zone covers 17.6 million hectares.

Climate: Hot and wet summer and cold winter with a mean annual rainfall of 500 to 1000 mm and the length of growing period 90 to 150 days. Certain districts of the states of Madhya Pradesh, Rajasthan and Gujarat are prone to drought once in three years.

Soil type: Deep loam to clay and black soils. Coastal areas in Gujarat have clay and sandy soils with slight alkalinity.

Vegetation and cropping pattern: This region is characterized by dry deciduous forest. Dry farming is practised in most areas with *kharif* crops like sorghum, pearl millet, pigeon pea,

groundnut, soybean, maize and pulses and with Rabi crops like safflower, sunflower and gram

Constraints:

- Intermittent or occasional drought occurrence
- Soil salinity or alkalinity due to imperfect drainage or inundation of seawater leading to crop failure

Potential of the region:

- Development through minor irrigation project
- Forestry and dryland horticulture activities

Agro Eco region number 6 hot semi-arid eco region 3)

Location: Western parts of Maharashtra (20 districts), Northern parts of Karnataka (6 districts) and Western parts of Andhra Pradesh (2 districts). The zone spreads over 31 million hectares.

Climate: Hot and humid summer and mild and dry winter with an annual rainfall of 600 to 1000 mm. Length of growing period is between 90 and 150 days. Some districts are drought prone and the drought spell may be severe once in 3 years.

Soil type: Shallow loam to Clay soils with calcareous or alkaline nature

Vegetation and cropping pattern: The region is found with tropical dry deciduous tropical thorn forest. Mono-cropping is followed under rainfed condition with *kharif* crops like pearl millet or post rainy season crops like safflower and sunflower. With irrigation facilities crops like cotton and groundnut are grown.

Constraints :

- Prolonged dry spells leading to reduced growth and crop failure
- Soil erosion
- Nutrient imbalance in soil

Potential of the region :

- Achievable high productivity with better water management practices
- Dryland Agroforestry and horticulture

Agro Eco region number 7 (Hot semi-arid eco region 4)

Location: *Deccan* Plateau and Eastern parts of Andhra Pradesh (14 districts). This region spreads over 16.5 million hectares.

Climate : Hot and moist summer and mild and dry winter with the mean annual rainfall of 600 to 1100 mm. Length of the growing period is ranging between 90 and 150 days in a year. In this zone 6 districts are prone to drought.

Soil type: Black cotton soils are calcareous and strong alkaline in nature. Isolated track are found with red soils, which is non-calcareous and neutral in reaction.

Vegetation and cropping pattern : Tropical dry deciduous and thorny forest. Traditional farming under rainfed condition is followed with *kharif* crops like sorghum, cotton, pigeon pea, rice, groundnut and castor and *rabi* crops like sorghum, sunflower, safflower and other oil seeds, rice is the major crop under irrigated condition.

Constraint:

- Soil erosion due to high runoff leading to loss of soil and nutrients
- Crop failure due to frequent drought under rainfed condition
- Imperfect drainage under irrigated conditions leading to salinity and sodicity

Potential of the region:

- Achievable high productivity with better water management practices
- Dryland Agroforestry and horticulture
- Watershed program

Agro Eco region number 8 (Hot semi-arid eco region 5)

Location : Eastern *Ghats* and Southern parts of *Deccan* Plateau covering the parts of Andhra Pradesh (one district), Karnataka (9 districts) and Tamil Nadu (15 districts) and extending over an area of 19.1 million hectares.

Climate: Hot and dry summer and mild winter with a mean annual rainfall of 600 to 1000 mm and the length of growing period is 90 to 150 days in a year. Parts of Karnataka receive rainfall in summer season and rest of the region receives rain during winter.

Soil type: Red loamy soil

Vegetation and cropping pattern: Tropical dry deciduous and thorny forest. Under irrigated conditions, cotton, sugar cane and rice are the major crops. Rainfed cultivation is the traditional practice with crops like millets, pulses and oilseeds especially groundnut in *kharif* season and with crops like sorghum and oilseeds especially safflower in Karnataka in *Rabi* season.

Constraints:

- Severity of soil erosion
- Severity of drought due to poor moisture holding capacity of soil

Potential of the region:

- Dryland Horticulture with suitable fruit crops
- Floriculture under irrigated condition

x-x-x-x-x

4 Soil Erosion: Soil and Water Conservation Techniques

Soil erosion:

Soil erosion is the process of detachment of soil particles from the top soil and transportation of the detached soil particles by wind and / or water.

The agents causing erosion are wind and water. The detaching agents are falling raindrop, channel flow and wind. The transporting agents are flowing water, rain splash and wind.

Nature and extent of erosion

The problem of soil erosion exists all over the country. Out of the 329 m. ha of India's geographical area about 175 m. ha (53.3%) is subjected to soil erosion and some kind of land degradation (Druvanarayana, 1993). About 150 m. ha is subjected to wind and water erosion. It is estimated that about **5333 Mt of soil** is detached annually. Out of this 29 % is carried away by rivers to seas and about 10% is deposited in reservoirs resulting in 1-2 % of loss of storage capacity annually. The estimated annual soil loss is 16.35 tones /ha/year.

Losses due to erosion

i	Loss of fertile top soil	**vi**	Reduction in soil depth
ii	Loss of rain water	**Vii**	Floods
iii	Loss of nutrients	**Viii**	Adverse effect on public health
iv	Silting up of reservoirs	**ix**	Loss of fertile land
v	Damage to forests	**x**	Economic losses

Types of erosion:

There are two major types of soil erosion

a) Geological erosion (Natural or normal erosion): is said to be in equilibrium with soil forming process. It takes place under natural vegetative cover completely undisturbed by biotic factors. This is very slow process.

b) Accelerated erosion: is due to disturbance in natural equilibrium by the activities of man and animals through land mismanagement, destructing of forests over grazing etc., Soil loss through erosion is more than the soil formed due to soil forming process.

Based on the agents causing erosion, erosion is divided into

a. Water erosion b. Wind erosion c. Wave erosion

A. Water erosion

Loss of soil from land surface by water including run off from melted snow and ice is usually referred to as water erosion.

Major erosive agents in water erosion are impacting/ falling raindrops and runoff water flowing over soil surface.

Process of water erosion

Detachment of soil particles is by either raindrop impact or flowing water. Individual raindrops strike the soil surface at velocities up to 9 m/s creating very intensive hydrodynamic force at the point of impact leading to soil particle detachment. Over land flow

detaches soil particles when their erosive hydrodynamic force exceeds the resistance of soil to erosion. Detached soil particles are transported by raindrop splash and runoff. The amount of soil transported by runoff is more than due to raindrop splash. Thus the falling raindrops break the soil aggregates and detach soil particles from each other. The finer particles (silt and clay) block the soil pores and increase the rate of runoff and hence loss of water and soil.

Forms/Types of water erosion

Water erosion occurs in stages identified as sheet erosion, rills, gullies, ravines, landslides and stream bank erosion.

a) **Sheet erosion**: It is the uniform removal of surface soil in thin layers by rainfall and runoff water. The breaking action of raindrop combined with surface flow is the major cause of sheet erosion. It is the first stage of erosion and is least conspicuous, but the most extensive.

b) **Rill erosion**: When runoff starts, channelization begins and erosion is no longer uniform. Raindrop impact does not directly detach any particles below flow line in rills but increases the detachment and transportation capacity of the flow. Rill erosion starts when the runoff exceeds 0.3 to 0.7 mm/s. Incisions are formed on the ground due to runoff and erosion is more apparent than sheet erosion. This is the second stage of erosion. Rills are small channels, which can be removed by timely normal tillage operations.

c) **Gully erosion**: It is the advanced stage of water erosion. Size of the unchecked rills increases due to runoff. Gullies are formed when channelized runoff form vast sloping land is sufficient in volume and velocity to cut deep and wide channels. Gullies are the spectacular symptoms of erosion. If unchecked in time no scope for arable crop production.

d) **Ravines**: They are the manifestations of a prolonged process of gully erosion. They are typically found in deep alluvial soils. They are deep and wide gullies indicating advanced stage of gully erosion.

e) **Landslides**: Landslides occur in mountain slopes, when the slope exceeds 20% and width is 6 m. Generally, landslides cause blockage of traffic in *ghat* roads.

f) **Stream bank erosion**: Small streams, rivulets, torrents (hill streams) are subjected to stream bank erosion due to obstruction of their flow. Vegetation sprouts when streams dry up and obstructs the flow causing cutting of bank or changing of flow course.

Factors affecting water erosion

a) Climate: Water erosion is directly a function of rainfall and runoff. Amount, duration and distribution of rainfall influences runoff and erosion. High intensity rains of longer duration causes severe erosion. Greater the intensity, larger the size of the raindrop. Rainfall intensity more than 5 cm/hr is considered as severe. Total energy of raindrops falling over a hectare land with rainfall intensity of 5 cm /hr is equal to 625 H.P. This energy can lift 89 times the surface 17.5 cm of soil from one ha to a height of 3 ft. Two- thirds of the above energy is used for sealing soil pores. Runoff may occur without erosion but there is no water erosion without runoff. The raindrop thus breaks down soil aggregates, detaches soil particles and leads the rainwater with the fine particles. These fine particles seal the pores of the surface soil and increases runoff causing erosion.

b) Topography: The degree, length and curvature of slope determine the amount of runoff and extent of erosion. Water flows slowly over a gentle slope where as at a faster rate over a

steeper one. As water flows down the slope, it accelerates under the forces of gravity. When runoff attains a velocity of about 1 m/s it is capable of eroding the soil. If the percent of slope is increased by 4 times the velocity of water flowing down is doubled. Doubling the velocity quadruples the erosive power and increases the quantity of soil that can be transported by about 32 times and size of the particles that can be transported by about 64 times.

c) Vegetation: Vegetation intercepts the rainfall and reduces the impact of raindrops. It also decreases the velocity of runoff by obstructing the flow of water. The fibrous roots are also effective in forming stable soil aggregates, which increases infiltration and reduces erosion.

d) Soil Properties: Soil properties that influence soil erodability by water may be grouped into two types.

i. Those properties that influence the infiltration rate and permeability
ii. Those properties that resist the dispersion, splashing, abrasion and transporting forces of rainfall and runoff.

The structure, texture, organic matter and moisture content of upper layers determine the extent of erosion. Sandy soils are readily detachable but not readily transportable. Soils of medium to high clay content have low infiltration capacities and they are readily transported by water after they are dispersed, but their detachability is generally low.

e) Man and beast

Man and beast accelerates erosion by extensive farming and excessive grazing. Faulty practices like cultivation on steep slopes, cultivation up and down the slope, felling and burning of forests etc., leads to heavy erosion. Excessive grazing destroys all vegetation and increases the erosion.

Estimation of soil loss by water erosion

Based on the mechanism and factors influencing soil erosion, a universal soil loss equation (USLE) developed by Wischmeier (1959) is most useful for predicting soil loss due to water erosion. It is an empirical equation and estimates average annual soil loss per unit area as a function of major factors affecting sheet and rill erosion. It enables determination of land management erosion rate relationships for a wide range of rainfall, soil slope and crop and management conditions and to select alternative cropping and management combinations that limit erosion rates to acceptable limits.

$$A = R \times K \times L \times S \times C \times P$$

where,

A= predicted soil loss in t/ha/year
R= rainfall erosivity factor or index
K= soil erodibility factor
L= length of slope factor
S= slope steepness factor
C= soil cover and management factor and
P= erosion control factor

B. Wind erosion

Erosion of soil by the action of wind is known as wind erosion. It is a serious problem on lands devoid of vegetation. It is more common in arid and semi-arid regions. It is essentially a dry weather phenomenon stimulated by the soil moisture deficiency. The process of wind erosion consists of three phases:

a. initiation of movement b. transportation and c. deposition.

About 33 m.ha in India is affected by wind erosion. This includes 23.49 m.ha of desert and about 6.5 m.ha of coastal sands. The *Thar* Desert is formed mainly by blow in sand.

Mechanism of wind erosion

Lifting and abrasive action of wind results in detachment of tiny soil particles from the granules or clods. The impact of these rapidly moving particles dislodge other particles from clods and aggregates. These dislodged particles are ready for movement. Movement of soil particles in wind erosion is initiated when the pressure by the wind against the surface soil grains overcomes the force of gravity on the grains. Minimum wind velocity necessary for initiating the movement of most erodable soil particles (about 0.1 mm diameter) is about 16 km /hr at a height of 30.5 cm. Most practical limit under field conditions, where a mixture of sizes of single grained material present is about 21 km/hr at a height of 30.5 cm.

In general movement of soil particles by wind takes place in three stages: saltation, surface creep and suspension.

a. Saltation:

It is the first stage of movement of soil particles in a short series of bounces or jumps along the ground surface. After being rolled by the wind, soil particles suddenly leap almost vertically to form the initial stage of movement in saltation. The size of soil particles moved by saltation is between 0.1 to 0.5 mm in diameter. This process may account for 50 to 70% of the total movement by wind erosion.

b. Surface creep:

Rolling and sliding of soil particles along the ground surface due to impact of particles descending and hitting during saltation is called surface creep. Movement of particles by surface creep causes an abrasive action of soil surface leading to break down of non-erodable soil aggregates. Coarse particles longer than 0.5 to 2.0 mm diameter are moved by surface creep. This process may account for 5 to 25% of the total movement.

c. Suspension:

Movement of fine dust particles smaller than 0.1 mm diameter by floating in the air is known as suspension. Soil particles carried in suspension are deposited when the sedimentation force is greater than the force holding the particles in suspension. This occurs with decrease in wind velocity. Suspension usually may not account for more than 15% of total movement.

Soil & Water Conservation Techniques

Definition of soil conservation

Soil conservation is using and managing the land based on the capabilities of the land itself involving application of the best management practices leading to profitable crop production without land degradation.

Control of water erosion

Water erosion occurs simultaneously in two steps: detachment of soil particles by falling raindrops and transportation of detached particles by flowing water. Hence preventing the detachment of soil particles and their transportation can minimize water erosion.

Principles of water erosion control are….

- Maintenance of soil infiltration capacity
- Soil protection from rainfall
- Control of surface runoff and
- Safe disposal of surface runoff

For a sound soil conservation program every piece of land must be used in accordance with the land capability classification.

Measures of water erosion control

1. Agronomic measures
2. Mechanical measures (Engineering measures)
3. Agrostological measures

AGRONOMIC MEASURES OF SOIL CONSERVATION

In soil and water conservation programs agronomic measures have to be considered in co-ordination with others for their effectiveness. These measures are effective in low rainfall areas particularly in fairly erosion resistant soils having gentle slope (< 2 %).

The different agronomic measures include

1. Land preparation
2. Contour cultivation
3. Choice of crops
4. Strip cropping
5. Crop rotation / cropping systems
6. Cover crops
7. Mulching
8. Application of manures and fertilizers
9. Application of chemicals

a) **Land preparation**: Land preparation including post-harvest tillage influence intake of water, obstruction to surface flow and consequently the rate of erosion. Deep ploughing or chiseling has been found effective in reducing erosion. Rough cloddy surface is also effective in reducing erosion.

b) **Contour cultivation (Contour farming)**: A line joining the points of **equal elevation** is called contour. All the cultural practices such as ploughing, sowing, inter-cultivation etc. done across the slope reduce soil and water loss. By ploughing and sowing across the slope,

each ridge of plough furrow and each row of the crop act as obstruction to the runoff and provide more time for water to enter into the soil leading to reduced soil and water loss.

c) **Choice of crops**: Row crops or tall growing crops such as sorghum, maize, pearl millet etc. are not effective in conserving soil as they expose majority of the soil and hence they are known as erosion permitting crops. Whereas close growing crops such as cowpea, groundnut, green gram, black gram etc., which protect soil are known as erosion resisting crops as they are very effective in reducing soil loss by minimizing the impact of rain drop and acting as obstruction to runoff.

d) **Strip cropping**: It is a system of growing of few rows of erosion resisting crops and erosion permitting crops in alternate strips on contour (across the slope) with the objective of breaking long slopes to prevent soil loss and runoff. Close growing erosion resisting crops reduce the transporting and eroding power of water by obstructing runoff and filtering sediment from runoff to retain in the field. The width of the erosion permitting and erosion resisting crops vary as per the slope of the field. The strip cropping resembles the intercropping.

With increase in per cent slope of the soil, the width of erosion permitting and erosion resisting crops decreases. **The normal ratio between the erosion resisting crops and erosion permitting crops is 1: 3.**

The strip cropping is divided into four types as follows

i) **Contour strip cropping**: The erosion permitting crops and erosion resisting crops are grown in alternate strips along the contours.

ii) **Field strip cropping**: Alternate strips of erosion permitting crops and erosion resisting crops are raised across the general slope not necessarily on exact contour

iii) **Wind strip cropping**: Strip cropping of erosion permitting and erosion resisting crops across the direction of the most prevailing wind irrespective of the contour.

iv) **Buffer strip cropping**: this type of strip cropping is practiced in areas having steep slopes and badly eroded soils where strips of permanent cover crops or perennial legumes or grasses or shrubs are alternated with field crops.

The strip cropping is simple, cheap and effective soil conservation practice and can be adopted by the farmers.

e) **Crop rotation / cropping system**: Mono-cropping of erosion permitting crops accelerates soil and water loss year after year. Intercropping of erosion permitting crops and erosion resisting crops or their rotation has been found effective for reducing soil and water loss. Inclusion of legumes like lucerne in crop rotation reduces soil loss even in soils having 13% slopes.

f) **Cover crops**: Good grounds cover by canopy gives the protection to the land like an umbrella and minimize soil erosion. Besides conserving soil and moisture, the cover crops hold those soluble nutrients, which are lost by leaching. The third advantage of the cover crops is the addition of organic matter. The legumes provide better cover and better protection. Among the legumes cowpea has been found to produce maximum canopy followed by horsegram, green gram, black gram and dhaincha.

g) **Mulching**: Mulching of soil with available plant residues reduce soil loss considerably by protecting the soil from direct impact of raindrop and reducing the sediment carried with runoff .A minimum plant residue cover of 30 per cent is necessary to keep runoff and soil

loss within the acceptable limits. Vertical mulching also reduce soil loss particularly in vertisols by increasing infiltration.

h) **Application of manures and fertilizers** : Organic manures besides supplying nutrients improve soil physical conditions thereby reduce soil loss. Fertilizers improve vegetative canopy, which aid in erosion control.

i) **Use of chemicals**: Breakdown of aggregates by the falling raindrops is the main cause of detachment of soil particles. Soils with stable aggregates resist breakdown and thus resist erosion. Aggregate stability can be increased by spraying chemicals like poly vinyl alcohol @ 480 kg/ha (rate will depend on the type of soil). Soils treated with bitumen increase water stable aggregates and infiltration capacity of the soil.

MECHANICAL MEASURES (ENGINEERING MEASURES)

The basic principle are: (*i*) shaping the land surface manually or with implements in such a way as to reduce the velocity of runoff, (*ii*) to allow more time for rainfall to stand on soil surface, and (*iii*) to facilitate more infiltration of rainfall into soil layers.

Choice of any particular method under a given situation is influenced by rainfall characters, soil type, crops, sowing methods and slope of land.

(*i*) **Basin listing:** Formation of small depressions (basins) of 10–15 cm depth and 10–15 cm width at regular intervals using an implement called basin lister. The small basins collect rainfall and improve its storage. It is usually done before sowing. It is suitable for all soil types and crops.

(*ii*) **Bunding:** Formation of narrow based or broad based bunds across slope at suitable intervals depending on slope of field. The bunds check the free flow of runoff water, impound the rainwater in the inter-bund space, increase its infiltration and improve soil moisture storage. Leveling of inter-bund space is essential to ensure uniform spread of water and avoid water stagnation in patches. It can be classified into three types:

(*a*) ***Contour bunding:*** Bunds of 1 m basal width, 0.5 m top width and 0.5 m height are formed along the contour. The distance between two contour bunds depends on slope. The inter-bund surface is leveled and used for cropping. It is suitable for deep red soils with slope less than 1%. It is not suitable for heavy black soils with low infiltration where bunds tend to develop cracks on drying. Contour bunds are permanent structures and require technical assistance and heavy investment.

(*b*) ***Graded/field bunding:*** Bunds of 30-45 cm basal width, and 15-20 cm height are formed across slope at suitable intervals of 20-30 m depending on slope. The inter-bund area is leveled and cropped. It is suitable for medium deep-to-deep red soils with slopes up to 1%. It is not suitable for black soils due to susceptibility to cracking and breaching. Bunds can be maintained for 2-3 seasons with reshaping as and when required.

(*c*) ***Compartmental bunding:*** Small bunds of 15 cm width and 15 cm height are formed in both directions (along and across slope) to divide the field into small basins or compartments of 40 sq. m. size (8 × 5 m). It is suitable for red soils and black soils with a slope of 0.5-1%. The bunds can be formed before sowing or immediately after sowing with local wooden plough. It is highly suitable for broadcast sown crops. CRIDA has recommended this method as the best *in situ* soil moisture conservation measure for Kovilpatti region of Tamil Nadu. Maize, sunflower, sorghum performs well in this type of bunding.

(*iii*) **Ridges and furrows:** Furrows of 30-45 cm width and 15-20 cm height are formed across slope. The furrows guide runoff water safely when rainfall intensity is high and avoid water stagnation. They collect and store water when rainfall intensity is less. It is suitable for medium deep todeep black soils and deep red soils. It can be practiced in wide row spaced crops like cotton, maize, chillies, tomato etc. It is not suitable for shallow red soils, shallow black soils and sandy/ gravelly soils. It is not suitable for broadcast sown crops and for crops sown at closer row spacing less than 30 cm. Since furrows are formed usually before sowing, sowing by dibbling or planting alone is possible. Tie ridging is a modification of the above system of ridges and furrows where in the ridges are connected or tied by a small bund at 2–3 m interval along the furrows. Random tie ridging is another modification where discontinuous furrows of 20–25 cm width, 45–60 cm length and 15 cm depth are formed between clumps or hills of crops at the time of weeding. Yet another modification of ridges and furrows method is the practice of sowing in lines on flat beds and formation of furrows between crop rows at 25–30 DAS. This enables sowing behind plough or through seed drill.

(*iv*) **Broad Bed Furrow (BBF):** Here beds of 1.5 m width, 15 cm height and convenient length are formed, separated by furrows of 30 cm width and 15 cm depth. Crops are sown on the beds at required intervals. It is suitable for heavy black soils and deep red soils. The furrows have a gradient of 0.6%. Broad bed furrow has many advantages over other methods.

- It can accommodate a wide range of crop geometry *i.e.,* close as well as wide row spacing.
- It is suitable for both sole cropping and intercropping systems.
- Furrows serve to safely guide runoff water in the early part of rainy season and store rainwater in the later stages.
- Sowing can be done with seed drills.
- It can be formed by bullock drawn or tractor drawn implements. Bed former cum seed drill enables BBF formation and sowing simultaneously, thus reducing the delay between rainfall receipts and sowing.

(*v*) **Dead furrow-** At the time of sowing or immediately after sowing, deep furrows of 20 cm depth is formed at intervals of 6–8 rows of crops. No crop is raised in the furrow. Sowing and furrowing are done across slope. It can be done with wooden plough in both black and red soils.

AGROSTOLOGICAL METHODS

The use of grasses to control soil erosion, reduce run off and improve soil moisture storage constitutes the agrostological method. Grasses with their close canopy cover over soil surface and profuse root system, which binds soil particles, provide excellent protection against runoff and erosion. The following are the various agrostological methods of ***in situ*** moisture conservation.

(*i*) **Pastures/grass lands:** Raising perennial grasses to establish pastures or grass lands is recommended for shallow gravelly, eroded, degraded soils. Grass canopy intercepts rainfall, reduces splash erosion, checks runoff and improves soil moisture storage from rainfall.

(*ii*) **Strip cropping with grasses:** Alternate strips of grasses and annual field crops arranged across slope check runoff and erosion and help in increasing moisture storage in soil.

(*iii*) **Ley farming:** It is the practice of growing fodder grasses and legumes and annual crops in rotation. Grasses and legumes like *Cenchrus, stylo*are grown for 3–5 years and followed by annual crops like sorghum for 2 year. When the field is under grasses or legumes, soil moisture conservation is improved.

(*iv*) **Vegetative barriers:** Vegetative barrier consists of one or two rows of perennial grasses established at suitable interval across the slope and along the contour. It serves as a block to free runoff and soil transport. *Vetiver, Cenchrus*etc., are suitable grasses. Vetiver can be planted in rows at intervals of 40 m in 0.5% slope. Plough furrows are opened with disc plough first before commencement of monsoon. 5–8 cm deep holes are formed at 20 cm interval and two slips per hole are planted in the beginning of rainy season. The soil around the roots is compacted. Vetiver barriers check runoff and prevent soil erosion. While they retain the soil, they allow excess runoff to flow through their canopy without soil loss. It is adapted to drought and requires less care for maintenance. It does not exhibit any border effect on crops in adjacent rows. It allows uniform spread of water to lower area in the field resulting in uniform plant stand thus increasing yield of a crop by 10–15%. It facilitates better storage of soil moisture. If fodder grasses like *Cenchrus glaucus*or marvel grass are used, fodder can also be harvested and given to the animal. Vegetative barriers are best suited for black soil. Unlike contour bunding, which gives way due to development of crack in summer in black soils, vegetative barriers do not allow such phenomenon in black soil. Hence, the vegetative barriers can be effectively maintained in black soil for 4–5 years. After 4–5 years, replanting material can also be had from the old barrier by ‘quartering’.

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5 Drought; Types, effect of water deficit on physio-morphological characteristics of the plants

5.1 Introduction

Low rainfall or failure of monsoon rain is a recurring feature in India. This has been responsible for droughts and famines. The word drought generally denotes scarcity of water in a region. However, aridity and drought are due to insufficient water, aridity is a permanent climatic feature and is the culmination of a number of long-term processes. However, drought is a temporary condition that occurs for a short period due to deficient precipitation for vegetation, river flow, water supply and human consumption. Drought is due to anomaly in atmospheric circulation.

Aridity Vs. Drought

Particulars	Aridity	Drought
Duration	Permanent feature	Temporary condition of scarcity of varying duration
Factors	Culmination of many long term processes , considers all climatic features	Caused by deficient rainfall
Aspect described	Description of Climate	Description of Water availability

5.2 Definition of drought

There is no universally accepted definition for drought.

- Early workers defined drought as prolonged period without rainfall.
- According to Ramdas (1960) drought is a situation when the actual seasonal rainfall is deficient by more than twice the mean deviation.
- **American Meteorological Society** defined drought as a period of abnormally dry weather sufficiently prolonged for lack of water to cause a severe hydrological imbalance in the area affected.
- Prolonged deficiencies of soil moisture adversely affect crop growth indicating incidence of agricultural drought. It is the result of imbalance between soil moisture and evapo-transpiration needs of an area over a fairly long period so as to cause damage to standing crops and to reduce the yields.
- **The irrigation commission of India** defines drought as a situation occurring in any area where the annual rainfall is less than 75% of normal rainfall.

Criteria of Drought:

- **NCA (1976) Agricultural drought** as an occasion when at least four consecutive weeks receive rainfall half of the normal (normal rainfall being 5 mm or more) during

the *kharif* crop season

- **Drought areas:** Regions which experienced drought in more than 20 per cent of years
- **Chronic drought areas:** Regions which experienced drought in more than 40 per cent of the years
- **Drought free period:** When cumulative AE curve is above cumulative PE/2 curve
- **Moderate drought period:** When cumulative AE curve lies b/w cumulative PE/2 and PE/4 curves.
- **Severe drought period:** When cumulative AE curve is below cumulative PE/4 curve

***Annawary* system:**

Crop condition assessed through visual estimates

1. Production above 75 % of normal: No drought
2. Production 50 to 75 % of normal: Moderate drought
3. Production 25 to 50 % of normal: Severe drought
4. Production less than 25 % of normal: Disastrous drought

5.3 Classification of drought

Drought can be classified based on duration, nature of users, time of occurrence and using some specific terms.

5.3.1 Based on duration

a. Permanent drought: This is characteristic of the desert climate where sparse vegetation growing is adapted to drought and agriculture is possible only by irrigation during entire crop season.

b. Seasonal drought: This is found in climates with well defined rainy and dry seasons. Most of the arid and semiarid zones fall in this category. Duration of the crop varieties and planting dates should be such that the growing season should fall within rainy season.

c. Contingent drought: This involves an abnormal failure of rainfall. It may occur almost anywhere especially in most parts of humid or sub humid climates. It is usually brief, irregular and generally affects only a small area.

d. Invisible drought: This can occur even when there is frequent rain in an area. When rainfall is inadequate to meet the evapo-transpiration losses, the result is borderline water deficiency in soil resulting in less than optimum yield. This occurs usually in humid regions.

5.3.2 Based on relevance to the users (National Commission on Agriculture,1976)

a) Meteorological drought: It is defined as a condition, where the annual precipitation is less than the normal over an area for prolonged period (month, season or year).

b) Atmospheric drought: It is due to low air humidity, frequently accompanied by hot dry winds. It may occur even under conditions of adequate available soil moisture. It refers to a condition when plants show wilting symptoms during the hot part of the day when

transpiration exceeds absorption temporarily for a short period. When absorption keeps pace with transpiration the plants revive. (Mid day wilt).

c) Hydrological drought: Meteorological drought, when prolonged results in hydrological drought with depletion of surface water and consequent drying of reservoirs, tanks etc. It results in deficiency of water for all sectors using water. This is based on water balance and how it affects irrigation as a whole for bringing crops to maturity.

d) Agricultural drought (soil drought): It is the result of soil moisture stress due to imbalance between available soil moisture and evapotranspiration of a crop. It is usually gradual and progressive. Plants can therefore, adjust at least partly, to the increased soil moisture stress. This situation arises because of scanty precipitation or its uneven distribution in both space and time.

Relevant definition of agricultural drought appears to be a period of dryness during the crop season, sufficiently prolonged to adversely affect the yield. The extent of yield loss depends on the crop growth stage and the degree of stress. It does not begin when the rain ceases, but actually commences only when the plant roots are not able to obtain the soil moisture rapidly enough to replace evapo-transpiration losses.

5.3.3 Based on time of occurrence

a) Early season drought: It occurs due to delay in onset of monsoon or due to long dry spells after early sowing

b) Mid season drought: Occurs due to long gaps between two successive rains and stored moisture becoming insufficient during the long dry spell.

c) Late season drought: Occurs due to early cessation of rainfall and crop water stress at maturity stage.

5.3.4. Other terms to describe drought

a) Relative drought: The drought for one crop may not be a drought situation for another crop. This is due to mismatch between soil moisture condition and crop selection. For eg. A condition may be a drought situation for growing rice, but the same situation may not be a drought for growing groundnut.

b) Physiological drought: Refers to a condition where crops are unable to absorb water from soil even when water is available, due to the high osmotic pressure of soil solution due to increased soil concentration, as in saline and alkaline soils. It is not due to deficit of water supply.

5.5 Periodicity of drought

The Indian Meteorological Department examined the incidence of drought for the period from 1871 to 1967, utilizing the monthly rainfall of 306 stations in the country. It was seen that during 1877, 1899, 1918 and 1972 more than 40 per cent of the total area experienced drought. General observation on the periodicity of drought in respect of different meteorological sub divisions of India is given below.

Meteorological sub divisions	Period of recurrence of drought
Assam	Very rare, once in 15 years
West Bengal, MP, Konkan, Coastal AP, Kerala, Bihar, Orissa	Once in 5 years
South interior Karnataka, Eastern UP, Gujarat, Vidharbha, Rajasthan, Western UP, TN, Kashmir, Rayalaseema and Telangana	Once in 3 years
Western Rajasthan	Once in 2.5 years

5.6 Important causes for agricultural drought are

- Inadequate precipitation
- Erratic distribution
- Long dry spells in the monsoon
- Late onset of monsoon
- Early withdrawal of monsoon
- Lack of proper soil and crop management

5.7 Effect of drought/water deficit on physio-morphological characteristics of plants

Effect on water deficit on crop

a) **Water relations:** Alters the water status by its influence on absorption, translocation and transpiration. The lag in absorption behind transpiration results in loss of turgor as a result of increase in the atmospheric dryness.

b) **Photosynthesis:** Photosynthesis is reduced by moisture stress due to reduction in Photosynthetic rate, chlorophyll content, leaf area and increase in assimilates saturation in leaves (due to lack of translocation).

c) **Respiration:** Increase with mild drought but more serve drought lowers water content and respiration.

d) **Anatomical changes:** Decrease in size of the cells and inter cellular spaces, thicker cellwall, greater development of mechanical tissue. Stomata per unit leaf tend to increase.

e) **Metabolic reaction:** All most all metabolic reactions are affected by water deficits.

f) **Hormonal Relationships:** The activity of growth promoting hormones like cytokinin, gibberlic acid and indole acetic acid decreases and growth regulating hormone like abscisic acid, ethylene, etc., increases.

g) **Nutrition:** The fixation, uptake and assimilation of nitrogen are affected. Since dry matter production is considerably reduced, the uptake of NPK is reduced.

h) **Growth and Development:** Decrease in growth of leaves, stems and fruits.

Maturity is delayed if drought occurs before flowering while it advances if drought occurs after flowering.

i) **Reproduction and grain growth:** Drought at flowering and grain development determines the number of fruits and individual grain weight, respectively. Panicle initiation in cereals is critical while drought at anthesis may lead to drying of pollen. Drought at grain development reduces yield while vegetative and grain filling stages are less sensitive to moisture stress.

j) **Yield:** The effect on yield depends hugely on what proportion of the total dry matter is considered as useful material to be harvested. If it is aerial and underground parts, effect of drought is as sensitive as total growth. When the yield consists of seeds as in cereals, moisture stress at flowering is detrimental. When the yield is fiber or chemicals where economic product is a small fraction of total dry matter moderate stress on growth does not have adverse effect on yields.

x-x-x-x-x

6 Crop adaptation and mitigation to drought

6.1 Crop Adaptations

The ability of crop to grow satisfactorily under water stress is called drought adaptation. Adaptation is structural or functional modification in plants to survive and reproduce in a particular environment.

Crops survive and grow under moisture stress conditions mainly by two ways: (i) escaping drought and (ii) drought resistance (Fig. 6.1)

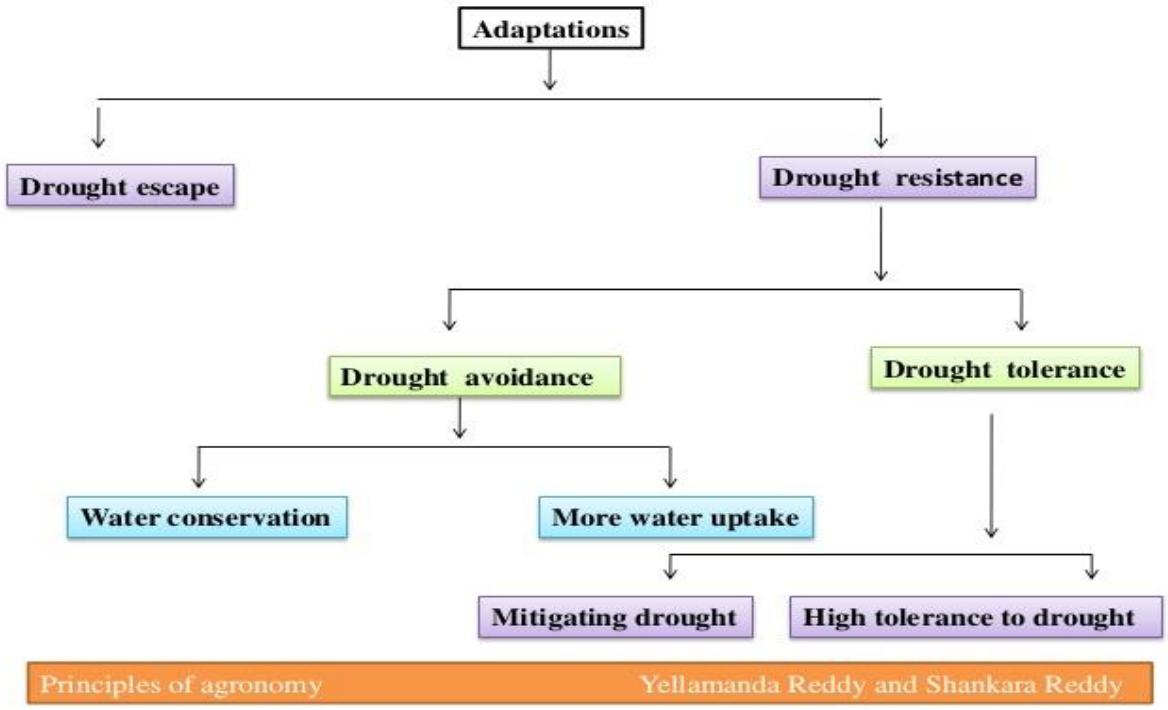


Fig. 6.1 Flow chart showing different mechanisms for overcoming moisture stress

6.1.1 Escaping Drought

Evading the period of drought is the simplest means of adaptation of plants to dry conditions. Many short duration desert plants, (**ephemerals)**, germinate with rains and mature in five to six weeks. These plants have no mechanism for overcoming moisture stress and are, therefore, are not drought resistant.

In cultivated crops, the ability of a cultivar to mature before the soil dries is the main adaptation to growth in dry regions. However, only very few crops have such a short growing season to be called as ephemerals. Certain varieties of pearl millet mature within 60 days after sowing. Short duration pulses like cowpea, greengram, black gram can be included in this category. In addition to earliness, they need drought resistance because there may be dry spells within the crop period of 60 days. The disadvantage about breeding early varieties is that yield is reduced with reduction in duration.

6.1.2 Drought Resistance

Plants can adopt to drought either by avoiding stress or by tolerating stress due to different mechanisms. These mechanisms provide drought resistance.

i. Drought avoidance

A. Restricting transpiration (water savers)	**B. Accelerating water uptake (water spenders)**
1. Early stomata closer 2. Increased photosynthetic efficiency 3. Low rates of cuticular respiration 4. Lipid deposition on foliage 5. Reduced leaf area 6. Morphology of leaf surface 7. Water storage in the plant	1. Efficient root system 2. High root/shoot ratio 3. Increases osmotic potential

ii. Drought tolerance

A. Mitigating stress	**B. High tolerance**
1. Resistance to dehydration 2. Thick cuticle 3. Maintenance of high osmotic pressure	1. Metabolic strain 2. Plastic strain

6.1.3 Avoiding Stress

Stress avoidance is the ability to maintain a favorable water balance, and turgidity even when exposed to drought conditions, thereby avoiding stress and its consequences. A favorable water balance under drought conditions can be achieved either by: (i) conserving water by restricting transpiration before or as soon as stress is experienced; or (ii) accelerating water uptake sufficiently so as to replenish the lost water.

6.2 Strategies for drought management

The different strategies for drought management are discussed under the following heads.

6.2.1 Adjusting the plant population: The plant population should be lesser in dryland conditions than under irrigated conditions. The rectangular type of planting pattern should always be followed under dryland conditions. Under dryland conditions whenever moisture stress occurs due to prolonged dry spells, under limited moisture supply the adjustment of plant population can be done by

a) Increasing the inter row distance: By adjusting more number of plants within

the row and increasing the distance between the rows reduces the competition during any part of the growing period of the crop. Hence it is more suitable for limited moisture supply conditions.

b) Increasing the intra row distance: Here the distance between plants is increased by which plants grow luxuriantly from the beginning. There will be competition for moisture during the reproductive period of the crop. Hence it is less advantageous as compared to above under limited moisture supply.

6.2.2 Mid-season corrections: The contingent management practices done in the standing crop to overcome the unfavorable soil moisture conditions due to prolonged dry spells are known as mid-season conditions.

a) Thinning: This can be done by removing every alternate row or every third row which will save the crop from failure by reducing the competition

b) Spraying: In crops like groundnut, castor, red gram, etc., during prolonged dry spells the crop can saved by spraying water at weekly intervals or 2 per cent urea at week to 10 days interval.

c) Ratooning: In crops like sorghum and bajra, ratooning can practiced as mid-season correction measure after break of dry spell.

6.2.3 Mulching: It is a practice of spreading any covering material on soil surface to reduce evaporation losses. The mulches will prolong the moisture availability in the soil and save the crop during drought conditions.

6.2.4 Weed control: Weeds compete with crop for different growth resources ore seriously under dryland conditions. The water requirement of most of the weeds is more than the crop plants. Hence they compete more for soil moisture. Therefore the weed control especially during early stages of crop growth reduces the impact of dry spell by soil moisture conservation.

6.2.5 Water harvesting and lifesaving irrigation:

The collection of runoff water during peak periods of rainfall and storing in different structures is known as water harvesting. The stored water can be used for giving the life saving irrigation during prolonged dry spells.

x-x-x-x-x

7 Water Harvesting

7.1 Meaning of water harvesting:

The process of runoff collection during periods of peak rainfall in storage tanks, ponds etc., is known as water harvesting. It is a process of collection of runoff water from treated or untreated land surfaces/ catchments or roof tops and storing it in an open farm pond or closed water tanks/reservoirs or in the soil itself (in situ moisture storage) for irrigation or drinking purposes. **Runoff farming** and **rainwater harvesting agriculture** are synonymous terms, which imply that farming is done in dry areas by means of runoff from a catchment.

Runoff farming is basically a water harvesting system specially designed to provide supplemental or lifesaving irrigation to crops, especially during periods of soil moisture stress.

Collecting and storing water for subsequent use is known as water harvesting. It is a method to induce, collect, store and conserve local surface runoff for agriculture in arid and semiarid regions. All water harvesting systems have three components viz., the catchment area, the storage facility and the command area. The catchment area is the part of the land that contributes the rain water. The storage facility is a place where the runoff water is stored from the time it is collected until it is used. The command area is where water is used.

Water harvesting is done both in arid and semi-arid regions with certain differences. In arid regions, the collecting area or catchment area is substantially in higher proportion compared to command area. Actually, the runoff is induced in catchment area in arid lands whereas in semi-arid regions, runoff is not induced in catchment area, only the excess rainfall is collected and stored. However, several methods of water harvesting are used both in arid and semiarid regions.

Water harvesting (WH) is generally considered as a rudimentary form of irrigation. The difference is that with WH the farmer's has no control over timing. Runoff can only be harvested when it rains. Water harvesting in its broadest sense will be defined as the "collection of runoff for its productive use". Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral water courses. Water harvesting techniques which harvest runoff from roofs or ground surfaces fall under the term 'rainwater harvesting' while all systems which collect discharges from water courses are grouped under the term 'flood water harvesting'.

In regions where crops are grown entirely rainfed, a reduction of 50% in the seasonal rainfall, for example, may result in a total crop failure. If, however, the available rain can be concentrated on a smaller area, reasonable yields will be received. In a year of severe drought there may be no runoff to collect, but an efficient water harvesting system will improve plant growth in the majority of the years. Hence, collecting and storing rainwater for subsequent use is called as '*water harvesting'*. It is a method to induce, collect, store and conserve local surface runoff for arid and semi-arid regions. It is also known as '*runoff farming*' in rainfed areas.

7.2 Components and principles of water harvesting:

All water harvesting systems have three components viz., the catchment area, the storage area and the command area. The catchment area (donor area) is the part of the land that contributes the rainwater. The storage facility is a place where the runoff water is stored

from the time it is collected until it is used for human beings and their needs. The area in which collected water is used is called command area (recipient area). The donor area is generally not suitable for crop production.

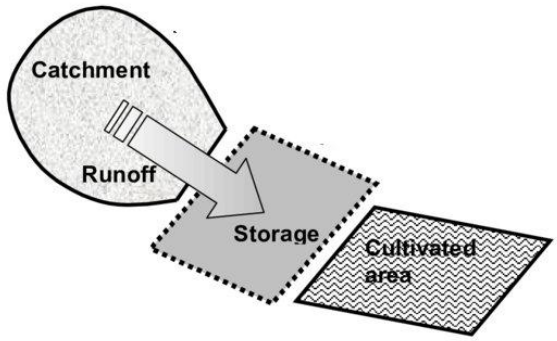


Fig. Components of a water harvesting system

Water harvesting is a process of collection of peak rainfall runoff water from treated or untreated land surfaces / catchments / roof tops and storing it in an open farm pond or closed water tanks / reservoirs or in the soil itself (*in-situ* moisture storage) for agriculture or domestic purposes. In runoff farming, a water harvesting system is specially designed to provide supplemental irrigation to crops, especially during periods of soil moisture stress.

The **aim** of water harvesting is to mitigate the effects of temporal shortage of rain, so called dry spells, groundwater recharge, risk minimizing in drought-prone areas, combating desertification by tree plantation, to cover both household needs (for drinking, cooking, sanitation, etc.) as well as for productive use (protective irrigation).

The implementation of water harvesting might, however, bring about a number of drawbacks. The main **disadvantages of rainwater harvesting technologies** are mainly due to the limited supply and uncertainty of rainfall. The others are:

1. Increased soil erosion when slopes are cleared for higher runoff rates.
2. Loss of habitat of flora and fauna on these slopes and depressions.
3. Upstream-downstream conflicts among the beneficiaries.
4. Competition among the farmers and the herders.

7.3 The importance of water harvesting can be summarised as:

1. In arid and semi-arid areas where rainfall is low and unfavourably distributed, water harvesting makes farming possible on part of the land provided other production factors are favourable.
2. It can provide additional water to supplement rainfall to increase and stabilize crop production in dryland areas.
3. It can alleviate the risk associated with the unpredictability of rainfall in drought-prone areas.
4. In remote areas (islands and deserts) where public water supply for domestic and animal rearing is not available, inducing runoff from treated area and stored in a reservoir/ cistern for later use is a common practice.
5. In islands and high hilly areas, due to limited extent of fresh water aquifers, rainwater harvesting is the most preferred source of water for domestic use.
6. The arid lands suffering from desertification, water harvesting would improve the vegetative cover and help to halt the environmental degradation.
7. Water harvesting arrest decline in groundwater levels, to overcome the inadequacy of surface water to meet our demands.

7.4 **Water harvesting structures**

At present most water harvesting structures are built under the holistic programme of watershed development which includes:

- Roof top rainwater harvesting for domestic use;
- Creating surface water storages in the form of check dams, dug ponds for irrigation and drinking;
- Recharging ground water through check dams, percolation tanks, sub-surface dykes to augment water availability in wells, tube wells, hand pumps etc.;
- Soil conservation through afforestation, gully plugging, contour cropping, control and regulation of grazing;
- Soil moisture conservation especially in rainfed hilly areas, through bench terracing, contour bunding, *khadins* to suppress soil salinity;
- Improving cropping pattern, crop calendar etc. for enhancing farm income;
- Improving marketing facilities for farm produce;
- Providing additional livelihood options such as dairy farming, poultry farming, bee keeping, sericulture etc,;
- Promoting social forestry to meet the fuel wood requirement where alternative sources of fuel are not feasible.

7.5 Techniques of Inducing Runoff

Rainwater harvesting is possible even in areas with as little as 50 to 80 mm average annual rainfall. Ancient desert dwellers harvested rain by redirecting the water running down the slopes into fields or cisterns (storage structures). This small amount of runoff collected over large area may be useful for supplying water to small villages, households, cattle *etc*. For collection of higher amount of rainfall, runoff is induced either by inter-plot water harvesting or by land alteration or by surface chemical treatment.

a) Land alterations:

Land smoothing reduce surface depression storage and infiltration losses. Clearing away rocks and vegetation and compacting the soil surface can increase runoff. However, land alteration may lead to soil erosion except where slope is reduced. When erosion is not excessive and low cost hill side land is available, land alteration can be very economical way to harvest rainwater in arid lands.

b) Surface chemical treatment:

A promising method for harvesting rainwater is to treat soils with chemicals that fill pores or make soil repellent to water. Some materials used for this purpose are sodium salts of silicon, latexes, asphalt and paraffin wax. Surface treatment of soil with bitumen and asphalt is effective for inducement of runoff. Most of the treatments for inducing runoff are location-specific and depends on importance of runoff collection and cost associated with the treatment.

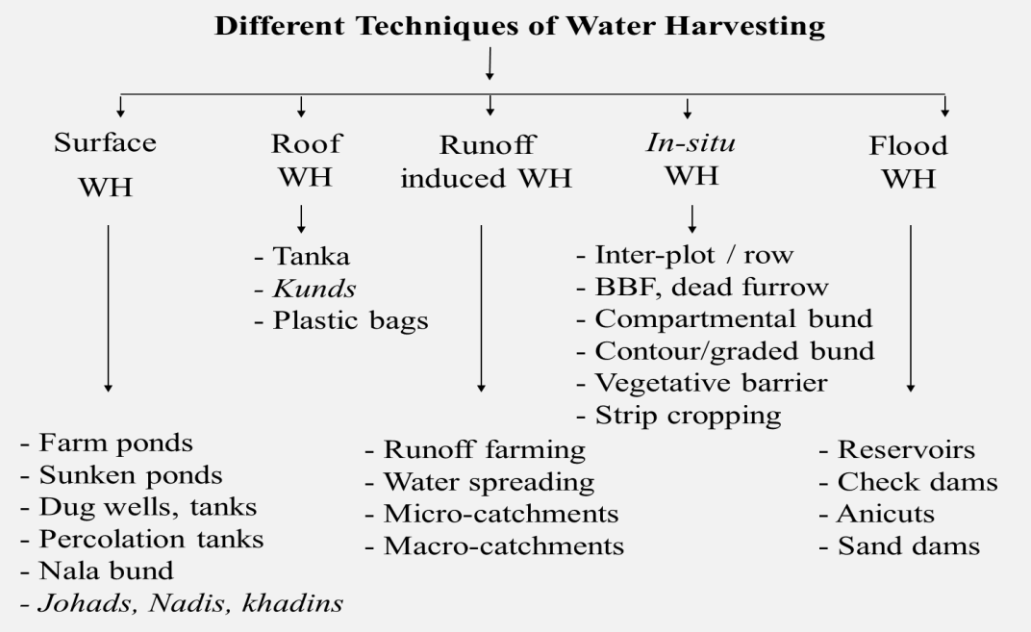
c) Soil cover:

Surface modifications may be required to get more runoff. Runoff may be induced by using low density polyethylene sheets, butyl rubber, asphalt and fibre glass, compacting surface or spreading sodic soil on surface as soil cover. In cropping systems, crop is sown in narrow strips between wide intervals that are ridged as artificial miniature watersheds. Compacting the soil surface is the cheapest way to induce runoff in rainfed areas.

7.6 Techniques of Rainwater Harvesting:

The water harvesting techniques are classified into five groups. These are sketched as given below:

Water harvesting is done both in arid and semi-arid regions with certain differences. In arid regions, the collecting area or catchment area is substantially in higher proportion compared to command area. Actually, the runoff is induced in catchment area in arid lands whereas in semi-arid regions, runoff is not induced in catchment area, only the excess rainfall is collected and stored. However, several methods of water harvesting are used both in arid and semi-arid regions.



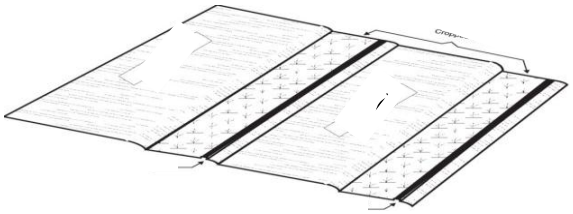
The different methods of water harvesting that are followed in arid and semi-arid regions are discussed below.

7.6.1 Arid Regions

The catchment area should provide enough water to mature the crop, and the type of farming practiced must make the best use of water. In general, perennial crops are suitable as they have deep root systems that can use runoff water stored deep in the soil which is not lost through evaporation.

a) Runoff farming:

Ancient runoff farms in the Negev desert (Israel) had several cultivated fields fed by water from watersheds of 10 to 50 ha. The watersheds were divided into small catchment areas of 1 to 3 ha that allowed runoff water to be collected in easily catchment channels on the hill sides and were small enough to prevent uncontrollable amount of water. The channels that led the water to cultivated fields were terraced and had stone spillways so that surplus water in one field could be led to lower ones. Farmers constructed small check dams with rocks across the small gullies and guided the water to fields.



The farmers of Madhya Pradesh (Rainfed central India) have developed a unique and indigenous rainwater management system based on water harvesting and runoff farming, locally

known as '***Haveli'***. In this system, rainwater is harvested (0.2–1.2 m depth) in the field during monsoon (June–September) by constructing embankments along the field boundary. The farmers allow rainwater to flow from one field to another. The impounded water is then drained out from the field during September–October. The winter crops (wheat, pea, lentil and chickpea) are grown which utilize the stored moisture seeped in the soil profile. '*Haveli'* fields contribute 4–6 mm rainwater per day for 90–100 days in the rainy season, corresponding to 40–60 cm conserved moisture in upper soil profile. The drained water from '*Haveli'* fields is also used for irrigation by the adjacent farmers to grow rice. It helps greatly to control weeds, soil moisture conservation and ground water recharge.

b) Water spreading:

In arid areas, the limited rainfall is received as short intense storms. Water swiftly drains into gullies and then flows towards the sea. Water is lost to the region and floods caused by this sudden runoff can be devastating often to areas otherwise untouched by the storm. Water spreading is a simple irrigation method for use in such a situation. Flood waters are deliberately diverted from their natural courses and spread over adjacent plains. The water is diverted or retarded by ditches, dikes or small dams. The wet flood plains or valley floods are used to grow crops. Sorghum and millets are the most common crops.

The major characteristic of water spreading bunds is that, as their name implies, they are intended to spread water, and not to impound it. They are usually used to spread floodwater which has either been diverted from a watercourse or has naturally spilled onto the floodplain. The earthen bunds slow down the flow of floodwater and spread it over the land to be cultivated, thus allowing it to infiltrate. The dikes can be constructed with a tractor and mouldboard plough or with a road grader.

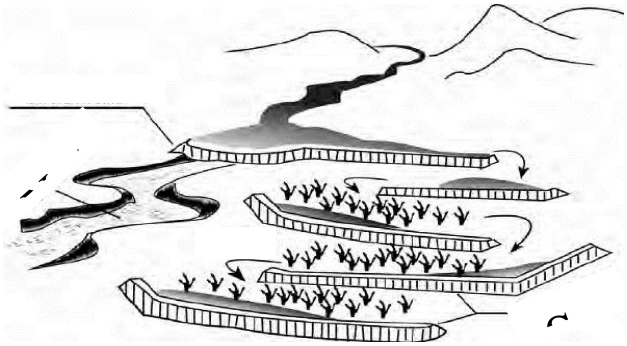


Fig.
Water spreading system in Pakistan to divert excess flood water for agricultural use.
If a site received <200 mm annual precipitation or <100-130 mm during the growing season, it would typically not produce enough runoff to justify installation of a water spreader.

c) Micro-catchments (Negarim):

A plant can grow in a region with too little rainfall for its survival if a rainwater catchment basin is built around it. At the lowest point within each micro-catchment, a basin is dug about 40 cm deep and a tree is planted in it. The basin stores the runoff from micro-catchment. In Africa these are used for cultivation of sorghum, maize and millets. Appropriate for tree planting in situations where land is uneven or only a few trees are planted. Widely used micro-catchments are contour ridges, semi-circular and trapezoid bunds and small runoff basins. The main limitation is that it is not easily mechanised therefore limited to small scale. Not easy to cultivate between tree lines.

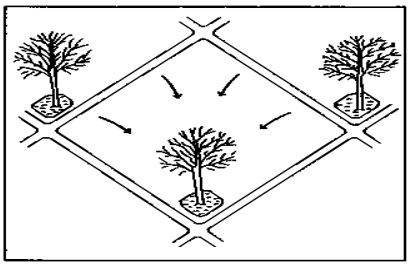


Fig.
Negarim micro-catchment for trees

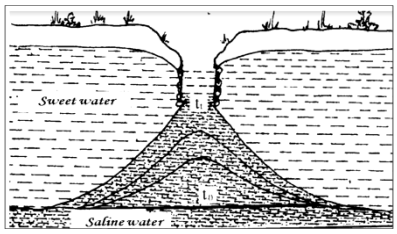
It works great with rainfall rates starting from 150 mm/year and they are applied on slopes upto 15%.

Macro-catchments having runoff water collected from relatively large natural catchments. Generally these catchments are located outside the farm boundaries where individual farmers have little or no control over them. Percolation tank is an example of macro-catchment WH system.

d) Traditional water harvesting systems:

Tanka, Virda, Kunds, Nadi, Johad and khadin are the important traditional water harvesting systems of Rajasthan. The maximum conservation of water is in the form of lakes. The GOI, reconstructed these traditional WH systems under MGNREGA all over the country.

Tanka is the most prevailing rainwater harvesting structure in Indian Thar desert. It is an underground circular tank or cistern constructed for collection and storage of runoff water from natural catchment or artificially prepared clean catchment or from a roof top. The vertical walls are lined with stone masonry or cement concrete and the base with 10 cm thick concrete. The capacity of the tank ranges from 1,000 to 6,00,000 L. A traditional *tanka* constructed with lime plaster and thatched with bushes has a life span of 3–4 years. CAZRI (Jodhpur) has designed an improved *tanka* (life-span 25 years) of 21,000 L capacity which gets filled with an annual rainfall of 125 mm. The catchment area needed for this capacity is 700 m².

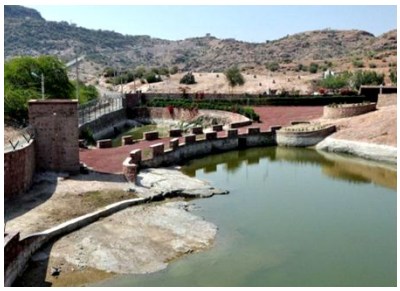


Virdas are shallow holes which are made in the sands of dry riverbeds and lakes for collecting drinking water. These are found all over the *Banni* grasslands, a part of the great Rann of Kutch in Gujarat. The topography of the area is undulating, with depressions on the ground. In *virdas*, the sweet freshwater remains in the upper layer from which the water is collected, and the saline water remains below the freshwater zone because of its higher density and, hence, it is theoretically possible to keep the harvested sweet rainwater stored to float over the denser saline water.

With this knowledge, Maldharis (local nomadic people) first developed this unique structure in the Rann of Kutch, which is essentially like a well in a tank. A group of thorny bush branches enclosed a *virda* to ward off animals.

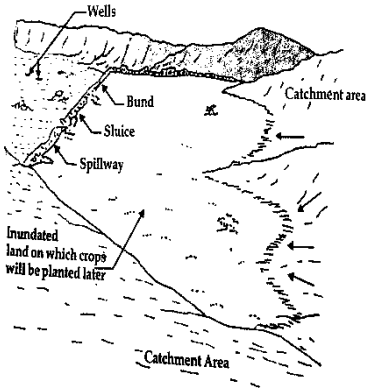
Kunds were more prevalent in the western arid regions of Rajasthan, and in areas where the limited groundwater available is moderate to highly saline. Usually it is constructed with local materials or cement. The *kund* consists of a saucer-shaped catchment area with a gentle slope towards the centre where a tank is situated. Openings or inlets for water to go into the tank are usually guarded by a wire mesh to prevent the entry of floating debris, birds and reptiles. The top is usually covered with a lid from where water can be drawn out with a bucket.

An area receiving rainfall of 25 mm/annum, a *kund* with a catchment of 100 km² could easily collect 10,000 L of water. Even if we assume that only 40 - 50% of rain will turn into runoff, a *kund* can still store 0.1 million litres of water. The catchment size of *kunds* varies from about 20 m² to 2 ha depending on the runoff needed, water use and the availability of spare land.



Nadi or dugout village pond (*Pokhar*) is constructed for storing water from natural catchments. It is more prevalent in western Rajasthan. The depth and capacity of the n*a*di may varies from1.5 to 12 meters and 400 m^3 to 70,000 m^3, respectively. A large amount of sandy sediments were regularly deposited in them, resulting in quick siltation. The water is muddy and dirty which is unfit for human consumption. However, due to water scarcity peoples used this water for all purposes.

Khadin is unique land use system of Thar desert where in runoff water from rocky catchments are collected in valley plains during rainy season. It is practised where rock catchments and valley plains occur in proximity to sandy hills. This old water harvesting system was first practised by the Paliwal Brahmins of Jaisalmer, western Rajasthan in the 15th century.



The standing water in a *khadin* assists in continuous groundwater recharge. Its main feature is a very long (100–300 m) earthen embankment built across the lower hill slopes lying below gravelly uplands. Sluices and spillways allow excess water to drain off. Crops are grown in the winter season after water is receded in shallow pond on the residual soil moisture. At least one crop is cultivated even in the arid region on *khadin* bed. The soils in *khadin* are extremely fertile due to frequent deposition of fine sediment.

Johads are crescent-shaped small earthen bunds which is built across a slopping catchment/ seasonal channels that capture and conserve rainwater, improving percolation and groundwater recharge. Unlike a normal dam, the rainwater is collected during monsoon and allowed to percolate into the soil.

Since 1984, a total of 8600 *johads* have been built in 1086 villages of Alwar district in Rajasthan, covering 6500 km² area under the leadership of Tarun Bharat Sangh and its leader Rajendra Singh, the Water Man of Rajasthan. These *johads* have helped the farming communities from abject poverty to prosperity, a miraculous transformation. This has resulted in the shallow aquifer recharge in groundwater bringing up the water table from about 100–120 meter depth to 3–13 meter at present. The area under single and double cropping was 11% and 3%, which was increased to 70% and 50%, respectively. The forest cover, which used to be around 7%, increased to 40% through agro-forestry and social forestry, providing sufficient fuel wood and sequestering carbon from the atmosphere.

7.6.2 Semi-arid Regions

Water harvesting techniques followed in semi-arid areas are numerous and also ancient. These are-

a) Dug Wells:

Hand dug wells have been used to collect and store underground water and this water is lifted for irrigation. The quality of water is generally poor due to dissolved salts.

b) Tanks:

Runoff water from hill sides and forests is collected on the plains in tanks. The traditional tank system has following components *viz*., catchment area, storage tank, tank bund, sluice, spillway and command area. The runoff water from catchment area is collected and stored in storage tank on the plains with the help of a bund. To avoid the breaching of tank bund, spillways are provided at one or both the ends of the tank bund to dispose of excess water. The sluice is provided in the central area of the tank bund to allow controlled flow of water into the command area. Water from the tanks is used to irrigate the command area by gravity flow. The command area of many tanks ranges from 25 to 100 ha. Unlike wells, the quality of water is good in tanks.

c) Percolation Tanks:

Flowing rivulets or big gullies are obstructed and water is ponded. Water from the ponds percolates into the soil and raises the water table of the region. The primary purpose of percolation tank is to recharge groundwater. A strict regulation on the silt load entering the downstream reservoirs is an additional advantage of percolation tanks. The improved water level in the wells lower down the percolation tanks are used for supplemental irrigation.

d) Farm Ponds:

A portion of the excess runoff water after allowing maximum *in-situ* moisture conservation is collected in farm ponds. As far as possible, the pond should be location in the lower patches of the field to facilitate better storage and less seepage losses. The size of the farm should be worked out on the basis of annual rainfall, probable runoff and catchment area. Generally, 10-20% of the seasonal rainfall is considered as runoff in medium black soils. A farm pond of 150 m^3 capacity with side slopes of 1.5:1 is sufficient for one ha of catchments area in black soils.

Depending upon their construction and suitability to different topographic conditions farm ponds are classified as:

- Excavated farm ponds : Suitable for flat topography
- Embankment ponds : Suitable for hilly terrains and
- Excavated cum embankment ponds

There are three types of excavated farm ponds – square, rectangular and circular. Circular ponds have high water storage capacity. Farm ponds of size 100 to 300 m^3 may be dug to store 30% of runoff. The problem associated with farm ponds in red soils is high seepage loss. This can be reduced by lining walls. Some of the traditional methods for seepage control are the use of bentonite, soil dispersants and soil-cement mixture. Bentonite has excellent sealing properties if kept continuously wet, but cracks develop when dried.

Soil-cement mixture can be used. A soil-cement lining of 100 mm thickness reduces seepage losses up to 100 per cent. The pit lined continuously develops cracks but no cracks develop when applied in blocks. The other alternative sealant for alfisols is a mixture of red and black soil in the ratio of 1:2.

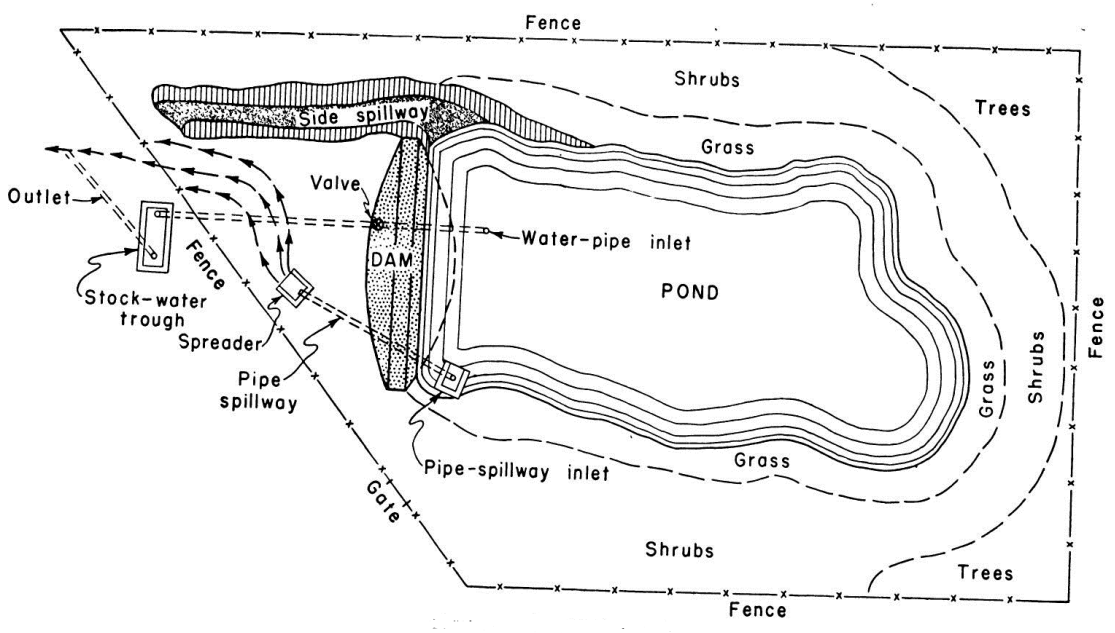


Fig. Typical layout of a farm pond

In arid and semi-arid regions, rains are sometimes received in heavy down pours resulting in runoff. The runoff event ranges from 4 to 8 during the rainy season in arid and semi-arid region. The percentage of runoff ranges from 10 to 30% of total rainfall. The size of the farm

pond depends on the rainfall, slope of the soil and catchment area. The dimensions may be in the range of 10×10 m × 2.5 to 15 × 15 m × 3.5 m. The side slope 1.5:1 is considered sufficient. A silt trap is constructed with a width of slightly higher than the water course and depth of 0.5 to 1 m and with side slope of 1.5:1.

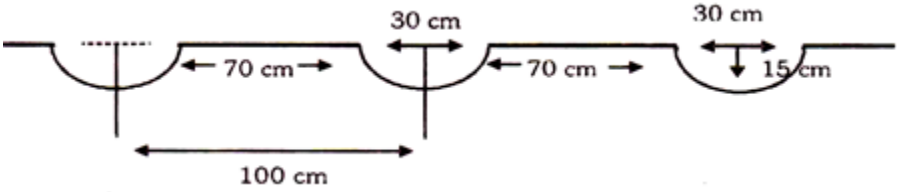
The different types of lining materials are soil-cement, red and black soils, cement-concrete, bricks, *kadapa* slabs, stone pitching, polythene sheet *etc*. In alluvial sandy loam to loamy sand soils of Gujarat and red sandy loams soils of Bangalore, a soil + cement (8:1) mixture is the best lining material.

Soil without sieving and cement in 6:1 ratio is very effective and cheap lining material for red sandy loam soils. In laterite silty clay loam soils of Ooty, medium black soils of Kota, bitumen was effective. Clay soil linings are generally the most economical for farm ponds. Evaporation losses can be reduced in farm ponds especially in arid regions by rubber or plastic floats.

Farm pond lined with soil+cement (6:1 ratio)

e) Inter-row water harvesting (IRWH)

Under this system, furrows of about 30-40 cm width (15 cm deep) are alternated by ridges of 60-70 cm).The furrows and ridges are formed with ridger at right angles to the slope. The water collected from the ridge is stored in furrow and the crop is benefitted by high moisture. The ridge may be left without ploughing while cultivation is done in the furrow only. The ridge provides partial shading of the furrow for 6 to 7 hours a day and reduces evaporation by 25-35% immediately after rain. It is, particularly, suitable for heavy textured soils. In light soils, crops are grown in furrows whereas in heavy soils, planting is usually on ridges to eliminate the problem of water-logging. In this system, the raindrops absorbed where it falls and does not flow out of the field. Generally it is practiced in areas having annual rainfall between 200-300 mm.



Raised and sunken bed system is the traditional system followed by the farmers of Chhattisgarh. Rice is grown in the sunken bed and soybean is sown on the raised bed, thereby meeting the water requirement of both the crops.

f) Inter-plot water harvesting (IPWH):

In this method, harvested water is diverted to the cropped area. It is suitable where rainfall is scanty (<500 mm) and even there is difficulty of harvesting a single crop. In this technique, runoff water is made available to cropped plots from adjacent bare plots either on one side or both sides. Adjacent plots are given certain slope to augment runoff towards cropped plot for improving profile moisture storage. Catchments with strips of 0.75 m width on either side of 3.0 m wide levelled area are desirable. Catchment to cultivated area ratio of 0.5 could be optimum for most crops.

Slopes on both sides of cropped area appear to be more appropriate for arid-fruit trees. The 1:1 cropped to non-cropped area on both side slopes gave better results followed by 1:1 and 1:2 one side slope

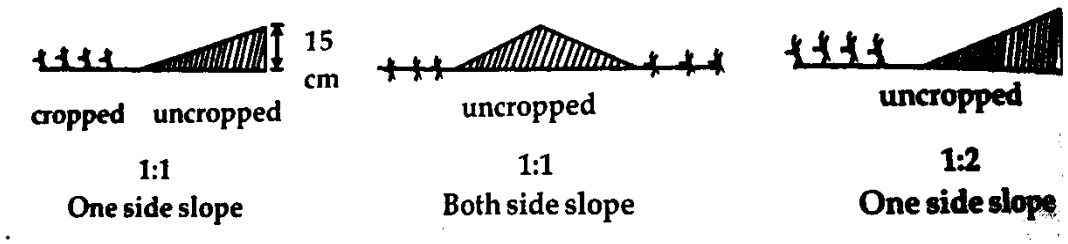


Fig. Inter-plot or micro-plot water harvesting for field crops

g) Broad Bed & Furrows (BBF):

When seedbed is made into wide beds alternated with furrows is called BBF. This practice has been recommended by ICRISAT for vertisols or black soils in high rainfall areas (>750 mm). The system involves creation of 90-150 cm wide, 15-20 cm high raised beds with 0.3 to 0.5% grades. The beds are separated by 50 cm wide furrows that drain into grassed waterways. The beds are stable for 2 to 4 years and conveniently adapted to planting of upland crops in rows spaced at 30, 45, 75 or 150 cm. The system tends to conserve soil, rainwater *in-situ* and improves crop yields and sustainability.

Advantages of Broad Bed & Furrow

- ✓ It helps in moisture storage.
- ✓ Safely dispose-off surplus surface runoff without causing erosion.
- ✓ Provide better drainage facilities.
- ✓ Facilitate dry seeding.
- ✓ It can accommodate a wide range of crop geometry *i.e.* close as well as wide row spacing.
- ✓ It is suitable for both sole cropping and intercropping systems.
- ✓ Sowing can be done with seed drills.

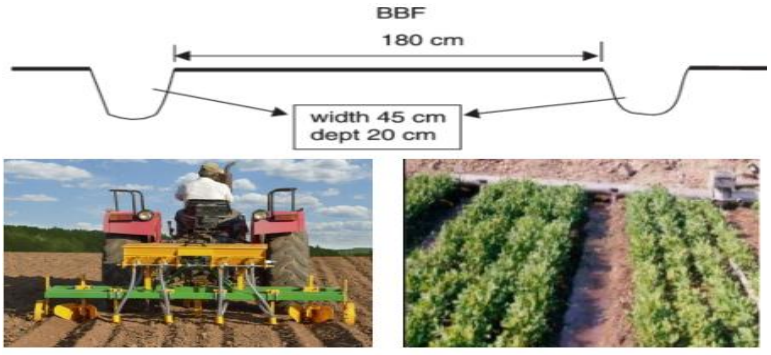


Fig. BBF design, planter and crops grown

7.7 Storage, management and use of harvested rainwater:

Storage is an important and integral part of any water harvesting system. In run-off farming, the storage reservoir will be the soil itself. But where water is to be used for domestic/supplemental irrigation purposes, a storage facility of some kind would be provided. There are three basic means of storing harvested water viz., excavated pits/ponds, masonry tanks and closed plastic storage bags. **At on-farm level, three approaches are being adopted in rainwater management viz.,**

a) Absorbed where it falls and does not flow out of the field.

a) Harvesting rainwater into dug out structures like farm ponds. To check the seepage losses from these ponds several sealing materials are used.
b) Recycling of stored water to donor area as supplemental /life-saving irrigation.

Supplemental / life-saving / protective irrigation:

The runoff collected from different water storage structures is of immense use for protecting the dryland crops from soil moisture stress during prolonged dry spells. In dry areas, water, not land is the most limiting resource for crop production. Maximizing the water productivity but not the yield per unit land is the better strategy for dry farming areas. Supplemental irrigation is a highly efficient practice for increasing productively of crops in arid regions. The response to supplemental irrigation varies with crops, time, depth & method of water and fertilizer application. *Irrespective of the stage of crop, irrigation is scheduled when soil moisture approaches PWP to save the crop. This is called life-saving irrigation.* The benefit of supplemental irrigation last for one week.

a) Quantity of irrigation water:

Crops differ in responding to amount of irrigation water by supplemented irrigation during dry spell.

Crops	Soil type	Critical stage	Quantity of water (mm)	Methods of application
Groundnut	Alfisols	Pod development	10 mm	Sprinkler / drip
Cotton	Vertisols	Boll formation	30 mm	Sprinkler / drip
Chickpea	Black soils	Flowering	30-40 mm	Sprinkler / drip
pigeonpea	Black soils	Pod development	20 mm	Drip

Life-saving irrigation can be provided near the row, covering about 20% of the cropped area, leaving 80% of inter-row zone. Pot watering, applying small quantity of water (around 250 ml) manually to each hill, is highly useful either for sowing or for transplanting in widely spaced crops like cotton, pigeonpea, castor, tomato, tobacco *etc*. Productivity of harvested water can be increased by applying small quantity of water to large areas than heavy irrigation to small area. If rains occur immediately after irrigation, there will be no impact of irrigation and in black soil, it may reduce yield.

b) Time of irrigation:

Unlike in irrigated agriculture, the critical stage concept does not suit well, as dry spell may reduce the growth and yield of crop at any stage. Vegetative stage is considered as, non-critical stage in irrigated agriculture but in arid regions, dry spell during vegetative stage prolongs the crop duration which may ultimately result in crop failure due to end season drought. Death of seedlings also cause reduction in yield due to dry spell in vegetative stage, therefore, the strategy for getting successful crop is providing small quality of water, if available, at any stage if the dry spell is >10 days in light soils and 15 days in heavy soils.

When critical stage for irrigation is to be chosen e.g. for *kharif* sorghum the flowering stage is most critical. In Tobacco, irrigation at 3 weeks before topping had the maximum pay off. For wheat and barley CRI stage is most critical stage. Long duration crops with deeper root systems that responded to higher levels of irrigation compared to short duration shallow rooted crops. Hence, it is important to wet the active root profile for best results.

c) Method of irrigation:

Surface methods of irrigation like check basin, basin, and furrow methods are not suitable for supplemental irrigation, mainly for three reasons: the rainfed lands are uneven, conveyance losses may go upto 30% and limited amount of water available for irrigation. Subsurface drip irrigation is very efficient for providing supplemental irrigation. The main drawback of micro-irrigation system is high initial cost of the system. Pot watering is another efficient method being used by the farmers for transplanting crops like tobacco, chilly, tomato *etc*.

d) Economics of water harvesting:

Water harvesting and use of water for sowing and supplemental irrigation increase the productivity of wheat and onion in mountainous watershed in Himachal Pradesh. The benefit-cost ratio ranges from 0.41 to 1.33 for water harvesting structures of different sizes with an estimated life of 25 and 40 years, respectively.

e) Water productivity:

The limited water productivity can be increased through timely sowing, use of improved varieties, STCR based fertilizer application, timely weeding and efficient irrigation system.

7.8 Efficient utilization of rainwater through soil management practices:

In rainfed agriculture, no other input can perhaps enhance the yield without effectively tackling of the rainfall aberration related sub-optimal moisture availability by managing both soil and rainwater.

The important practices are-

1. Avoiding and rectifying soil degradation

The major forms of soil degradation are water and wind erosion and deterioration of both physical (crusting, compaction, waterlogging) and chemical (Loss of organic matter, acidification, salinization, pollution etc.). Soil crusting and compaction in arable soils may be rectified by cultivation, Increasing soil organic matter content by incorporating organic manures and pond sediments improve the stable soil aggregates. Salinization can be controlled by leaching the surface salts with rainwater irrigation. In alkali soils, application of gypsum resulted in increased infiltration rate. The best method of avoiding waterlogging is by providing surface drainage.

2. Managing soil nutrients

If yields are to be maintained and the soils used to produce crops on a continuing basis, a method by which N, P, K and other nutrients can be replaced has to be adopted. If yields are to be maintained and the soils used to produce crops on a continuing basis, a method by which nitrogen, phosphorus, potassium and other nutrients can be replaced has to be found. Nitrogen can be fixed by natural and symbiotic fixation like *Rhizobia* in legumes, *Azolla* in rice and by using biofertilizers. Maintaining P, K and other nutrients normally requires the use of inorganic fertilisers. Organic manures (FYM, compost, green manures, farm wastes) should be used for balanced supply of essential nutrients as well as having additional beneficial effects on the soil.

3. Managing soil physical conditions

Conservation tillage with lighter machinery is the most effective way to alter and improve soil physical conditions. Under Indian conditions, satisfactory soil physical condition of rainfed soils can be maintained by deep ploughing once in 3 to 5 years,

application of bulky organic manures in alternate years and shallow inter-cultivation for weed management.

4. Improving soil moisture regime

There is no practical method by which available WHC of a soil can be increased. Addition of silt, clay, organic matter etc. increases field capacity and also raises wilting point leading to marginal increase in available WHC. If good soil is available, 1:1:1 ratio of soil, organic matter and sand make an excellent mixture. If the soil is sand, a mixture of 1:1:1 with soil, organic matter and clay soil is suitable. Never mix the heavy sticky clays in these soils. Contour farming and sub-surface barriers helps to reduce runoff as well as soil loss.

5. Managing soil organic matter and soil biological conditions

Organic matter is a direct contributor to crop nutrition of crops and its role in stabilising soil aggregates and supporting the soil organisms which create the pores through which air and water move, has already been mentioned. In addition, it hinders the formation of insoluble complexes of iron and aluminium with phosphate in acid soils thus avoiding reduction in the amount of phosphate available to plants. Activities that promote the accumulation and supply of organic matter, such as use of FYM, crop rotation, cover crops and those that reduce decomposition rates, such as reduced and zero tillage, leads to an increase in the organic matter content in the soil and its biological activities.

x-x-x-x-x

8 MANAGEMENT OF CROPS IN RAINFED AREAS

Under rainfed conditions soil moisture is the most limiting factor for crop production. It is lost as evaporation from soil surface and as transpiration from the plant surfaces. The combined loss of moisture through these two processes is known as evapotranspiration.

Crop management practices under rainfed areas:

1. Efficient cropping systems

Cropping intensity in dryland agriculture is, generally 100%, implying that single crop is taken during the year. Cropping intensities of these areas can be increased through intercropping and sequential cropping by way of more efficient use of resources. Crops and cropping systems selected should match the length of crop growing season to avoid soil moisture stress. **Double cropping**, either by sequential cropping or relay cropping, is possible in regions with rainfall >900 mm, extended rainy season and high soil moisture storage capacity. Double cropping is also possible with rainwater harvesting in farm ponds. **Intercropping** of groundnut + castor (4:1) was pursued vigorously in Rajkot (Gujarat). Even at Solapur, leafy vegetables and some short duration beans are grown as intercrops during the rainy season.

Some dominant intercropping systems in different dry lands of India

Locations	Soil	Rainfall (mm)	intercropping	Row ratio
Anantapur	Alfisols	550	Groundnut + pigeonpea	7:1
Akola	Vertisols	825	Sorghum + pigeonpea	2:1
Rajkot	Vertisols	590	Groundnut + castor	4:1
Sholapur	Vertisols	560	Chickpea + safflower	3:1
Bangalore	Alfisols	890	Finger millet + pigeonpea	8:1

Potential cropping systems (CS) for dryland agriculture

Annual rainfall (mm)	Soil types	Water availability (days)	Potential suggested CS
350 - 600	Alfisols Aridisols Vertisols	< 140 < 140 < 140	Single kharif crop. Single crop either kharif or rabi. Single rabi crop.
600 - 750	Alfisols Vertisols Entisols	140 - 210	Double cropping with sufficient moisture conservation practices or intercropping
750 - 900	Entisols Vertisols Alfisols Inceptisols	> 210	Double cropping with moisture conservation and monitoring
> 900	Vertisols Inceptisols	> 210	Double cropping

2. Choice of crops and cultivars and crop substitution

Crops and varieties for drylands should have following characteristics:

- Plants with erect leaves and stem.
- Short duration and early vigour.
- Deep root system with ramified roots.
- Dwarf and moderate tillering in case of tillering crops and varieties.
- Resistance/tolerance to biotic stresses.
- Lesser period between flowering and maturity so that the grain filling is least affected by adverse weather.
- Resistance/ tolerance to abiotic stresses.
- Low rate of transpiration.
- Less sensitive to photoperiod.
- Wider adaptability.

Traditional cultivars are of longer duration, photosensitive, inefficient users of soil moisture and often have poor response to PoP. The guiding principle of choice of crops, varieties and cropping systems for dry lands should be their suitability to vagaries of monsoon. It is imperative to select crops and varieties, which possess wider adaptability, shorter duration and evade or tolerate rainfall vagaries by virtue of their ability to maintain high internal water content with deep root system and less transpiration. Such crops and cultivars should be substituted with productive crops and cultivars.

Pulses and oilseed crops perform better than cereals if the sowings are delayed during *kharif*. Among the pulse crops, cluster bean, moth bean and horse gram are better choice for low rainfall areas relative to other *kharif* pulses. Among oilseed crops, castor and sunflower perform better than groundnut under conditions of delayed sowing. For crops on receding soil moisture during *rabi*, chickpea and lentil are preferred over peas and French bean. In the rapeseed-mustard group of crops, taramira is the best choice for light soil with low moisture storage capacity, followed by Indian mustard. Among the *kharif* cereals, coarse cereals (millets and sorghum) are better choice over maize and rice, similarly, in *rabi*, barley does well under conserved soil moisture than wheat. Among the millets, *setaria* (kodra) is most suited for late sown condition without any serious effect on productivity.

3. Land preparation

Tillage is a well-known soil and water conservation practice which makes soil surface more permeable to increase infiltration rate, which in turn reduces runoff, soil and nutrient losses and enhance crop yields. Deep tillage in problem soils promotes better root system development and helps in higher yields during low rainfall years, leading to more efficient use of sub-soil resources. Off-season or pre-monsoon tillage also has a marked impact on weed control and rainwater intake. All the cultural practices should be done across the slope (contour cultivation) to reduce soil and water loss. By ploughing and sowing across the slope, each ridge of plough furrow and each row of the crop act as obstruction to the runoff water.

4. Early sowing of crops in the season

It is an established fact that early sowing alone contributes to around 63% of the final crop yield. Early sowing leads to optimum yield due to efficient use of growth resources besides minimizing the incidence of pests and diseases. However, the problem is that how to sow the crop early in the season when the onset of monsoon is delayed. The practical solution to this problem appears to be land preparation for early/timely seeding, taking advantage of

summer showers. Taking advantage of these summer showers, the land can be prepared for taking advantage of the early monsoon rains.

In some regions, where heavy clay soils dominate, sowing after rains is impossible due to high stickiness of soil. As such, sowing may be done in dry soil, 2-3 weeks before the onset of monsoon (**dry seeding**). For sorghum on black soils, dry seeding is recommended at 1-2 weeks before onset of monsoon with depth of sowing at 5 cm and seed hardening with potassium di-hydrogen phosphate or potassium chloride. For cotton on black soils, dry seeding is recommended at 2-4 weeks before commencement of monsoon, with a sowing depth of 5 cm and seed hardening with CCC (500 ppm) or potassium chloride or 2% DAP.

5. Planting patterns and plant densities

Crop geometry refers to the arrangement of plant population (intra and inter-row spacing) in the field. Choosing the optimum plant population and width of row spacing continues to be one of the most difficult challenges for dryland farmers. At too densities, crop yields are reduced because too much of soil water is used up to vegetative growth early in the season; too low densities do not effectively exploit available moisture.

Recommendations are frequently made that do not differentiate between crop grown on stored moisture (Sept.-Oct. to Jan.-Feb.) and those grown during rainy season (June-July to Oct.-Nov.). For crops grown during rainy season, the usual recommendation is to increase the distance between plants within the row, to adjust to a low moisture supply.

6. Managing soil crust problems

Soil crusts are dry, thin and hard soil surface layers that develop due to the action of rain drop or irrigation water. On subsequent drying, it results in the development of continuous layer of closely packed soil particles. Soil crusts often hinder the emergence of seedlings and hence establishment of crop stand. Management practices to overcome crust problems include:

- Shallow and dense sowing.
- Dragging heavy thorny branches on crusted soil surface.
- Loosening the crusted surface by using spike-tooth harrow.
- Mulching.
- Light blade harrowing 2-3 days after rain.
- Planting on shallow furrows and on sides of ridge

7. Minimizing Evaporation losses

There are three principles of evaporation control under field conditions.

a. Decreasing the turbulent transfer of water vapor to the atmosphere by growing plants, raising wind breaks, straw mulches etc.,

b. Decreasing capillary conductivity by rapid drying of the surface soil layers.

c. Decreasing the capillary flow and moisture holding capacity of the surface soil layers.

For evaporation control, mostly mulches are used.

7.1 Mulches

Mulch is any covering material applied on the soil surface to reduce evaporation losses. This material may be grown and maintained in place, or any material grown and modified before placement or any material processed or manufactured and transported before placement. **or**

Mulch is any material (crop residues, leaves, bark, manure, paper, plastic films, petroleum products, gravel, coal etc.) used to cover the soil surface. Mulches are used for various reasons but water conservation and erosion controls are undoubtedly the most important for agriculture in dry lands.

7.1.2 Types of mulches

Based on the material used for mulching, mulches can be classified into following categories:

a. Organic mulches: In this, crop residues of cereals and pulses, straw or stalks of cotton, pigeonpea, rapeseed-mustard etc or stubbles of the crops such as maize, sorghum, sugarcane including roots or husks of the seed of various crops or saw dust are left on the soil surface or spread on the soil surface. Use of such materials as mulches help in soil and moisture conservation, enhances nutrient availability; reduce soil crusting, soil salinity control, soil structure improvement, crop quality control, weed control and moderate soil temperature.

b. Soil mulch: In soil mulching, a thin layer of loose soil surface that can be created by frequently stirring the soil with surface tillage implements like *danthis, guntakas* (blade harrows) etc. Surface mulch of dry soil of about 5 to 8 cm depth is created by stirring the surface soil to turn it into fine dust particles. By adopting this practice, some amount of moisture is lost from the upper layer. After the preliminary loss of moisture, the soil mulch effectively controls further evaporation from sub-soil by breaking the capillaries continuity. The soil mulch also prevents deep cracks in soils (especially black soils) by reducing the direct action of atmosphere and hence evaporation is also reduced. The repeated inter-cultivations done in *rabi* crops even in the absence of weeds help in reducing evaporation losses. This system of mulching is highly suitable for moisture conservation in medium to heavy texture soils, which tend to shrink and crack deeply on drying. Among the different mulches soil mulch is the cheapest.

c. Dust mulching*:* The cracks are filled and covered by the loose layer of dust mulch. It is used as a mid-season correction measure for moisture conservation.

d. Straw and stubble mulch: Straw and other crop residues like stubbles, groundnut shells, cotton stalks etc; can be used as mulches on soil surface for moisture conservation. Straw mulches reduce both the amount of energy absorbed by the soil and its movement above the soil and hence reduce evaporation. However, the availability of adequate crop residues is a problem for use as mulches.

e. Chemical mulches:

In chemical mulching, aluminum foils, plastic, polythene sheets etc. are spread on the soil surface to moderate soil temperature for controlling weeds, to optimise temperature for germination of seeds and to induce runoff of rainwater for ex-situ water conservation and harvesting. Beside this, some chemicals such as hexadecanol (a long chain alcohol) when mixed in the top 6 to 7 mm soil layer, results in a significant reduction of about 40% evaporation. The surface layer of a treated soil dries out more rapidly than that of untreated soil, creating a diffusional layer to evaporation.

f. Plastic mulches: Plastic mulches are very effective as mulches for evaporation control provided cost is not a limiting factor. The plastic mulches may be either white or black. Black

plastic mulches will absorb the solar radiation and enhance the soil temperature for hastening the germination of winter crops like wheat; barley etc., White plastic mulches will reflect the incident radiation and reduce evaporation of soil moisture.

g. Vertical mulching: In heavy black soils, where infiltration of rainwater is a problem, vertical mulching can be practiced keeping straw/ stalk/ stubbles as vertical mulch wherein trenches of 40 cm wide, 15 cm deep are dug at 2 to 4 m interval across slope and filled with stubbles or organic wastes to a height of 10 cm above soil surface. Around vertical mulching, soils remained porous for longer period, thus maintains high rate of infiltration during the rainy season. Vertical mulching has been found to enhance available soil moisture by 4 to 5 cm. Runoff is checked, collected in the shallow trenches and redistributed to adjoining soil layers and infiltration is increased in black soils.

h. Live mulching: Is the term used to describe the covering of soil surface through the plant canopy in intercropping system. Eg. Sorghum + forage cowpea, sorghum + sword bean

i. Pebble mulch: Where small pebbles like stone are placed on the soil surface. This mulching will be successful in dryland fruit tree culture. The pebbles placed on the basins of trees not only reduce evaporation but also facilitate infiltration of rain water into the basin.

Mulching is more advantageous during *rabi*/summer months than in *kharif* season. Organic mulches particularly under receding soil moisture conditions increase crop growth by conserving soil moisture.

7.1.3 Effect of mulches on soil properties

1. **Soil structure**: Surface mulches reduce the impact of falling raindrops, thus reducing dispersion and sealing of soil pores leading to crust formation. Hence the soil structure is protected. The mulches also improve soil structure due to decomposition of mulch.
2. **Soil salinity**: Under dry land conditions due to limited precipitation, soluble salts move only to a limited depth and readily return to the surface as the soil water evaporates. Due to salt accumulation in surface layers the germination and seedling establishment may be adversely affected. Hence, mulches will reduce soil salinity problem by increasing infiltration and reducing evaporation.
3. **Soil water**: The soil moisture content is improved by induced infiltration, reduced evaporation and reduced transpiration by weeds. Surface mulches also obstruct the free exchange of water vapor from soil surface into the atmosphere and hence increase soil water content.
4. **Soil temperature**: The effects of mulches on soil temperature are highly variable and depend up on the type of mulch material. White or reflective types of plastic mulches generally decrease soil temperature, while black plastic mulches may increase soil temperature. Crop residues moderate temperature by decreasing it in summer and by increasing in winter season. This is due to combined effect of radiation interception and evaporative cooling. The sugarcane trash mulch will enhance the germination of sugarcane setts during summer by temperature reduction.
5. **Soil erosion**: The ease by which soil particles are moved by wind and water is related to size of soil particles and wind and water velocity. The particles of size greater than 0.84 mm in diameter are generally not eroded by wind but they are easily eroded by water.

The mulches reduce the direct impact of falling raindrops on soil, thereby preventing soil dispersion and consequent sealing of soil pores leading to reduced soil erosion.

Loss of soil moisture through evaporation from soil surface and through transpiration from plant surfaces can be minimised by using mulches and antitranspirants.

8. Reducing losses due to transpiration

Nearly 99% of water absorbed by the plant is lost in transpiration. Hence transpiration reduction is needed for maintaining favorable water balance in the plants. Transpiration has become unavoidable evil as the stomata, which allow CO_2 exchange also allows water vapour transfer into the atmosphere.

There are four principles of transpiration control

a. By increasing leaf resistance to water vapor transfer by application of materials, which tend to close or cover stomata (ex: both stomatal closing and film forming type of antitranspirants).

b. By reducing amount of energy absorbed by leaf surface (Eg: leaf reflectants)

c. By reducing top growth of plants (Eg: Growth retardants)

d. By increasing air resistance to water vapor transfer by shelter belts/ wind breaks

The transpiration losses can be controlled by use of **Antitranspirants**, use of **Wind Breaks/Shelter Belts** and **Efficient Weed Control.**

8.1 Antitranspirants

Any material that is applied to transpiring plant surfaces with the aim of reducing or inhibiting water loss from plant surface is called antitranspirants. The antitranspirants are also known as transpiration suppressants. The best antitranspirants reduce transpiration losses up to 30-40%. The possibility of reducing plant transpiration by chemical without reducing photosynthesis is of great practical importance in arid and semi-arid regions. Where crop production is limited by water scarcity, the maintenance of favourable water balances in plants is must. However, the potential use of antitranspirants is not restricted to water conservation.

8.1.1 There are four principles of transpiration control:

1. By increasing leaf resistance to water vapour transfer by application of materials which tend to close or cover stomata. Both stomatal closing and film forming type of antitranspirants are used for this purpose.
2. By reducing amount of energy absorbed by leaf surface (leaf reflectants).
3. By reducing top growth of plants (growth retardants).
4. By increasing air resistance to water vapour transfer by shelterbelts/ windbreaks

8.1.2 There are four types of antitranspirants.

a. Stomatal closing type: Transpiration mostly occurs through stomata on the leaf surface. Some fungicides like PMA (phenyl mercuric acetate) and herbicides like atrazine in low concentrations serve as antitranspirants by closing of stomata. PMA is known to inhibit mesophyll photosynthesis. Though the success was reported from glasshouse studies, their effectiveness under field conditions is limited.

b. Film forming type: The plastic and waxy materials, which form a thin film on the leaf surface, retard the escape of water due to formation of physical barrier. The success of

these chemicals is limited since they also reduce photosynthesis. The desirable characteristics of film forming type of antitranspirants are: they should form a thin layer, they should be more resistant to the passage of water vapour than carbon dioxide and the film should maintain continuity and should not break. These film forming antitranspirants may be of either thin film or thick film.

Thin film forming type: Hexadeconol

Thick film forming type: Mobileaf, Polythene S-60

c. Leaf reflectant type: These are the white materials, which form a coating on the leaves and increase leaf reflectance (albedo). By reflecting the radiation they reduce leaf temperatures and vapour pressure gradient from leaf to atmosphere and hence reduces transpiration. About 5% of kaolin spray reduces the leaf temperature by 3- 4°C and decrease in transpiration by 22 to 28 per cent. Celite and hydrated lime are also used as reflectant type of anti transpirants.

d. Growth retardant type: These chemicals reduce shoot growth and increase root growth and thus enable the plants to reduce transpiring surface and resist drought conditions. They increase root/shoot ratio. Eg : Cycocel – (2-chloroethyl) Trimethyl ammonium chloride (CCC), Phosphon–D, Maleic Hydrazide (MH)

Antitranspirants generally reduce photosynthesis. Therefore, their use is limited to save the crop from death under severe moisture stress. If crop survives, it can utilize the rainfall that is received subsequently. Antitranspirants are also useful for reducing the transplantation shock of nursery plants. They have some practical use in nurseries and horticultural crops. Waxy materials are used for reducing post-harvest shrinkage of fruits.

Types of important antitranspirants

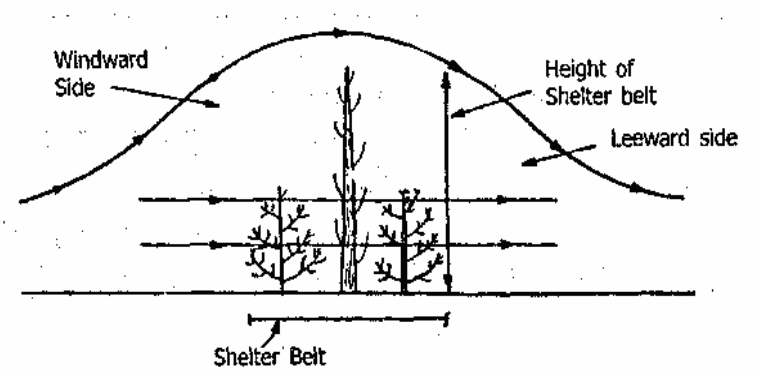
Stomatal closing type	Film forming type	Reflectant type	Plant growth regulators (PGRs)
• *Herbicides*: 2,4-D, Phosphon-D, Atrazine • *Fungicide*: PMA • *Metabolic-inhibitors*: Hydroxy sulfonates, potassium metabisulphite • *Growth hormones*: ABA, TIBA, CCC, ethrel, succinic acid, ascorbic acid	• Mobileaf • Hexadecon ol • Silicone • Waxol	• Kaoline • China clay • $CaCO_3$ • Celite • Lime water	• CCC • Mepiquat chloride • Cvtokinins • Salicylic acid • Brassinolide • Ascorbic acid

8.2 Use of wind breaks and shelterbelts:

Wind breaks are any structures that obstruct wind flow and reduce wind speed while shelterbelts are rows of trees planted for protection of crops against desiccating wind, reduce soil erosion and create a suitable micro-climate. Generally, shelterbelts give protection from desiccating winds to the extent of 5-10 times their height on windward side and upto 30 times on leeward side. A conical cross-section of windbreaks will provide the best protection from the winds. A conical cross-section of windbreaks will provide the best protection from the winds.

The direction from which wind is blowing is called windward side and direction to which wind is blowing is called leeward side.

Shelterbelts are planted across the direction of wind. They do not obstruct the wind flow completely. Depending upon their porosity, certain amount of wind passes through the shelterbelts while the rest deflects and crosses over the shelterbelts. It thus reduces wind speed without causing turbulence.



The protection offered by the shelterbelts is dependent on the height of central tree row in the shelterbelts.

Generally, shelterbelts give protection from desiccating winds to the extent of 5 to 10 times their height on windward side and up to 30 times on leeward side. Due to reduction in wind speed, evaporation losses are reduced and more water is available for plants. The beneficial effect of shelterbelts is seen more clearly in drought years. In addition, shelterbelts reduce wind erosion.

8.3 Effective weed control:

Weeds transpire frequently greater amount of water per unit of dry matter production than the crop plants. Therefore controlling weeds especially at early stages of crop growth will be most effective means of increasing the amount of water available for crops. This is the most useful method to reduce transpiration losses.

Weed management can be achieved through judicious management using good crop agronomy and a variety of weed management strategies. Weed competition in crop field is invariably severe in early stages of crop growth than at later stages. Generally, in a crop of 100 days duration, the first 35 DAS should be maintained weed free for optimum yield. In general, crops must be maintained weed free during the first one-third period of life cycle. The IWM combines different agronomic practices, mechanical, biological and herbicides use to manage weeds, so that the reliance on any one weed control technique is reduced.

9. Nutrient management

Indian dryland are not only thirsty but also hungry. Studies on the extent of nutrient deficiencies indicated that dryland soils are universally deficient in N, medium in P and high in K content. The stained crop production on these soils requites regular nutrient inputs through chemical fertilisers and organic manures to replenish soil nutrient reserves depleted by crops. The quantum of nutrients available for recycling via crop residues and animal manures is grossly inadequate to compensate for the amounts removed.

Following are the salient findings on fertiliser use in dryland agriculture:

1. Soils of dry regions are deficient in N in all soils, P in some soils, K is limited and Zn and Fe are sporadically. Most economical responses were with low rates of 25-30 kg N ha^{-1}. On heavy black soils, crops respond to about 30 kg P_2O_5 ha^{-1}. Legumes in cropping system contribute up to 25 kg N ha^{-1}.

2. Response of post-rainy season crops to fertilisers will depend on stored moisture in the profile and hence should be band placed in soil as basal application.
3. For *kharif* crops, N can be applied in splits depending on rainfall. Second split may be avoided if the soil moisture is not adequate for top dressing in time. Legumes are more responsive to P fertilisation.
4. Balanced fertiliser use resulted in yield advantage during normal rainfall year.

Thus, IPNS approach has come to play a key role in these areas. IPNS involves judicious and combined use of fertilisers, bio-fertilisers, organic manures and growing of legumes in the cropping systems. IPNS also encompasses balanced fertilisation and SSNM. In case of Zn deficiency, 30 kg of zinc sulphate is applied once in three years.

10. Mid-season corrections

Aberrant weather like late onset of monsoon, dry spell immediately after sowing, prolonged breaks during the crop period and early withdrawal of monsoon are common features of rainfed agriculture. The success of the implementable recommendations, largely, depends on the severity of soil moisture stress and stage of crop growth at which the crop is subjected to soil moisture stress. To boost production some practices are adopted as per the situation exists like-

Late onset of monsoon	:	Adopt dry seeding, transplantation and alternate cropping systems
Dry spell immediately after sowing	:	Maintain optimum plant stand and crop substitution
Breaks during the crop period	:	Intercropping for risk distribution, reducing the crop stand by thinning, rationing, mulching.
Early withdrawal of monsoon	:	Reduce plant population depending on the level of stored soil moisture, surface mulching with organic residues at 5 t/ha to minimise evaporation losses, protective irrigation at moisture sensitive stages, if possible, increasing frequency of inter-cultivation and stripping of leaves and use of antitranspirants to control moisture loss temporarily.

11. Alternate land use systems

Choice of land use systems viz., mono-cropping, double cropping, mixed cropping, mixed farming, agri-horticulture and silvi-pastoral should be practiced depending upon the rainfall, soil type and other climatic conditions.

12. Protective irrigation to crops from harvested rainwater is the best way to save crops.

x-x-x-x-x

9 CONTIGENT CROP PLANNING FOR ABBERANT WEATHER CONDITIONS

Rainfall behavior in dry farming areas is erratic and uncertain. The deviations in rainfall behavior include delayed onset, early withdrawal and intermediary dry spells during rainy season. The adverse effect of these rainfall aberrations on crop growth vary with the degree of deviation and the crop growth stage at which such deviations occur. Suitable manipulations in crop management practices are needed to minimize such adverse effects of abnormal rainfall behavior. These management decisions constitute contingency planning. Such management practices done after crop establishment and in the middle of growth are called midseason or midterm corrections.

Table 1 : Effect of Rainfall aberration on crop

Rainfall aberration	Effect on crops
Delay in onset of rainfall	Length of cropping season or cropping duration is reduced - crop sowing is delayed
Early withdrawal or cessation of rainfall	Moisture stress at maturity grain filling is affected (terminal stress)
Intermediate dry spells	
a. Immediately after sowing	Germination will be affected, plant population will be reduced
b. At vegetative phase	Affects stem elongation, leaf area expansion, branching or tillering
c. At flowering	Affects anthesis and pollination, grain / pod number is reduced
d. At ripening	Grain filling and grain size reduced

CONTINGENCY CROPPING

Contingency cropping is growing of a suitable crop in place of normally sown highly profitable crop of the region due to aberrant weather conditions. In dryland agriculture, contingency of growing another crop in place of normally grown crop arises due to delay in the onset of monsoon. Depending upon the date of receipt of rainfall, crops are selected. It is assumed that the rainfall for the subsequent period is normal and depending upon the economic status of the farmer, certain amount of risk is taken to get good profits if season is normal or better than normal.

Contingency cropping is highly location specific due to variation in amount and distribution of rainfall. Especially in arid regions, the spatial distribution of rainfall is highly variable. It is common to observe that rainfall received varies from field to field in the same location. Temperature gradually falls from August onwards reaching minimum in November and December. Contingency plan and midterm corrections vary with the type and time of occurrence of rainfall aberration.

Crops have to be selected with suitable crop duration to coincide with the length of the growing season. Generally short duration pulses like greengram, black gram and cowpea may suit the situation. However if the monsoon turns to be extraordinarily good, opportunity is lost if only short duration crops are sown. Farmers with economic strength and motivation for high profits with some amount of risk can go for crops of long duration. The long duration

crops with flexibility or elasticity in yield are more suitable. For example, pearl millet, and sorghum can be ratooned if monsoon extends. Sunflower can be introduced for higher profits with certain amount of risk. Crops like sorghum, pearl millet, can be grown for grain if monsoon extends and if not, fodder can be obtained.

Table 2 : Contingency Planning for Rainfall Abnormalities

Rainfall abnormality	Contingency plan and midterm correction
1. Delayed onset of rainfall	
a) Delay exceeding- 4 weeks	Alternate crops of short duration to be sown
Delay in South west monsoon Normal – June Delay – July Extreme Delay - August	 Groundnut Ragi/ Pearl millet Sama (Little millet / Ragi)
Delay in North east monsoon Normal – October Delay – Early November Extreme Delay - Late November	 Cotton / Sorghum Sunflower / Pearl millet / Ragi Coriander /Bengal gram
b) Delay of 1 to 2 weeks	Alternate varieties of short duration of the same crop e.g. Sorghum Co 19 (150 days), Co 25 (110 days), Red gram local (180 days), Co 5 (130 days)
2. Early withdrawal of rainfall	Antitranspirants spray, harvesting for fodder (millets), harvesting at physiological maturity
3. Intermediary dry spell	
a. Immediately after sowing	Gap filling with subsequent rains if stand reduction is less than 20%. Re-sowing if stand reduction is more than 20%, mulching between crop rows. Stirring soil surface to create dust mulch to reduce evaporation.
b. At vegetative phase	Mulching, antitranspirants spray, spraying potassium chloride, thinning of 33-50% population
c. At flowering	Antitranspirants spray, harvesting for fodder and ratooning with subsequent rains in millets (e.g. sorgum)
d. At ripening	Antitranspirants spray, harvesting for fodder and harvesting at physiological maturity

Crop planning for successful crop production under water scarcity and dry farming condition:

In low rainfall and water scarcity situations during *kharif*, the crops like Bajra, Castor and legumes crop like Tur, Moong, Black gram, Kidney bean, Guar and Cowpea. Crop planning for successful crop production under water scarcity and dry farming condition should be as under:

1. Bunding and leveling should be done to conserve the rain water in situ.
2. Sowing the crop at optimum time.
3. Tillage and sowing of the crop across the slope.
4. Use higher amount of organic manures like FYM, compost, vermicompost and cake.

5. Apply fertilizers at sowing under adequate soil moisture or as top dressing after irrigation.
6. Use drip irrigation in wide spaced crops and sprinkler irrigation in narrow spaced crops, if possible.
7. Inter culturing, weeding and crop protection measures should be done as and when required.
8. Adopt mixed and inter cropping systems.
9. Raise crop in strip cropping.
10. Create farm pond for life saving irrigation.

Table3 : Suggested Contingency Crop Planning For Some of the Dryland Regions of Gujarat

1. Latest Released varieties of major crops

The latest released varieties of major crops grown in Gujarat state are as under:

1	Paddy	:	Mahisagar, GAR 3, GR 14 and Gurjari
2	Maize	:	Gujarat Anand Yellow Maize Hybrid 1 and Gujarat Anand White Maize Hybrid 2 – early maturity hybrids for rainfed tribal areas
3	Bajra	:	GHB 558, GHB 744, GHB 905 and GHB 732
4	Tur	:	AGT 2 and GT 104
5	Moong	:	Gujarat Anand Moong 5, GM 6 and GM 7
6	Guar	:	Gujarat Guar 1 and Gujarat Guar 2
7	Cotton (Desi)	:	Anand Desi Cotton 1 (ADC 1), GADC 2, Gujarat Cotton 13 & 21 are recommended for *desi* cotton growing area of *Vagad* and *Bhal* regions
8	Cotton (Irrigated)	:	Gujarat Cotton Hybrid 6, Gujarat Cotton Hybrid 8, Gujarat Cotton Hybrid 10, Gujarat Cotton Hybrid 12 and GTHH 49
9	Tobacco	:	MRGTH 1, GABTH 2 and Gujarat Anand Bidi Tobacco 11 (GABT 11)
10	Fodder sorghum	:	COFS 29, GAFS 11 and GAFS 12
11	Fodder Bajra	:	Gujarat Anand Forage Bajra 4
12	Castor	:	Gujarat Castor Hybrid 7, Gujarat Castor Hybrid 8, Gujarat Castor Hybrid 9 and Gujarat Anand Castor 11
13	Sesame	:	Gujarat Till 3 & Gujarat Till 6, Purva
14	Soybean	:	NRC 37
15	Groundnut	:	GG 20, GJG 9, GJG 17 and GJG 22
16	Okra	:	GAO-5

3. Recommendation for late onset of monsoon

Generally, the period between 15th June to 15th September is considered as *kharif* season. However, it is required to change the crop planning in *kharif* season, if the rainfall pattern is

found uneven. If there is a late onset of monsoon, then select the crops and their verities as under:

1. **Onset of monsoon in the first week of July-** Groundnut varieties Gujarat Groundnut 2, Gujarat Groundnut 5 and Gujarat Groundnut 7 as well as cowpea variety Gujarat 1should be grown.
2. **If sufficient rainfall occurs during first fortnight of July -** Crops like bajra, moong, black gram, sesame, castor and tur should be grown.
3. **If sufficient rainfall occurs at the end of July –** Sesame (Purva 1) and forage sorghum variety Gundari should be grown.

4. Recommendation for regular monsoon:

Table 4 : Selection of the crop and their varieties

1	Cotton	:	High yielding *Bt* cotton varieties as well as Gujarat Hybrid 8 and Gujarat cotton 10,13,15,18 and 21. ADC 1 and 2 for rainfed cotton
2	Pearl millet	:	GHB 558, GHB 538, GHB 732, GHB 744 and GHB 905
3	Soybean	:	NRC 37
4	Groundnut	:	Spreading varieties
5	Castor	:	GCH 7, GCH 8, GCH 9 and Gujarat Anand Castor 11
6	Sesame	:	GT3, GT 4, GT 6 and Purva
7	Pigeon pea	:	AGT 2, GT 104 and Vaishali
8	Green gram	:	GAM5, GM 6, GM 7 and Meha
9	Mooth bean	:	Gujarat Mooth bean 1 and Baleshwar
10	Black gram	:	T 9 and Gujarat Black gram 1
11	Cowpea	:	Pusa falguni, Gujarat cowpea 1 and 2, AVCP 1
12	Sorghum (Fodder)	:	COFS 29, GAFS 11 and GAFS 12
13	Cluster bean	:	Gujarat Cluster bean 1 and Gujarat Cluster bean 2

5. Recommendations under long dry spell

There is a shortage of moisture in the soil, if the duration between two rainfall is extended even under normal on set on monsoon. If this period between rainfall is extended for longer time, than there is a partial or full failure of the crop. Under this situation crop planning should be done as under

1. Do interculturing and weeding. Keep crop weed free and do mulching.
2. When moisture stress prevails, thinning should be done. If more moisture stress prevails, remove alternate row and thin the plant in the field
3. Provide lifesaving irrigation to the crop if irrigation facility available
4. When sufficient rainfall received after dry spell, nitrogen fertilizer should be given as top dress to the crops except groundnut.
5. When crop failed due to long dry spell, after receiving sufficient rainfall farmers can grow hybrid pearl millet GHB 558, GHB 577.

6. Farmers should grow Sesame variety Purva 1 or Gujarat Til 1 or Castor variety GAUCH 1 and GAC 11. In addition farmers can also grow fodder sorghum or rajaka bajri.
7. Reduce the plants by harvesting the matured plants frequently, to save the conserved

6. **Recommendations when heavy rainfall occurs at the end of monsoon during August – September**

Many times during end of September or beginning of October late rainfall received. Under such situation following crop planning can be done.

1. For getting the benefits of good late rainfall sowing of fodder sorghum, short duration semi *rabi* and *rabi* crops *i.e.* castor, mustard, gram, safflower, fodder crops (maize/oat and lucerne) should be grown as relay crops between two rows of long duration crops i.e. cotton, tur and fennel.
2. Gram, mustard and fodder sorghum can be grown after harvesting of early maturing *Kharif* crops.

7. Recommendations made by Anand Agricultural University, Anand

1. The farmers willing to grow pigeon pea under organic farming system are recommended to grow variety BDN 2 with vermicompost 1 t/ha or FYM 5 t/ha.
2. In pigeon pea cv. AGT 2 recommended for fertilizer dose and additional 20 kg S/ha should be applied.
3. It is recommended that vegetable pigeon pea (GT 1) should be fertilized with 5 t FYM/ha.
4. For getting higher yield of soybean cv. NRC37, it is recommended to sow the crop at the onset of monsoon.
5. Farmers growing nematode resistant *bidi* tobacco variety ABT 10 are recommended to topping the plant at 18 leaves and give 4-5 irrigations at 15-20 days intervals.
6. The farmers growing vegetable cowpea (Vegetable cowpea 1) are recommended to fertilize with 5 t FYM/ha and 10:20:00 kg NPK/ha as basal dose. Sowing should be done at 45 X 45 cm after seed treatment with *Rhizobium* and PSB culture (Both @ 5 ml/kg seed).
7. Drilled paddy varieties DDR 97 and Ashoka 200 F are recommended for rainfed areas.
8. For rainfed areas, Gujarat Anand Yellow Maize Hybrid 1 as early variety and Gujarat Anand White Maize Hybrid 2 is recommended for unirrigated *kharif* cultivation.
9. For semi *rabi* castor cultivation, the sowing of GCH 7 variety should be done upto 10 to 25th September at spacing of 120 cm x 75 cm.
10. *Desi* cotton early maturity variety Anand *Desi* Cotton 1 and 2 is recommended for *Vagad* and *Bhal* regions.
11. It is not beneficial to apply phosphorus to *desi* cotton in North-Western Agro-climatic Zone areas. It is recommended to apply 100 % nitrogen from FYM (8 t/ha) or apply 75 % nitrogen from chemical fertilizer (30 kg/ha) + 25 % nitrogen from vermicompost (600 kg/ha).

12. The farmers of Middle Gujarat Agro-climatic Zone growing semi-*rabi* green gram are recommended to sow the crop during 3rd week of September at 30 cm spacing for obtaining higher yield and net return.
13. The farmers of *Bhal* and Coastal Agro-climatic Zone growing rainfed *desi* cotton are recommended to sow cotton variety Gujarat Cotton 21 at 60 x 30 cm spacing to get higher seed cotton yield.
14. The farmers of Middle Gujarat Agro-climatic Zone are advised to adopt semi *rabi* pearl millet by transplanting one month old seedlings of GHB 744 or GHB 732 during 20th to 30th September for getting higher grain and dry fodder yield as well as net return.

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10 Watershed Management

Introduction

Soil, water and vegetation are the most vital natural resources for the survival of the life on the biosphere. The prosperity and development of a nation depends, to a great extent on natural resources and their management. Today these resources are under tremendous stress due to ever increasing biotic pressure and mismanagement of resources. The optimal management of these natural resources with minimal adverse environmental impact is a desirable not only for sustainable development but also for human survival. For the efficient management, one has to look for suitable units of management so that these resources are handled and manages effectively, collectively and simultaneously. The soil, water and vegetation can be managed efficiently by the unit system. The watershed is an ideal unit for the natural resources management.

History of Watershed Development in India:

The earliest record of water management by manipulating the natural water regime in India is found in Inamgaon near Pune. During the rule of the Mauryan Dynasty (320 BC) the construction of water harvesting structure (WHS) and sustainable irrigated agriculture in semi-arid regions attained a high level of perfection. **The golden age of tank construction** in the Deccan Plateau was the reign of Chalukyas of Lakyan (973 to 1336 AD).

At national level, Soil Conservation Board was established in the Ministry of Food and Agriculture during the first five year plan (1951-56). Under the control of this Board, a chain of Soil Conservation Research, Demonstration and Training centres were established in the latter period of first plan and early period of second plan.

Location	Establishment Date	Problem area covered
Dehra Dun (HQ)	20th September, 1954	North-western Himalayan Region
Ootacamund	20th October, 1954	Southern hilly high rainfall region
Kota	19th October, 1954	Ravine problem on the banks of Chambal river
Bellary	20th October, 1954	Black soil region (semi-arid)
Vasad	11th May, 1955	Ravine problem on the banks of Mahi river (Gujarat)
Agra	1st October, 1957	Ravine problem on the banks of Yamuna river
Chandigarh	1st October, 1957	Sub-mountain tracts in NE region of India (Shiwalik hills)
Ibrahimpatnam	12th October, 1962	Red soil region (semi-arid)

Watershed development (WSD) projects in the country has been sponsored and implemented by GOI from early 1970s. Various WSD programmes were launched subsequently in various hydro-ecological regions which were primarily focused on soil conservation and water harvesting during 1980s and before. The GOI appointed a committee in 1994 under the chairmanship of **Prof. C.H. Hanumantha Rao.** The committee gave new guidelines for WSD programmes in 1995 and strongly emphasised on collective action and participation of primary stakeholders, local community, NGOs and *Panchayati Raj Institutions*.

Need for unification of multiplicity of watershed development programmes within the framework of a single national initiative was felt in 2001. A sub-committee constituted for this purpose suggested common guidelines for watershed development projects through Nation Authority for Development of Rainfed Areas (**NAFDORA**). This finally resulted in set up of National Rainfed Area Authority (**NRAA**) in November, 2006. The Common guidelines for WSD were released in 2008 (called ***Neeranchal*** guidelines) and revised in 2011 and 2013.

Chronology of watershed development (WSD) programmes and policies adopted in India are given below:

1973-74	:	Drought Prone Area Programme (DPAP)
1977-78	:	Desert Development Programme (DDP)
1987	:	National Research Centre for Agroforestry, Jhansi
1989-90	:	Integrated Wasteland Development Programme (IWDP)
1989	:	Integrated Afforestation and Eco-Development Scheme (IAEPS)
1990-91	:	National Watershed Development Project for Rainfed Areas (NWDPRA)
1992	:	Indo-German Watershed Development Programme (IGWDP)
1994	:	Guidelines for Watershed Development
1998	:	National Agricultural Technology Project (NATP)
1999-2000	:	Watershed Development Fund
2001	:	Common Guidelines for Watershed Development (Revised)
2002	:	National Afforestation Programme
2003	:	*Hariyali* Guidelines released
2005	:	Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS)
2006	:	Parthasarathy Committee report
2006	:	National Rainfed Area Authority (NRAA)
2008	:	Common Guidelines for WSD (called *Neeranchal*) released
2009	:	Integrated Watershed Management Programme (IWMP)
2011	:	Revised Common Guidelines for WSD were released
2013	:	Revisions added to 2008 *Neeranchal* Guidelines

What is Watershed?

All land everywhere is part of some watershed. It is a land area that captures rainfall and conveys the overland flow and runoff to an outlet in the main flow channel. The term ‘watershed’ strictly refers to the division separating one drainage basin from another. At present, the term ‘watershed’ is defined as ‘land area from which rainwater drains to a common point’. In this context, watershed is considered to be synonymous with ‘catchment’ and ‘drainage basin’. The word ‘watershed’ introduced in 1920 was used for the ‘water parting boundaries’. Watershed or catchment or drainage basin is that land area which drains to a common point called ‘outlet’. With respect to the outlet, the watershed consists all of the land area that collects water which flows to the outlet during a rainstorm. The watershed is also known as ridgeline in U.K.

In physical terms, a watershed refers to the area lying above a given drainage point. It may cover from <1 ha to thousands of hectares depending upon the point of reference. Rainwater from a few hectares of land may drain into a common small stream. The few hectares of land will, therefore, be the watershed area of that stream. This small stream runs into a larger stream. The land area drained by the small stream makes up the watershed of the larger stream into which they flow.

The watershed boundary is called the drainage divide. Precipitation received on the opposite side of a drainage divide does not contribute to the runoff of the particular adjoining watershed. Thus, *watershed is a geo-hydrological unit of delineated area from which the rainwater drains through a common outlet.* The people, animals and vegetation are part of the watershed community. All depends of the watershed and they, in turn, influence what happens on the topography of that area-whether for good or bad.

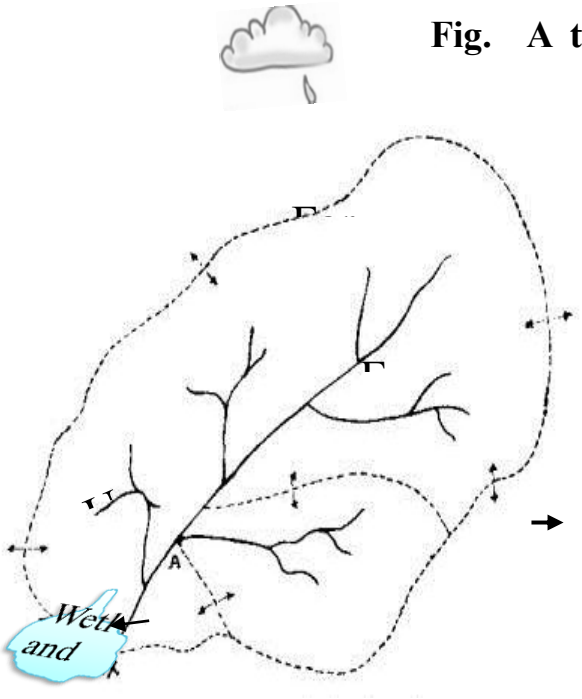

Fig. A typical watershed

Where, → Direction of water flow
A Minor ridgeline
B Major ridgeline
X Common outlet

Why Need of Watershed?

Since, watershed is a hydrological entity; natural resources management and their utilization are best attempted by taking it as a unit of development planning. Proper rainwater management, conservation, runoff control and development of water resources is essential for meeting water demands of domestic, drinking, irrigation and industrial needs is possible through it. Apart from development of agriculture, it may encourage areas of infrastructure development, energy, health, education and prosperity among the community. Management on watershed basis is now accepted as an essential feature for full and integrated development of any area. Hence, a watershed approach is needed for overall sustainable development.

Hierarchy of a watershed

Watershed is a smaller geographical unit of a river system. It is also a self-contained replica of the river system. The river system and its total catchment have a hierarchical relationship with its smaller watershed units. Generally, rainwater on a ridge is divided in the

direction of the slopes. The ridges acts as water divide, meaning that the rainwater diverges from here in two or more directions following the slope of the land. Within the area surrounded by the ridge (catchment area), the surface runoff of water converges to feed the drainage system. The rainfall in the watershed turns into surface and groundwater flows and passes through its drainage system, tending to exit the area through the lowest part of the trunk stream.

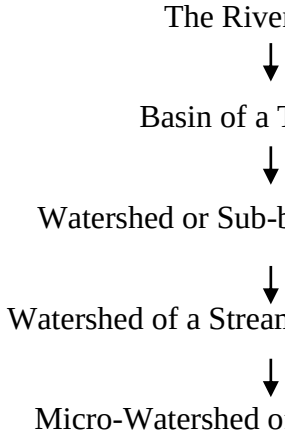

Fig. Watershed hierarchy and its river system

Small watersheds are drainage areas of a few thousands to a few tens of thousands of hectares. Larger drainage areas are usually called river basin. The micro-watersheds of agricultural fields may be considered as units which may range from a few hectares to hundreds of hectares. In an agricultural watershed, there may be several fields of farmers. The runoff collected from a watershed drains off into a natural water course. The movement of runoff depends on the topography of the land. Soil conservation measures adopted in a few fields in an isolated manner do not serve the purpose. Runoff, from fields where erosion control measures are not adopted, enters the fields situated at lower end of the watershed. It is necessary to adopt resource conservation measures over an entire watershed instead of individual fields. In addition, development is taken in the entire watershed area including wastelands, forests in addition to agricultural land from ridgeline to the outlet.

Delineation and Types of Watersheds:

The boundary of a watershed is defined by all points that shed water to the outlet. The delineation of a watershed is important for hydrologic design. A *Watershed Atlas of India* has been prepared by the Soil and Land Use Survey of India, 2018-19 which divides India into 6 major water resource regions, 37 river basins, 117 catchments, 588 sub-catchments and 3,854 watersheds, 49,618 sub-watersheds and 3,21,324 micro-watershed. There is both a macro level and micro level *delineation* (the action of indicating the exact position of a border or boundary).

Size of the watershed:

Questions are often asked on unit watershed size, particularly in the context of large-scale watershed development. However, a particular size of a watershed is depends on the objective of development. For major and medium irrigation projects, a watershed of thousands of km² in size has to be considered. At small storage structure on a farm, the watershed size may be only a few ha. However, the Government regards small catchments of 300–500 ha as a unit watershed. Large watersheds can be preferred in the plains valley areas

where pasture and forest development is the major objective. From the land management point of view, a convenient size of watershed may vary from 500 –1000 ha. On an average, the watershed size of 2,000 ha is considered reasonable for agricultural development. The most appropriate size of the *micro-watershed* for development at field level is around 500 hectares.

The technique adopted by SLUSI for classification of watersheds is tabulated below:

S. N.	Category of Hydrological Units	Size Range
Macro delineation		
1.	Regions	270 – 1130 lakh ha
2.	Basins	30 – 300 lakh ha
3.	Catchments	10 – 50 lakh ha
4.	Sub-catchments	2 – 10 lakh ha
5.	Watersheds	0.2 – 1.5 lakh ha
Micro delineation		
6.	Macro-watersheds	> 50,000 ha
7.	Sub-watersheds	10,000 – 50,000 ha
8.	Milli-watersheds	1,000 – 10,000 ha
9.	Micro-watersheds	100 – 1000 ha
10.	Mini-watersheds	1 – 100 ha

Problems of Watersheds:

Although, India has enormous potentiality to use water, the watershed areas of the country are suffered from various problems like:

a) ***Physical problems:*** Steep slopes, badlands, weak geological formations. Siltation of reservoirs, *etc*. can be found by observation of the existing maps. Problems such as heavy and intense rainfall, excessive runoff and strong winds can be identified from the weather and hydrological data.

b) ***Resource use problems:*** Problems such as shifting cultivation, excessive cropping, forest destruction, fire, over grazing, human and animal pressure, poor road construction and uncontrolled mining.

c) ***End problems:*** The final effects of watershed degradation *i.e.* soil erosion, landslides, heavy sedimentation, water pollution, floods and droughts.

c) ***Socio-economic and other problems:*** Serious-socio-economic problems can be major obstacles in carrying out watershed work. Any serious problem should be identified at the beginning of the stage. These may include land tenure, poverty, lack of education, low acceptance of innovations, seasonal shortage of labour *etc*.

Soil loss is a natural process and cannot be avoided completely but can be reduced to a maximum acceptable rate. A mean soil loss of 11 t/ha is generally accepted as appropriate. This value is as low as 2 t/ha where soils are shallow and highly erodible. It has been estimated that in India, about 5334 MT of soil is eroded annually. Out of which 29% is

permanently lost to the sea, 10% is deposited in reservoirs and 61% is transported from place to place.

What is Watershed Management?

Watershed management is the rational utilization of land, water and vegetation resources for optimum production with minimum hazards. It involves management of land surface and vegetation so as to conserve the soil and water for immediate use and long term benefits for the farmers and the society as a whole. In a watershed management system having favourable topography where improved land-use practices could be introduced easily and precipitation distribution is not much uneven or erratic, such a system may be termed as well-managed.

Watershed management is an integration of technologies within the natural boundaries of the drainage area for optimum development of land, water and plant recourses to meet the basic needs people in a sustained manner.

Watershed management may be defined as the process of formulating and carrying out a course of action involving manipulation of natural, agricultural and human resources of a watershed to provide resources that are desired by and suitable to the watershed community, but under the condition that soil and water resources are not adversely affected.

Concepts of Watershed Management:

It is not that watershed concept is not known, but many times the technical aspects of the development either not well understood or are badly applied. Since, no 'package of practices' of wade-scale application of watershed technologies exists.

The intensification of land use in the traditional agricultural setting is self-defeating because it is exploitive. The present agricultural practices greatly increase runoff and soil erosion, reduce groundwater recharge, cause floods and sedimentation of reservoirs *etc*. As a result, the cultivated land resource base is shrinking and its productive capacity is diminishing.

The management of watershed resources to produce more than one product is called "*multiple use concepts*". Most of the development activities are closely associated with the development and use of water resources. The main aim of multiple use management should be to manage natural resources for the most beneficial combinations in present and future uses. It is not necessary that every watershed is managed for all possible natural resource products simultaneously. In the '*watershed concept*' development is not confined to agricultural land alone but covers the entire watershed area.

Watershed management is a holistic development concept that encompasses land, water, agriculture, forestry and all related enterprises matters in relation to the people who inhabit the area and their socio-cultural system.

Watershed management envisages not only adoption of soil and water conservation measures, but all other measures for increasing productivity, production and economic return for the farmers in the watershed area. The object of watershed management is to meet the problems of land and water use not in terms of any one measure, but on the basis that all resources are interdependent and must be considered together.

As the entire process of agricultural development is depends on status of water resources. Hence, it is essential to have various developmental programmes on watershed basis in conjunction with basic soil and water conservation measures. The developmental activities need to be taken up from ridgeline to outlet point (ridge to valley).

Watershed management programme in drylands aimed at optimizing the integrated use of land, water and vegetation for providing an answer to alleviate drought, moderate floods, prevent soil erosion, improve water availability and increase food, fodder, fuel and fibre on sustained basis. The watershed is the natural framework for resource development in relation to crop production.

Objectives of Watershed Management:

There are various descriptions of the objectives of watershed management, mostly depending on the emphasis given in the proposed management programme. The main objective of its development and management is proper use of all the available recourses of watershed for optimum production with minimum hazards to natural resources. The overall objectives of a watershed management either single or in combinations are outlined as:

1. To control damaging runoff and soil erosion.
2. To protect, conserve, and improve the natural resources for efficient and sustained production.
3. To manage the watershed in order to minimize floods, droughts, landslides, etc.
4. To protect and enhance water resources, reducing silting of conservation structures and conserving rainwater.
5. To increase the groundwater recharge through in-*situ* conservation and water harvesting structures.
6. To rehabilitate the deteriorating lands.
7. To utilize the natural local resources for improving agriculture and allied occupations so as to improve the socio-economic conditions of the beneficiaries.

The objectives of watershed management programme can also be described in symbolic form of **POWER**. Here the letters symbolizes as:

P = Production of food-fodder-fuel-fruit-fibre-fish-milk on sustained basis
= Pollution control
= Prevention of floods

O = Over exploitation of resources minimization by controlling excessive biotic pressure
= Operational practicability of all on farm operations and follow up programmes

W = Water storage at convenient locations for different purposes
= Wild animal and indigenous plant life conservation at selected places

E = Erosion control
= Ecosystem safety
= Economic stability
= Employment generation

R = Recharge of groundwater
= Reduction of drought hazards
= Reduction of siltation in multipurpose reservoirs
= Recreation

Principles of Watershed Management:

The important principles of watershed management techniques are:

1. Utilizing the land according to its land capability classification (LCC)
2. Putting adequate vegetative cover on the soil surface for controlling soil erosion, mainly during the rainy season.
3. Conservation of maximum rainwater at the place where it falls on arable land by conservation practices.
4. Draining out excess water with safe velocity to avoid soil erosion and storing it in different rainwater harvesting structures for efficient future use.
5. Preventing gully formation and putting check dams and gully plugs at suitable intervals to control soil erosion and increase groundwater recharge.
6. Safe utilization of marginal lands through alternate land use systems.
7. Maximizing productivity per unit area, per unit time and per unit water.
8. Improving sustainability of ecosystem and socio-economic status of the inhabitants.

The principles of modern watershed management programmes are holistic and flexible, people-centred and participatory, multi-sectorial /multi-holders negotiations and dialog process, integration of multi-disciplinary sectors and effective collaboration and coordination.

The land is classified into 8 land capability classes, where class *I to IV* falls under suitable for cultivation and *V to VIII* not suitable for cultivation but exclusively suitable for other uses. The detailed 'LCC for Watershed Management' is presented in the book 'Fundamentals of Watershed Management Technology' (Singh and Poonia, 2003).

Steps for watershed management action plan:

Watershed management involves determination of alternative land management measures, for which it is essential that as much information as possible is obtained about the problems of soil, land, vegetation, water, animals and inhabitants involved in the watershed. In order to arrive at a practical solution to these problems, it is necessary to go through ten distinct steps:

1. Identification and selection of watershed.
2. Description of watershed.
3. Analysis of problems and identification of available solutions.
4. Designing the technology components.
5. Preparation of base maps of watershed.
6. Cost-benefit analysis to indicate estimated cost.
7. Fixing the time frame.
8. Monitoring and evaluation to assess the progress of the project.

9. On-farm research to identify solutions for site-specific problems.
10. Good organizational structure.

FACTORS AFFECTING WATERSHED MANAGEMENT

The factors affecting watershed management are divided into five groups:

1. Watershed characteristics
2. Climatic characteristics
3. Land use patterns
4. Social status of inability
5. Organization

1. Watershed Characteristics

Watershed characteristics influencing watershed management include size, shape, topography, slope, soils, vegetative cover and drainage density.

Size

Size of watershed determines the quantity of rainfall received, retained and surface runoff. A small watershed is pronounced by overland flow which is the main contributor to peak flow. The longer the watershed, the higher is the time of concentration while broader the watershed the smaller is the time of concentration. A large watershed has no overland flow, but channel flow is significant. Large watersheds are also affected by basin storage.

Shape

Shape contributes to the speed with which the runoff reaches the river. A long catchment area will take longer to drain than a circular catchment. Basin shape is not usually used directly in hydrologic design methods. A circular shaped watershed would results in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed having the outlet at one end of the major axis (having the same area as the circular watershed) would cause the runoff to spread out over time, thus producing a smaller flood peak than that of circular watershed.

Topography

Topographic configuration like slope, length, degree and uniformity of slope affect both disposal of water and soil loss. Time of concentration and infiltration of water are a function of degree and length of slope. Topography determines the speed with which the runoff will reach a river. If the land slope increases four times, the velocity of water flowing down the slope is doubled. When velocity is doubled, the erosive capacity increased four times. Clearly, rain that falls on steep mountainous areas will reach the primary river in the watershed faster than flat/slopping areas.

Slope

Watershed slope affects the momentum of runoff. Both watershed and channel slope may be of interest. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. It is usually calculated as the elevation difference between the end points of the main flow path divided by the length. Elevation difference may not necessarily be the maximum elevation difference within the watershed.

Soils

Soil of the watershed determines the amount of water that percolates, runoff and silt which will be washed down the valley. Erodibility and transportation of a soil depends on different soil characteristics**.**

Vegetative Cover

Vegetative cover is an important landscape element in any watershed. The type of vegetation and its extent of vegetation on watershed lands affect the infiltration, water retention, runoff production, erosion, sedimentation and the rate of evaporation. Vegetation intercepts rainfall, impedes overland flow and promotes infiltration. All of these factors reduce the quantity of runoff to streams. Vegetation binds and stabilizes soil, thereby reducing the potential for erosion. Vegetation also stabilizes stream banks and provides habitat for aquatic and terrestrial fauna. Vegetation functions to slow runoff and reduce soil compaction, allowing better percolation of rain into soil and groundwater recharge. In addition, the patterns, sizes and composition of the vegetation affect reduction of soil erosion.

Leaves and branches intercept the falling rain and reduce the effect of raindrop splash. The lesser the falling height of the raindrops, the lesser will be its energy to cause splash erosion. Vegetative litter builds up an organic surface that provides protection of the soil layer. Root systems also help to keep soil material stable from moving down slope.

Drainage density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well / poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow. Rivers that have a high drainage density will often have a more "flashy' hydrograph with a steep falling limb. High drainage density indicates a greater flood risk.

2. Climatic Characteristics

The greatest factor controlling stream flow is the amount of precipitation that falls in the watershed as rain or snow. However, not all precipitation that falls in a watershed flows out and a stream will often continue to flow where there is no direct runoff from recent precipitation.

Climate parameters like intensity and frequency of rainfall, temperature, humidity, wind velocity and direction affects watershed functioning. It regulates factors like soil properties and vegetation of the region. In the same way, the vegetation type of a region depends totally on its climate type. It is estimated that the total energy of the raindrops equals 100 HP on one ha land during the one cm rainfall for one hour. Thus, all climatic factors determine the amount of surface runoff and transportability of soil particles.

3. Land Use Pattern

Watersheds maintain the health of forests, fisheries, wetlands, coastal resources, agricultural landscapes, habitat and local communities. Protecting watersheds ensures sustainable environment that supports recreational activities and a healthy economy.

Type of land use, its extent and management are the key factors which affect watershed behaviour. Judicious land use by users is of vital importance to watershed management and functioning. Change of land use within the watershed, especially within the

variable source area, greatly affects the collection capacity and consequent runoff behaviour of the watershed. If the land use changes are local, then the impact of such changes is especially apparent in the storm hydrograph.

4. Social Status of Inability

Common contributors to water pollution are nutrients and sediment which typically enter stream systems after rainfall washes them off poorly managed fields. These types of pollutants are considered *nonpoint sources of pollution* because the exact point where the pollutants originated cannot be identified. Such pollutants remain a major issue for water ways because of the difficulty to control their sources hinders any attempt to limit the pollution. Point source pollution originates a specific point of contamination such as if a manure containment structure fails and its contents enter the drainage system.

5. Organization

The success of any WSD programme is depends on the type of organization. This is the crucial factor for watershed development. Land use questions can only be tackled in close collaboration with the owners and the local participatory inhabitants. To augment such interaction, the size of the watershed should not be too large or too small. People's participation is only effective when a watershed have an organized development agency.

COMPONENTS OF WATERSHED MANAGEMENT PROGRAMME

The main components of watershed management programmes include:

1. Soil and water conservation
2. Water harvesting
3. Crop management and
4. Alternate land use systems

1. Soil and water conservation measures:

Soil conservation is using and managing the land based on the capability of the land itself involving the application of the best management practices leading to profitable crop production without land degradation. The basic principle behind soil conservation measures is to minimize the velocity of surface runoff by transforming undulating topography into relatively flat surfaces which increases the opportunity time of the rainwater to infiltrate into the soil for future use by the crops.

Based on the nature and type of hydraulic barriers and their cost, the conservation measures in arable lands can be divided into three categories:

A. Permanent treatments (Hardware treatments):

Bunds, terraces and waterways are the permanent measures in watershed management project. These measures are provided to improve relief, physiography and drainage features of watershed, aimed at controlling soil erosion, regulating surface runoff and reducing peak flow rates. Contour bunds are suitable for low rainfall areas (<600 mm) and in permeable soils having slope up to 6%. Graded bunds are suitable for high rainfall areas (>600 mm) and for poor permeable soils having 2-6% slope. Bench terracing is suitable for soils having slopes 16-33%. Bench terraces reduce both slope length and degree of slope. At Ootacamund erosion rate decreased from 39 t/ha to less than 1.0 t/ha on 25% sloping land by bench terracing.

B. Semi-permanent treatments (medium software treatments):

These are usually inter-bund treatments where field sizes are large in conventionally bunded area. They are adopted to minimize the velocity of overland flow. It includes key-line bunds, strip levelling, live beds and vegetative. These measures may last for 2 to 5 years. In vegetative barriers, one or two barriers of close growing grasses or legumes along the bund and at mid length of slope can filter the runoff water or slow down over land flow. *Khus* grass (*Chrysopogon zizanioides)* is widely recommended as vegetative barrier.

C. Temporary treatments (short software treatments):

These are simple treatments for *in- situ* moisture conservation and needs renovation every year. Simple practices like contour farming, compartmental bunding, BBF, dead furrows, tillage and mulching have gained wide acceptance in the recent past.

Ridges and furrows: The field must be formed into ridges and furrows. Furrows of 30-45 cm width and 15-20 cm depth are formed across the slope. The furrows guide runoff water safely when rainfall intensity is high and avoid water stagnation. They collect and store water when rainfall intensity is less. It is suitable for medium deep to deep black soils and deep red soils. It can be practiced in wide row spaced crops like cotton, maize, chillies, tomato *etc*. It is not suitable for shallow red, shallow black and sandy soils.

Tied ridging: It is a modification of the ridge and furrow system, wherein; the ridges are connected or tied by a small bund at 2-3 m interval along the furrows to allow the rainwater collection in the furrows; which slowly percolated into the soil.

Dead furrows: At the time of sowing or immediately after sowing, deep furrows of 20 cm depth are formed at intervals of 6 to 8 rows of crops. No crop is raised in the furrow. The dead furrows can also be formed between two rows of the crop, before the start of heavy rains. The dead furrows increase the infiltration opportunity time.

Compartmental bunding: Small bunds of 15 cm width and 15 cm height are formed in both directions to divide the field into small basins or compartments of square or rectangular shape of 6×6 m to 10×10 m size using bund former. They are useful for temporary impounding of rain water which facilitates high infiltration resulting in high moisture storage in the soil. It is recommended for black soils with a slope of 0.5 to 1 per cent. Maize, sunflower, sorghum performs well in this type of bunding.

Scooping: Scooping the soil surface to form small depressions or basins help in retaining rain water on the surface for longer periods. They also reduce erosion by trapping eroding sediment and this practice can reduced runoff by 50% and soil loss by 3 to 8 t/ha.

Inter row/plot water harvesting: Water is drawn from part of a small catchment and used in lower portion for crop production.

Zing/ bench terracing: These are developed by A.W. Zing in USA. Zing terracing is practiced in low to medium rainfall areas in black soils with contour bunds. It is a method of land shaping where lower one third portion of the land adjacent to the contour is levelled to spread to the runoff water coming from the remaining two-third portion of the field. This rainfall multiplication technique ensures at least one good crop in one-third area even in low rainfall years. Usually during medium rainfall years water intensive crops (like paddy) are cultivated in the levelled portion (receiving area) while dry crops are cultivated in the unlevelled (donor) area.

2. Water harvesting in rainfed agricultural areas:

Runoff farming and rainwater harvesting agriculture are synonymous terms, which imply that farming is done in dry areas by means of runoff from a catchment. It is a process of collection of runoff water from treated or untreated land surfaces/catchments or roof tops and storing it in an open farm pond or closed water tanks/reservoirs or in the soil itself (*in situ* moisture storage) for irrigation or drinking purposes. Runoff farming is basically a water harvesting system specially designed to provide supplemental irrigation to crops, especially during periods of soil moisture stress. The rainwater harvested from catchment is used in command area.

3. Crop management in rainfed agricultural areas:

Location-specific package of practices for dryland crops have been developed by dryland research centres and SAUs for all the crops. The important crop management practices are:

a. Choice of crops	b. Land preparation	c. Contour cultivation
d. Strip cropping	e. Mulching	f. Cover crops
g. Effective weed control	h. Organic manures/ residues	i. IPNM
j. Cropping systems	k. Use of antitranspirants	l. Windbreaks/ shelterbelts

a. Choice of crops: Tall growing row crops (sorghum, maize, bajra etc.) are not effective in conserving soil as they expose majority of the soil, hence known as *erosion-permitting crops*. Whereas close growing crops (cowpea, peanut, greengram, blackgram etc.) protect the soil are known as erosion-resisting crops as they are very effective in reducing soil loss by minimising the impact of raindrop and acting as obstruction to runoff.

b. Land preparation: Tillage is a well-known soil and water conservation practice which makes soil surface more permeable to increase infiltration of water into the soil, which in turn reduces runoff, soil and nutrient losses and enhance crop yields. Tillage makes the soil surface permeable and thus, support water intake. **Deep tillage** (25-30 cm) assists in opening up of hard soil layers and faster penetration of rainwater. Deep tillage in problem soils promotes better root system development and helps in higher yields during low rainfall years. **Off-season tillage** has a marked impact on weed control and rainwater intake. **Conservation tillage**, which ensures at least 30% coverage of the soil surface with crop residue play very important role in organic carbon build up and soil and moisture conservation. Conservation tillage includes stubble mulch tillage, minimum tillage and zero tillage. Low intensity tillage favours consolidation of soils and imparts erosion resistance.

c. Contour cultivation: A line joining the points of equal elevation is called contour. All cultural practices such as ploughing, sowing, inter-cultivation etc. are done across the slope to reduce soil and water loss.

d. Strip cropping: It is a system of growing of few rows of *erosion-resisting crops* (ERC) and *erosion-permitting crops* (EPC) in alternate strips on contour (across the slope) with the objective of breaking long slopes to prevent soil loss and runoff. Close growing ERC reduce the transporting and eroding power of water (erosivity) by obstructing runoff and filtering sediment from runoff to retain in the field. The normal ratio of ERC and EPC is 1: 3. The

strip cropping is simple, cheap and effective soil conservation practice and can be adopted by the farmers.

It is divided into four types:

Contour strip cropping: When EP & ER crops are grown in alternate strips along the contours.

Field strip cropping: Alternate strips of EP and ER crops are raised across the general slope not necessarily on exact contour.

Wind strip cropping: When EP and ER crops are grown across the direction of the most prevailing wind irrespective of the contour.

Buffer strip cropping: This type of strip cropping is practiced in areas having steep slopes and badly eroded soils. Here strips of permanent cover crops (perennial legumes, grasses, shrubs) are alternated with field crops.

Strip widths of EP and ER crops at various slopes

Slope %	Width of EP strip (m)	Width of ER strip (m)
Up to 1	45	9
1 - 2	24	6
2 - 3	13.5	4.5

e. Mulching: Mulching of soil with available plant residues reduce soil loss considerably by protecting the soil from direct impact of raindrop and reducing the sediment carried with runoff. A minimum plant residue cover of 30% is necessary to keep runoff and soil loss within the acceptable limits. *Vertical mulching* reduces soil loss particularly in Vertisols by increasing infiltration. The types of mulching are dust mulch, straw/stubble mulch, plastic mulch, chemical mulch, live mulch, pebble mulch, etc.

f. Cover crops: Good ground cover by canopy gives the protection to the land like an umbrella and minimizes soil erosion. Besides conserving soil and moisture, the cover crops hold those soluble nutrients, which are lost by leaching, adds organic matter and control weeds. The legumes provide better cover and better protection. Among the legumes cowpea has been found to produce maximum canopy followed by horsegram, greengram. blackgram and dhaincha.

g. Effective weed control: In rainfed areas, limited generation of weeds occurs due to shorter period of water availability. However, their control is must. Weeds are removed in very early stage (before flowering) by repeated blade harrowing. Intercultivation is very common practice of weed control in rainfed areas.

h. Organic manures and residues: Organic manures, besides supplying nutrients improve soil physical conditions by way of soil aggregation. Improvement in soil aggregation improves water intake rate of soil leading to reduced runoff.

i. Integrated plant nutrient management (IPNM): Inadequate supply of plant nutrients and continuous use of inorganic fertilisers resulted in soil degradation. Sol health restoration should be the major in sustaining crop productivity in rainfed agriculture. Use of manures and

bio-fertilisers along with limited use of inorganic fertiliser appears ideal for restoring the degraded soils for sustained productivity of rainfed soils.

j. Cropping systems: Mono-cropping of EP crops accelerate soil and water loss year after year. Intercepting EP and ER crops or their rotation has been found effective for soil and water conservation. As the pulse crops are effective for soil conservation due to their smothering effect, they should be sown in time to develop adequate canopy by the time of peak rate of runoff. Intercropping is recommended in areas receiving rainfall in the range of 600-850mm/annum. Double cropping is highly suitable to areas receiving rainfall >900 mm and moisture storage capacity of 200 mm/m depth.

4. Alternate land use systems (ALUS)

To cope up with increasing population of both human and livestock and rising demand for food, fodder and fibre, more and more marginal and sub-marginal lands are brought under cultivation. These lands are unable to sustain productivity. Cultivating such lands leads to imbalances in the ecosystem. Hence, a pattern of land use that is different from the conventional can be described as an alternative land use system. When land is put under alternative production system to match its capability more appropriately to the new land use and achieve more sustainable biological and economic productivity on long term, it is known as alternative land use.

Advantages of alternative land use systems

1. Optimising resource use by enhancing biological productivity and profitability,
2. Conserving and enhancing the quality of resource base,
3. Integrating crops (arable and pastoral) and livestock,
4. Making agriculture less dependent on off-farm inputs,
5. Generating employment potential, and
6. Improving overall quality of farm life.

Depending upon component of farming systems, various types of land use can be integrated on watershed system mode. Alternate land use systems are applicable to all classes of land aiming at generation of assured income with minimum risk through efficient utilisation of available resources. Commonly known alternate land use systems are agroforestry, tree farming and ley farming.

5. Agroforestry:

Agroforestry is a collective name for a land use system in which woody perennials (trees/ shrubs) are deliberately mixed on the same land management unit as crop and/or animals either in some forms of spatial arrangement or in time sequence. Agroforestry based ALUSs reduces runoff erosivity and soil erodibility through dissipation of rainfall energy by canopy at low height, surface litter, obstructing overland flow, root binding and improving soil health. Satisfactory crop yield can be obtained when compatible species are grown and soil-water resources are sufficient to meet the water needs of both the species. Trees, crops and animals are the three basic sets of elements of components of an agroforestry. These are classified as:

1. Agri-silvicultural : Crops and trees including shrubs/vines/trees
2. Silvi-pastoral : Pastures, animals and trees

3. Agri-silvi-pastoral : Crops/pasture animals and trees
4. Agri-horticulture : Crops (short duration) and fruit species
5. Silvi-horticulture : Trees and fruit species
6. Silvi-horti pastoral : Trees/fruit species, animal and pastures

However, prolific seeding habit of component trees like *subabul* resulting in more weed growth and reduced crop yields; root and shade effects of trees on cultivated crops upto 20 m in case of *Acacia nilotica*; harbouring birds, pests and diseases; reduced scope of mechanisation, more labour intensive and allelopathic effects of trees on cultivated crops are the major disadvantages of the agroforestry based land management system.

6. Alley Cropping:

Alley cropping is broadly defined as the planting of rows of trees/ shrubs (single or multiple) at wide spacing, creating alleyways within which agricultural crops are produced. The shrub/tree rows are called *hedgerows* and the space between where the crops are grown are called *alleys*. Alley cropping is an agroforestry practice intended to place trees within agricultural cropland systems. The purpose is to enhance/ add income diversity (both long and short range), reduce wind and water erosion, improve crop production, improve utilisation of nutrients, improve wildlife habitat or aesthetics, and convert cropland to forest. Based on the objectives, three types of alley cropping systems are recognised:

1. Forage-alley cropping

In this system, both yield of crop and forage assume importance. The tree species suitable for hedge rows are *Leucaena leucocephala*, *Colliendra* and *Sesbania*. Pigeonpea or castor crops are suitable for growing in the alleys of *Leucaena*.

2. Forage-cum-mulch system

In this system, hedgerows are used for both forage and mulch. Loppings are used for mulching during the crop season and used as fodder during off season. Substantial increase in crop yields of sorghum, groundnut, greengram and blackgram have been observed at several places.

3. Forage-cum-pole system

Leucaena alleys are established at 5 m intervals along the contours. Hedgerows are established by direct seeding and topped every two months at 1 m height during crop season and every 4 months during the off-season. A *Leucaena* plant for every 2 m along hedgerows is allowed to grow into a pole.

7. Tree farming:

Trees can flourish and yield abundantly where arable crops are not profitable. Farmers of dry lands are inclined to tree farming because of labour cost, scarcity at peak periods of farm operations and frequent crop failure due to drought. Multipurpose tree species (MPTS) are those trees, which are purposely grown to provide more than one significant product or service function in the land use system in which they grow. On small farms, this, generally, means both wood and foliage use from the same tree. Their ability to provide fuel and timber, nitrogen, fodder, food, resins, fibre, medicines, shade etc. make them MPTS. For Gujarat plains and hills, *Prosopis cineraria* is the best MPTS followed by *Eucalyptus hybrid*, *Ailanthus excelsa*, *Dalbergia sissoo* and *Leucaena.*

8. Ley farming:

This system involves rotation of legume forages with cereals. A rotation system which includes pasture (ley) for grazing and conservation is called alternate husbandry or mixed farming. It is a low risk system for dry lands. Inclusion of *Stylosanthes hamata* (legume fodder) in rotation improved soil fertility besides increasing crop yields.

Recommended ALUS Options for Different Agroclimatic Conditions

Annual rainfall	Soil type/ depth	Land use systems	Suitable tree/grass/legume species
< 500	Shallow (0-0.30 m)	Tree farming	*Prosopis cineraria, P. juliflora, Acacia aneura, A. nilotica, A. tortilis, Pithecelliobium duice*
	Medium (0-0.45 m)	Pasture management	*Lasiurus sindicus* (light textured soils), *Cenchrus setigerus, Sehima nervosum, Stylosanthes scabra, Clitoria ternatea*
500 - 750 mm	Shallow (0-0.30 m)	Silvi-pastoral system	*Acacia nilotica, Colophosphermum mopane, Dalbergia sissoo, Hardwickia binata, Cassia sturti, Albizia amara, Leucaena leucocephala, Cenchrus ciliaris, C. setigerus, Dicanthium annulatum, Panicum antidotale, Stylosanthes hamata, Macroptillum atropurpureum.*
	Medium (0-0.45 m)	Horti-pastoral system	*Annona squamosa, Zizyphus mauritiana, Syzigium cuminil, Emblica officinalis, Tamarindus indica, Feronia limonia, Aegle marmelos, Cenchrus ciliaris, Panicum antidotale, Urchloa mosambicensis, Stylosanthes hamata, Macroptilum atropurpureum, Clitoria tenatea.*
> 750 mm	Shallow (0-0.30 m)	Ley farming / Silvi-pastoral system	3 years *Stylosanthes hamata* and 4th year arable crop (sorghum on heavier soils, pearl millet on lighter soils) Silvi-pastoral system as above.
	Medium (0.30-0.45 m)	Ley farming / Horti-pastoral system	Ley farming as above. *Mangifera indica, Achras zapota, Psidium guajava, Emblica officinalis, Stylosanthes hamata/ Macroptilium atropurpureum*
	Deep (>0.45 m)	Agri-silvi or Agri-horti system	*Acacia ferruginea, Prosopis cinneraria, Tectona grandis, Hardwickia binata, Dalbergia sissoo* + arable crops. *Mangifera indica, Achras zapota, Psidium guajava* + arable crops.

Integrated Watershed Management:

In dry farming areas, watershed approach provides an ideal means for integrated development. This approach will further the cause of sustainability which requires the best land and water use and ecological sustenance. There is need for a multi-pronged approach to maximize crop production and also ensuring stability in rural incomes. The various steps used in this are *in situ* moisture conservation, water harvesting and crop production; conjunctive use of rainwater; crop substitution with site-specific crop production techniques; afforestation and dryland horticulture, discouraging faulty practices, encouraging dairying, sericulture, cottage industries; custom-hire services for employment generation and training of inhabitants to develop a participatory model watershed.

Issues before Watershed Management Programmes: The major issues are-

1. Stakeholders were neither involved in selection of project ingredients nor encouraged others to participate in various project activities.
2. Benefits of watershed management accrued mainly to farming community where as the livelihood securities of the landless families have not been taken care.
3. The portfolio of alternate livelihood opportunities created for the beneficiaries could not cope with stress and shock and the primary stakeholders could not maintain activities after the completion of project period.
4. In majority of the cases sustainability had been causality mainly due to absence of primary stakeholders in project planning and implementation stages.

Planting and maintaining trees were considered noble acts. They were considered better than having sons, as has been said in Agnipuran (1000 BC)

दशक्रुप समावापी दशवापी समाहदः ।

दशहद समपुत्रौ दशपुत्र समातरुः ।।

Ten wells are equal to one tank, ten tanks are equal to one lake, ten lakes are equal to one son and ten sons are equal to one tree for giving Punya. In the Purans it is said

अपुत्रस्य पुत्रत्वं पाद्य़ा इह कुर्वते ।,

Which means for those who do not have sons; trees are like sons for them.

x-x-x-x-x

Glossary of Selected Terms

Accelerated erosion: Erosion much more rapid than normal, natural geological erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals.

Afforestation: Conversion of bare land into forest land by planting of forest trees. The planting of a forest crop on land that has not previously, or not recently, carried a forest crop.

Agroforestry system: A land-use system in which woody perennials (trees, shrubs, palms, bamboos) are deliberately used on the same land management unit as agricultural crops (woody or not), animals or both, either in some form of spatial arrangement or temporal sequence. In agroforestry systems there are both ecological and economic interactions between the different components.

Agroforestry: Any type of multiple cropping land-use that entails complementary relations between trees and agricultural crops.

Agrostology: The study of grasses.

Alley cropping: An agroforestry intercropping system in which species of shrubs or trees are planted at spacings relatively close within row and wide between row, to leave room for herbaceous cropping between, that is, in the 'alleys' (syn: hedgerow intercropping).

Aquifer: A saturated, permeable layer of sediment or rock that can transmit significant quantities of water under normal pressure conditions.

Arable land: Land that is capable of being cultivated and supporting agricultural production.

Arboriculture: A general term for the cultivation of trees.

Badland: A land type generally devoid of vegetation and broken by an intricate maze of narrow ravines, sharp crests, and pinnacles resulting from serious erosion of soft geologic materials. Most common in arid or semi-arid regions. A miscellaneous land type. Term used to describe a semi-arid landscape that has been influenced by heavy fluvial erosion. Characterized by deep ravines and gullies, shape ridges, and a generally barren surface.

Base flow: Stream discharge derived from effluent ground-water seepage.

Bed load: Portion of the stream load that is carried along the stream bed without being permanently suspend in the flowing water.

Bedrock: The solid rock underlying soils and the regolith in depths ranging from zero to several hundred metres.

Bench mark: A point of reference in elevation surveys.

Bench terrace: A shelf-like embankment of earth with a level top and steep or vertical down hill face, constructed along the contour of sloping land to control runoff and erosion.

Blowout: An excavation in areas of loose soil, usually sand produced by wind erosion.

Broad-base terrace: A ridge type terrace 25 to 50 cm high, and 4.5 to 9.0 m wide with gently sloping sides, a rounded crown, and a dish shaped channel along the upper side constructed to control erosion by diverting runoff along the contour at a non-scouring velocity. **It** may be level or have a grade toward one or both ends.

Buffer strips: Contour strips of grass or other erosion resisting vegetation between or below cultivated strips or fields.

Buffer zone: An area around a forest, national park, or any other conserved place that provides the local community with products that they would otherwise take from the forest, or that provides an opportunity to produce alternative products.

Bund: A barrier on the surface of the soil on sloping land to prevent runoff and soil erosion.

Carrying capacity: Amount of animal life, human life or industry that can be supported indefinitely with available resources on a given area. In wildlife management, the optimum population density that a given environment or range is capable of sustaining permanently.

Catchment area: The land surface on which rain falls. Sometimes called a 'water catchment'. When referring to particular streams or rivers, it is the land surface from which water (rain) flows into them, sometimes through tributaries (feeder streams).

Cavitation: Process of intense erosion due to the surface collapse of air bubbles found in constricted rapid flows of water. Causes the detachment of material from a surface.

Check dam: A small, low dam constructed in a gully or other water course to decrease the velocity of stream flow, for minimizing channel scour and promoting the deposition of eroded material. Usually built of inexpensive and temporary materials where dependence for ultimate protection in placed on vegetative cover.

Chiselling: The breaking or shattering of compacted soil or subsoil layers by use of a chisel.

Clear cutting: Strictly, the removal of an entire standing crop of trees. In practice, may refer to exploitation that leaves much unsaleable material standing. Also termed 'clear felling'. An area from which the entire timber stand has been cut. Removal of the entire stand in one cut. Reproduction is then obtained with or without planting or artificial seeding.

Companion crop: A crop which is grown with another crop.

Concentrated flow: The flowing of a rather large accumulated body of water over, or one which corresponds to a net rain storm of duration longer than one unit period.

Concentration point: The single geographical location at which all surface drainage from a given area comes together as outflow.

Concentration time: The time required for discharge from the most distant point in a drainage area to reach the concentration point.

Conservation tillage: An agricultural system using tillage techniques designed to reduce soil erosion and overland flow. Most conservation tillage techniques involve less manipulation of the soil than conventional techniques, leaving more plant matter on the soil surface.

Contour farming: Conducting field operations, such as ploughing, planting, cultivating and harvesting on the contour or a right angles to the natural direction of slope.

Contour furrows: Furrows ploughed on the contour on pasture or range land to prevent soil loss and allow water to infiltrate. Sometimes used in planting trees or shrubs on the contour.

Contour interval: The vertical distance between contour lines.

Contour ploughing: A soil conservation technique involving ploughing parallel to the contour, across a slope rather than up and down it.

Contour strip cropping: The production of crops in comparatively narrow strips planted on the contour and at right angles to the natural direction of slope. Usually strips of grass or close growing crops are alternated with those in cultivated crops.

Contour: An imaginary line connecting points of equal elevation on the surface of the soil.

Cover crop: A close growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production, or between trees and vines in orchards and vineyards.

Cover, ground: Any vegetation production a protecting 'mat on or just above the soil surface. In forestry, low-growing shrubs and herbaceous plants under the trees.

Creep: Slow mass movement of soil and soil material down relatively steep slopes primarily under the influence of gravity, but facilitated by saturation with water and by alternate freezing and thawing.

Crop rotation: The growing of different crops in recurring succession on the same land.

Deciduous forest: A forest composed of trees that shed their leaves at some season of the year. In tropical areas trees may lose their leaves during the hot season to conserve moisture. Trees of a deciduous forest in cool areas shed their leaves during the autumn to protect themselves against the cold and frost of winter. Deciduous forests produce valuable hardwood timber, such as teak and mahogany from the tropics, and oak and beech from the cooler areas.

Deflation: Process where wind erosion creates blowout depressions or deflation hollows by removing and transporting sediment and soil.

Dendrology: The study of trees, that is, a knowledge of the taxonomy, systematic relationships and field recognition of tree species.

Dendrometer: A device for measuring the diameter of the trunk or branch of a tree.

Depression storage: Water in puddles, small ponds and depressions.

Detention dam: A dam constructed for the purpose of temporary storage of stream flow, or surface runoff, and for releasing the stored water at controlled rates.

Dike: An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowland; a levee.

Disperse: To distribute or suspend fine particles, such as clay, in or throughout a dispersion medium, such as water.

Diversion dam: A structure or barrier built to divert part or all of the water of a stream to a different course.

Diversion: A diversion is a channel with a supporting ridge on the lower side constructed across the slope to intercept runoff and minimize erosion, or to prevent excess runoff from flowing into lower lying areas. In some areas a series of diversions are constructed across the slope similar to terraces, but with greater horizontal and vertical spacing. Also known as diversion terrace.

Drag: The force retarding the flow of water or wind over the surface of the ground. Drainage area: An area whose runoff is more or less separate from the runoff of adjacent areas, so that it can be considered a hydrologic unit.

Drainage divide: The boundary line, along a topographic ridge or along a sub-surface formation, separating two adjacent drainage basins.

Drainage: The frequency and duration of periods when the soil is free of saturation with water.

Drift: Material of any sort deposited in one place after having been moved from another. The term is most commonly used when referring to glacial drift.

Drop structure: A dam constructed in a gully or other water course to lower the grade of the water course and thereby decrease the velocity of flow, promote the deposition of sediment, and prevent further channel erosion.

Dryland farming: The practice of crop production in low rainfall areas without irrigation.

Dune: A mound or ridge of loose sand piled up by the wind; common where sand is abundant and wind usually strong as along lake and sea shores and in some desert and semi-desert areas.

Dust mulch: A loose, finely granular, or powdery condition on the surface of the soil usually produced by shallow cultivation.

Edaphic: Of or pertaining to the soil in its ecological relationships. Resulting from, or influenced by, factors inherent in the soil or other substrate rather than by climatic factors.

Effective precipitation: That portion of the total precipitation which becomes available for plant growth.

Eluviation: The transportation of soil material in suspension, or in solution within the soil, by the downward or lateral movement of water.

Energy Farming: The process of using land to grow crops, woody or otherwise, that provide fuel, for example, close-planted, fast-growing tree species such as poplar (temperate) or leucaena (tropical). These may be harvested by hand or mechanically. Hydrocarbon fuels can be extracted from other kinds of plants, for example, from some *Euphorbia* species.

Enriched fallow: A form of agroforestry in which useful, mainly woody species are sown or planted before cultivation ceases, or at the time it does, so that during the fallow period, or when the land is next cleared for cultivation, products are available for household use or market that would not otherwise have been there (for example, fruits, bamboos, rattans, medicinals).

Entrainment: One of three distinct processes involved in erosion. More specifically, it is the process of particle lifting by an agent of erosion.

Erode: To wear away or remove the land surface by wind, water, or other agents.

Erodibility: Susceptibility to erosion, erosion proneness.

Erodible: Susceptible to erosion.

Erosion pavement: A layer of coarse fragments, such as sand or gravel, remaining on the surface of the ground after the removal of fine particles by erosion.

Erosion: (i) The wearing away of the land surface by running water, wind, ice or other geological agents, including such processes as gravitational creep; (ii) Detachment and movement of soil or rock by water, wind, ice, or gravity.

Erosive: Tending to cause erosion; the term applies to the eroding agent, such as wind or water.

Erosivity: Potential ability of physical dynamic agents such as water, wind or ice to cause erosion.

Estuary: Somewhat enclosed coastal area at the mouth of a river where nutrient rich fresh water meets with salty ocean water.

Eutrophication: Nutrient enrichment of lakes, ponds, and other such waters that stimulates the growth of aquatic organisms, which leads to a deficiency of oxygen in the water body.

Fallow: Allowing crop land to lie idle, either tilled or untilled, during the whole or greater portion of a growing season. Tillage is usually practiced to control weeds and encourage the

storage of moisture in the soil. Land rested from deliberate cropping, not necessarily without cultivation or grazing but without sowing.

Felling: Cutting trees for their removal.

Field border plantings: Vegetation establishment on field borders to conserve soil and provide cover and food for wildlife.

Field strip cropping: A system of strip cropping in which crops are grown in parallel strips laid out across the general slope but which do not follow the contour. Strips of grass or close-growing crops are alternated with those in cultivated crops.

Filter strip: A strip of permanent vegetation of sufficient width and vegetative density above farm ponds, diversion terraces and other structures to retard flow of runoff water, causing it to deposit soil, thereby preventing silting of structure or reservoir below.

Firebreak: In forestry, an existing barrier, or one constructed before a fire occurs, from which flammable materials have been removed, designed to stop or check creeping or running fires. Also serves as a line from which to work and to facilitate the movement of men and equipment in fire suppression.

Flood plain: The land bordering a stream, built up of sediments from overflow of the stream and subject to inundation when the stream is at flood stage.

Geological erosion: The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, the building up of flood plains, coastal plains, *etc*.

Glacial drift: Rock debris that has been transported by glaciers and deposited, either directly from the ice or from the melt-water. The debris mayor may not be heterogeneous.

Glacier: A large long lasting accumulation of snow and ice that develops on land. Most glaciers flow along topographic gradients because of their weight and gravity.

Gley: Soil with impeded drainage. Used in soil classifications based on profile leaching.

Graded terrace: A terrace having a constant or variable grade along its length.

Grassed waterway: A natural or constructed waterway, usually broad or shallow, covered with erosion-resistant grasses, used to conduct surface water from crop land.

Grassland: Land covered with grasses and other herbaceous species. Woody plants may be present, but if so, they do not cover more than 10% of the ground. There are many different types of grassland designated by ecozone, topography, climate, soil conditions, and so on. Derived grassland is maintained in that condition by regular burning; edaphic grassland arises on particular soil types, for example, those found in or around permanent or seasonal swamps.

Grazing: A method of feeding by herbivores characterized by repeated removal of only a part, generally the leaf, of the plant, which is most commonly called herbage.

Groundwater basin: A groundwater storage area more or less separate from neighbouring groundwater storage areas, so that it can be considered a hydrologic unit.

Groundwater: The general sub-surface water body in the zone of saturation.

Grubbing: Felling trees and shrubs by exposing and cutting the roots.

Gully erosion: The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 30 to 60 cm as much as 22.5 to 30 cm.

Gully: A channel resulting from erosion and caused by the concentrated, but intermittent, flow of water usually during and immediately following heavy rains. Deep enough to interfere with, and not to be obliterated by, normal tillage operations.

Hedge row: A barrier of bushes, shrubs, or small trees growing close together in a line.

Infiltration: The downward entry of water into the soil.

Interpolated cropping: A cropping sequence where two or more species are grown on the same unit of land but at least one species has a later sowing (planting) time and an earlier harvest than the other(s). Refers to situations where the crop duration of species is very different.

Land capability classification: The arrangement of land units into various categories based upon the properties of the land or its suitability for some particular purpose.

Land capability: The suitability of land for use without damage. Land capability involves consideration of (a) the risks of land damage from erosion or other causes and (b) the difficulties in land use owing to physical land characteristics including climate.

Landscape: All the natural features such as fields, hills, forests, water *etc*. which distinguish one part of the earth's surface from another part. Usually that portion of land or territory which the eye can comprehend in a single view, including all its natural characteristics.

Landslide: A mass of material which has slipped down hill under the influence of gravity, frequently assisted by water (when the material is saturated).

Leaching: The washing out of material from the soil, both in solution and in suspension.

Level terrace: A terrace that follows the absolute contour as contrasted with a graded terrace. Used only on permeable soils where conservation of moisture for crop use is particularly important or where outlet channels are impractical.

Ley farming: Rotation of arable crops with two or more years of sown pasture.

Ley pasture: A temporary pasture grown as a specific phase in a defined crop rotation sequence.

Loess: Deposit of wind-transported fine-textured material, uniform and unstratified, mostly silt, but may contain some fine sand and clay.

Lopping: Cutting one or more branches of a standing tree, for example, for fuel or fodder.

Mangroves: Open or closed stands of trees and bushes occurring in the tropics in intertidal zones, usually around the mouths of rivers, creeks and lagoons where soils are heavy textured and have a fluctuating salt content and soil level.

Meadow strip: A sloping field or strip of grassed land which, in addition to yielding a hay crop, acts as a broad shallow water channel during periods of runoff. Often used as a terrace outlet channel and usually much larger in extent than a grassed water way.

Mulch farming: A system of farming in which the organic residues are not ploughed into or otherwise mixed with the soil but are left on the surface as a mulch.

Mulch: Any material such as straw, sawdust, leaves, plastic film, loose soil *etc*. that is spread upon the surface of the soil to protect the soil and plant roots from the effects of rain drops, soil crusting, freezing, evaporation *etc*.

Multipurpose tree: A woody perennial purposefully grown to provide more than one significant contribution to the production or service functions (for example, shelter, shade, land sustainability) of the land-use system that it occupies.

Natural erosion: Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, *etc*. undisturbed by man.

Niche: A place or position adapted to the character, or suited to the merit, of a person or thing. The sum total of adaptations of an organismic unit. In ecology, the total range of conditions under which the individual (or population) lives and replaces itself, or the position or status of an organism within its community and ecosystem resulting from the organism's structural adaptations.

Normal erosion: The gradual erosion of land used by man which does not greatly exceed natural erosion.

Overland flow: Flow of water over the land surface as sheet flow not in channels.

Parent material: The horizon of weathered rock or partly weathered soil material from which the soil is formed.

Pasture improvement: Any practice of grazing, moving, fertilizing, liming, seeding, scattering droppings, contour furrowing, or other methods of management designed to improve the vegetation for grazing purposes.

Pasture: In U.S. terminology, land on which the natural vegetation is not grass, but which is used primarily for grazing.

Percolation: The downward movement of water through soil.

Productivity: The capacity of a soil in its normal environment, for producing a specified plant or sequence of plants under a specified system of management. Productivity emphasized the capacity of soil to produce crops and should be expressed in terms of yields.

Rainforest: Generally, a forest that grows in a region of heavy annual precipitation. There are both tropical and temperate rainforests.

Range management: The scientific management of range land for the continuous production of forage and livestock, consistent with the use of the land for other purposes.

Range: Land that produces primarily native forage suitable for grazing by livestock.

Rangeland: Land that provides or is capable of providing forage for grazing animals.

Reach: A specific portion of the length of a stream channel.

Reforestation: Replacing forests after felling.

Relief: The relative differences in elevation between the upland summits and the lowlands or valleys of a given region.

Resilience: The capacity of a soil (or other ecosystem) to return to its original state after a disturbance.

Ridge terrace: A long, low ridge of earth with gently sloping sides, and a shallow channel along the upper side, to control erosion by diverting surface runoff across

the slope instead of permitting it to flow uninterrupted down the slope. Types of ridge terraces include the broad base, drainage, grades level, narrow base *etc*.

Rill erosion: An erosion process in which numerous small channels of only several centimetres in depth are formed; occurs mainly on recently cultivated soils.

Rill: A small, intermittent water course with steep sides; usually only a few centimetres to deep and, hence, no obstacle to tillage operations.

Riparian forest: Vegetation, with trees and shrubs, growing alongside or close to a watercourse, lake, swamp, or the like, and often dependent on its roots reaching the watertable.

River wash: Barren alluvial land, usually coarse-textured, exposed along streams at low water and subject to shifting during normal high water. A miscellaneous land type.

Riverine: An environment created along permanent and semi-permanent streams because of the increase in soil moisture. This is termed a riverine environment.

Rotational grazing: Grazing systems in which the pasture is subdivided into a number of enclosures, with at least one more of these than there are groups of animals. The practice of submitting a grazing area to a regular sequence of grazing alternating with rest.

Runoff: Runoff is that part of precipitation, snow or ice melt or irrigation water that flows from the land to the streams or other water surfaces. The portion of the precipitation on an area that is discharged from the area through stream channels. That which is lost without entering the soil is called *surface runoff* and that which enters the soil before reaching the stream is called *groundwater runoff* or *seepage flow* from groundwater. (In soil science *runoff* usually refers to the water lost by surface flow; in geology and hydraulics *runoff* usually includes both surface and subsurface flow).

Sediment: Fragmented organic or inorganic material derived from the weathering of soil, alluvial, and rock materials; removed by erosion and transported by water, wind, ice, and gravity.

Sedimentation: The deposition of sediment from a state of suspension in water or air.

Sheet erosion: The removal of a fairly uniform layer of soil from the land surface by runoff water.

Shelterbelt: An extended wind break of living trees and shrubs established and maintained for protection of farm lands over an area larger than a single farm.

Silting: The deposition of water-borne sediments in stream channels, lakes, reservoirs, or on flood plains, usually resulting from a decrease in the velocity of the water.

Slash: In forestry, the vegetation (branch and other woody and leafy debris) left on the forest floor after trees have been felled or trimmed.

Slope: The degree of deviation of a surface from horizontal, measured in a numerical ratio, percent, or degrees.

Social forestry: The planting and tending of trees or shrubs for the well-being and betterment of local communities.

Spillway: A conduit in or around a dam for the escape of excess water.

Splash erosion: The spattering of small soil particles caused by the impact of rain drops on very wet soils. The loosened and spattered particles mayor may not be subsequently removed by surface runoff.

Spur terrace: A short terrace used to collect or divert runoff.

Stream gaging: The collection of stream-flow data by direct measurements of discharge and water surface elevations.

Strip cropping: The practice of growing crops which require different types of tillage, such as row and sod, in alternate strips along contours or across the prevailing direction of wind.

Stubble mulch: The stubble of crops or crop residues left essentially in place on the land as a surface cover before and during the preparation of the seedbed and at least partly during the growing of a succeeding crop.

Surface sealing: The orientation and packing of dispersed soil particles in the immediate surface layer of the soil, rendering it relatively impermeable to water. j

Terrace: A raised, more or less level or horizontal strip of earth usually constructed on or nearly on a contour and supported on the downslope side by rocks or other similar barrier and designed to make the land suitable for tillage and to prevent accelerated erosion.

Through fall: The proportion of the gross precipitation that reaches the ground and is not intercepted by, or retained in, the canopy.

Tie ridging: In contour furrowing or trenching, a narrow transverse strip of ground left unexcavated (or ridged).

Wasteland: Land not suitable for, or capable of, producing materials or services of value.

Water harvesting: A general term for any means of collecting and re-distributing runoff water.

Watershed: The total land area, regardless of size, above a given point on a waterway that contributes runoff to the flow at that point.

Waterway: A natural course for the flow of water.

Weir: A dam across a stream for diverting or for measuring the flow.

Windbreak: A planting of trees, shrubs *or* other vegetation, usually perpendicular or nearly so to the principal wind direction, to protect soil, crops, homesteads, roads *etc*. against the effects of winds, such as wind erosion and the drifting of soil and snow. A group of trees or shrubs in any arrangement that will afford protection from high winds to animals or crops or both. When the arrangement is in a long line the group is called a shelterbelt**.** If an associated reason is also to harvest timber at some future date it is sometimes called a 'timberbelt'.

Wind erosion: The detachment, transportation and deposition of soil by the action of wind.

Wind strip cropping: The production of crops in long, relatively narrow strips, placed cross wise of the direction of the prevailing winds without regard to the contour of the land.

Zero-grazing: A method of keeping animals that involves bringing fodder to them rather than letting the animals graze freely.

ABBREVIATIONS

AICRPDA	:	All India Coordinated Research Project on Dryland Agriculture, Hyderabad
AISSLUP	:	All India Soil Survey and Land Use Planning, New Delhi
CADA	:	Command Area Development Authority
CAZRI	:	Central Arid Zone Research Institute, Jodhpur
CRIDA	:	Central Research Institute for Dryland Agriculture, Hyderabad
CSWCRTI	:	Central Soil & Water Conservation Research & Training Institute, Dehradun
DDP	:	Desert Development Programme
DPAP	:	Drought Prone Area Programme
ICARDA	:	International Centre for Agriculture Research on Dry Areas, Aleppo, Syria
ICRAF	:	International Centre for Research on Agroforestry, Nairobi, Kenya
ICRISAT	:	International Crops Research Institute for the Semi-Arid Tropics, Hyderabad
IFOAM	:	International Federation for Organic Agricultural Movements
IGFRI	:	Indian Grassland and Fodder Research Institute, Jhansi
IPCC	:	Intergovernmental Panel on Climate Change
IREP	:	Integrated Rural Energy Programme
IWDP	:	Integrated Wasteland Development Project
LCC	:	Land Capability Class
NBSS & LUP	:	National Bureau of Soil Survey and Land Use Planning, Nagpur
NRCAF	:	National Research Centre for Agroforestry, Jhansi
NRSA	:	National Remote Sensing Agency, Hyderabad
NWDB	:	National Wasteland Development Board, New Delhi
NWDPRA	:	National Watershed Development Programme for Rainfed Areas
RADAS	:	Reclamation & Development of Alkali and Acid Soil
RVP & FPR	:	River Valley Project & Flood Prone River
UNCED	:	United Nations Conference on Environment and Development
WALAMTARI	:	Water and Land Management Training Research Institute
WDF	:	Watershed Development Fund
WDPSCA	:	Watershed Development Project for Shifting Cultivation Area