As per the Fifth Dean Committee Recommendations for the
B. Sc. (Hons.) Agri. Course Curriculum

Lecture note

Ag. Chem. 1.1
Fundamentals of Soil Science (2+1)

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CHAPTER 1: SOIL – AN INTRODUCTION

1.1 Definition and concept of soil

The noun soil is derived through old French from the Latin solum, which means floors or ground. What, a soil scientist calls soil, a geologist may calls fragmented rock, an engineer may calls earth, and an economist may call land. In general, soil is defined as the more or less loose and crumby part of the outer earth crust. Since time immemorial soils have been christened as a medium of plant growth to meet basic food, fuel and fiber needs of humans. Soil health care was central to ancient farmers, amply depicted in a quotation from Sanskrit believed to have been made in 1500 BC "Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel and our shelter and surround us with beauty. Abuse it and the soil will collapse and die taking man with it". Some of the famous ancient and contemporary proverbs listed below highlight the importance of soil resource and its management:

"We know more about the movement of celestial bodies than about the soil underfoot" – **Leonardo da Vinci**
"A nation that destroys its soils destroys itself" – **Franklin D. Roosevelt**
"To forget how to dig the earth and to tend the soil is to forget ourselves" – **Mahatma Gandhi**
"Soil is a rock on its way to ocean" – **W. L. Lindsay**

Soil is considered as a geomembrane of the earth, protective filter, buffer, mediator of energy, water, and biogeochemical compounds; sustainer of productive life, ultimate source of elements, and the habitat for most biota; foundation that supports humans; and the dust to which humans would finally return. Generally, soil refers to the loose surface of the earth as identified from the original rocks and minerals from which it is derived through weathering process.
The widely accepted definition according to **Buckman and Brady (1969)** is:*"Soil is a dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms"*.

Soil as a three dimensional entity

Soil is a three dimensional body having length, breadth and depth. They form a continuation over the land surface and differ in properties from place to place. Its upper boundary is air or water and lower boundary is the rock lithosphere.

> *"Soil is a three-dimensional, a natural and dynamic material on earth's surface that has important function of serving as a substratum of plant, animal and human life and acts as a reservoir of nutrients and water"*

For a farmer, soil refers to the cultivated top layer (surface soil) only, that is, up to 15-18 cm of the plough depth. Soils widely vary in their characteristics and properties.

Important functions of soil

- Medium for plant growth – Supplies all essential plant nutrients
- Recycling system for nutrients
- Recycle of raw materials – assimilates great quantities of organic waste, and turning it into beneficial *humus*
- Natural habitat for so many organisms –Home to organisms
- Foundation for engineering structures
- System for water supply and purification
- Modifier of the atmosphere – major source of water vapour in the atmosphere

1.2 Soil Science – definition and approaches

Soil science is the study of soil as a natural resource on the surface of the Earth including soil formation, classification and mapping; physical, chemical, biological, and fertility properties of soils; and these properties in relation to the use and management of soils. Sometimes, terms which refer to branches of soil science, such as ***pedology*** (formation, chemistry, morphology and classification of soil) and ***edaphology*** (influence of soil on organisms, especially plants), are used as synonymous with soil science. One treats soil as a natural body, weathered and synthesized product innature (**Pedology**) while other treats soil as a medium for plant growth (**Edaphology**). The two basic approaches *–Pedological and Edaphological*are used in studying the soils.

(i) Pedological approach: The origin of the soil, its classification, and its description are examined in pedology (from the Greek word ***pedon***, means soil or earth). ***Pedology*** is the study of the soil as a natural body and does not focus primarily on the soil's immediate practical utilization. A pedologist studies, examines, and classifies soils as they occur in their natural environment.

(ii) Edaphological approach: Edaphology (from the Greek word ***edaphos***, which means soil or ground) is the study of soil from the standpoint of higher plants. Edaphologists consider the various properties of soils in relation to plant production. They are practical and have the production of food and fiber as their ultimate goal. To achieve that goal, edaphologists must be a scientist to determine the reasons for variation in the productivity of soils and find means of conserving and improving productivity.

Soil Science has major six well defined and developed disciplines:

1. **Soil Fertility :** Deals with the nutrient supplying capacity of soils.
2. **Soil Chemistry :** Studies of soil chemical properties and the chemical reactions.
3. **Soil Physics :**Studies of soil physical properties.
4. **Soil biology :** Deals with the soil organisms and their roles in soil fertility.
5. **Soil Conservation:** Deals with protect and conserve the soils.
6. **Soil Pedology :** Deals with the soil genesis, soil survey, mapping and classification.

International Union of Soil Sciences highlighted following key facts of soils:

- It can take more than 1000 years to form a centimeter of topsoil.
- There are over 10000 different types of soil exist worldwide.
- A handful of soil can contain billions of soil microorganisms. There are more individual organisms in a handful of fertile soil than world's human population.
- Soil is one of the most complicated biological materials on our planet.
- Soil stores 10% of world's CO_2 emissions.Soil carbon is the largest global carbon pool.

CHAPTER 2: SOIL FORMING ROCKS AND MINERALS

2.1 The Earth's crust

There are three divisions of earth's sphere corresponding to the solid, liquid and gas, which constitutes the Earth. The solid zone is called *Lithosphere*. The incomplete covering of water bodies, such as seas and oceans known as *Hydrosphere* and the gaseous envelope around the earth's surface is called *Atmosphere*.

The Earth's crust is only about 3-5 miles (8 km) thick under the oceans (oceanic crust) and about 25 miles (32 km) thick under the continents (continental crust). The first layer consists of approximately 16 km of rocks and loose materials, we call them the ***'Earth crust'***. Underneath the continents, the crust is almost three time as thick as it is under the ocean (**Figure 2.1**).

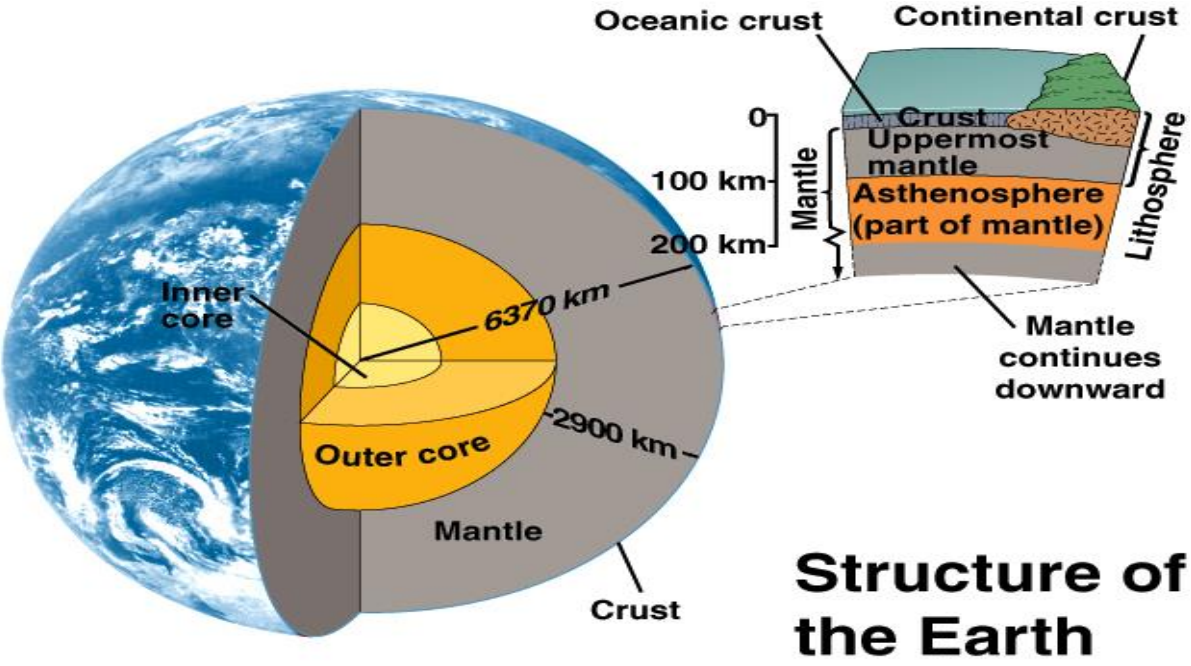


Figure 2.1: The Earth's crust layers

Atmosphere

An atmosphere (from Greek *atmos*, meaning 'vapour', and *sphaira*, meaning 'sphere') is a layer of gases surrounding a planet.The atmosphere is composed of nitrogen (~78%), oxygen (~21%), Argon (~0.9%) with carbon dioxide and other gases in trace amounts. Oxygen is used by most organisms in respiration process, nitrogen is fixed into the soil by bacteria and lightning to produce ammonia, that is used in the construction of nucleotides and amino acids of microorganisms, and carbon dioxide is used by plants, algae and cyanobacteria in the photosynthesis process. The atmosphere helps protect living organisms from the solar ultraviolet radiation, solar wind and cosmic rays.

Hydrosphere

It is the combined mass of waterfound on, under, and above the surface of the Earth. It is the layer of waterbodies such as seas, rivers, oceans, etc., surrounding the lithosphere. It covers 70% of the earth. It has been estimated that there are 1386 million cubic kilometers of water on the Earth.Saltwater accounts for 97.5% of this amount. Fresh water accounts for only 2.5%. Of this fresh water, 68.9% is in the form of ice and permanent snow cover in the Arctic, the Antarctic, and mountain glaciers. 30.8% is in the form of fresh groundwater. Only 0.3% of the fresh water on Earth is in easily accessible lakes, reservoirs and river systems.

Lithosphere

It is the rigid, outmost shell of the planet earth. That visible portion of the lithosphere, which rises above the seawater is known as land. The land is only about one-fourth of the total surface of the earth. Most land is situated in the northern hemisphere. The lithosphere consists of two portions, viz., (i) the upper or outer cool solid surface, and (ii) the inner hot and molten mass.
In terms of density, it is the heaviest amongst the three spheres, having density of 5.5 (water density is 1.0). The outer crust has density of ~2.5 to 3.0, while the inside core, consists of much heavier materials. The outer solid layer, called as the *earth's crust* is estimated to be ~16 to 32km thick. It consists various rocks together with thin mantle of soil enveloping them. On this crust that life, both animal and plant sustains. The inner mass, which forms the interior of the earth, is in molten condition. In short, the Earth's lithosphere includes the crust and the uppermost mantle, which constitute the hard and rigid outer layer of the Earth.The uppermost part of the lithosphere that chemically reacts to the *atmosphere*, *hydrosphere* and *biosphere* through the soil forming process is called the *pedosphere*.

Biosphere

The biosphere (from Greek *bíos*'life') which can also be termed as life on Earth, all the living things in or on the planet are categorized as biosphere. The entire ecological communities within the physical surrounding of the earth are within the umbrella of living things (biosphere). These ecological communities interactswith the hydrosphere, lithosphere, and the atmosphere.

2.2 The Earth crust – elemental composition

The earth's crust is principally composed of mineral matter. Altogether, There are 118 elements that have been identified, of which the first 94 occur naturally on the Earth and rest 24 are synthetic elements. These elements which are known to us are found in the earth crust in various combinations to form compounds. The oxygen is most abundant element, but it usually occurs in combination with other elements, which reflects the importance of silicate (SiO_2-based) minerals. About 98.5% of the crust is comprised of just 8 elements: In decreasing concentration order of: **O >Si >Al** >Fe >Ca >Na >K >Mg >others (**Table 2.1**).

Table 2.1: Elemental composition of the Earth's crust

Element	**O**	**Si**	**Al**	**Fe**	**Ca**	**Mg**	**Na**	**K**	**Others**
Content (%)	**46**	**27**	**8**	5	4	2	3	3	2

The two elements occurring in greatest abundance are non-metallic (O and Si) and comprises 75% of the total composition of the crust. In the process of cooling, the elements began to combine into compounds. The compounds so formed aggregated into large masses giving rise to a variety of minerals. These mineral masses got cemented or pressed into the rocks, as they are now present in the earth's crust. These rocks were then exposed to the action of weathering processes over thousands of years. The disintegrated rocks gradually evolved into the soils. Therefore, knowledge of soil forming rocks and minerals and the weathering processes is essential in the studying of soils.

The materials of the earth's crust fall into two principal categories: *Minerals and Rocks*.
Mineral is a solid, inorganic, naturally formed substance that has a crystalline structure and specific chemical composition. Rock is a solid, inorganic, naturally formed substance without a particular structure or chemical composition. Rock is a solid aggregate of one or more minerals. Most common minerals consist of silica (SiO_2) mixed in varying proportions with other elements such as Fe, Mg, Al, Ca, K, and Na.

2.3 Soil formation

The soil formation is the process of **two consecutive stages**: (i) the weathering of rocks into ***Regolith*** (layers of loose, heterogeneous materials including solid broken rocks; an unconsolidated residues of rocks and minerals lying on the surface of the earth at varying depths), and (ii) the formation of true soil from the regolith.

In general, soils may be formed in place from rock or formed in weathered rock and minerals that have been transported from where the original rock occurred. Rock is consolidated mass of one or more minerals. Rock is mixture of minerals and therefore, their physical and chemical compositions vary with the characteristics of minerals present in them. Rock is formed due to cooling and solidification of molten magma. It is mixture of one or more minerals. Term ***Petrology*** is referred to the science of rocks,includes the ***Petrography*** deals with the description and the ***Petrogenesis*** is the study of the origin of rocks.

2.4 Rocks

Geologists classify the Earth’s rocks as igneous, sedimentary and metamorphic on the basis of their origin.

2.4.1 Igneous rocks (Latin *ignis*, means fire)

Igneous rocks are formed from solidification of molten materials (magma) (**Figure 2.5**). It includes common rocks, granite and diorite. They are characterized by non-laminar massive structure and as a whole, make-up 95% of the Earth’s crust, and about 88% of the mass of these rocks consist of Feldspars, Quartz and Amphiboles.

The igneous rocks contains primary minerals, e.g., light-coloured minerals (quartz, muscovite, and feldspar) and dark-coloured minerals (biotite, augite, and hornblende). Dark-coloured minerals contain Fe and Mg, are more easily weathered. So, dark-coloured igneous rocks such as Gabbro, Basalt and Peridolite are more easily broken down than light-coloured rocks such as Granite, Syenite, Rhyolite, Andesite, Felsite, and Diorite. Worldwide, light-coloured minerals are generally more prominent than the dark-coloured minerals.

Igneous rocks have been grouped into several types based on: (i) Mode of origin or occurrence, and (ii) Chemical composition. Based on mode of origin, igneous rocks are classified into two categories **(Table 2.2)**: Plutonic (intrusive) and volcanic (extrusive) igneous rocks.

- **Plutonic / Intrusive Igneous rocks**

  Plutonic or intrusive rocks formed when magma cools and crystallizes slowly within the Earth's crust at moderate or greater depth. A common examples of this type are Granite, Syenite, and Gabbro. They are crystalline rocks and the size of crystals are relatively larger and light-coloured.

  *When the rocks consolidated in vertical cracks and formed wall like masses termed as **dikes or dykes,** whereas those consolidated in horizontal cracks are called **sills*** **(Figure 2.4)**. *In some cases the molten material is consolidated in irregular and narrow cracks is called a **vein**.*

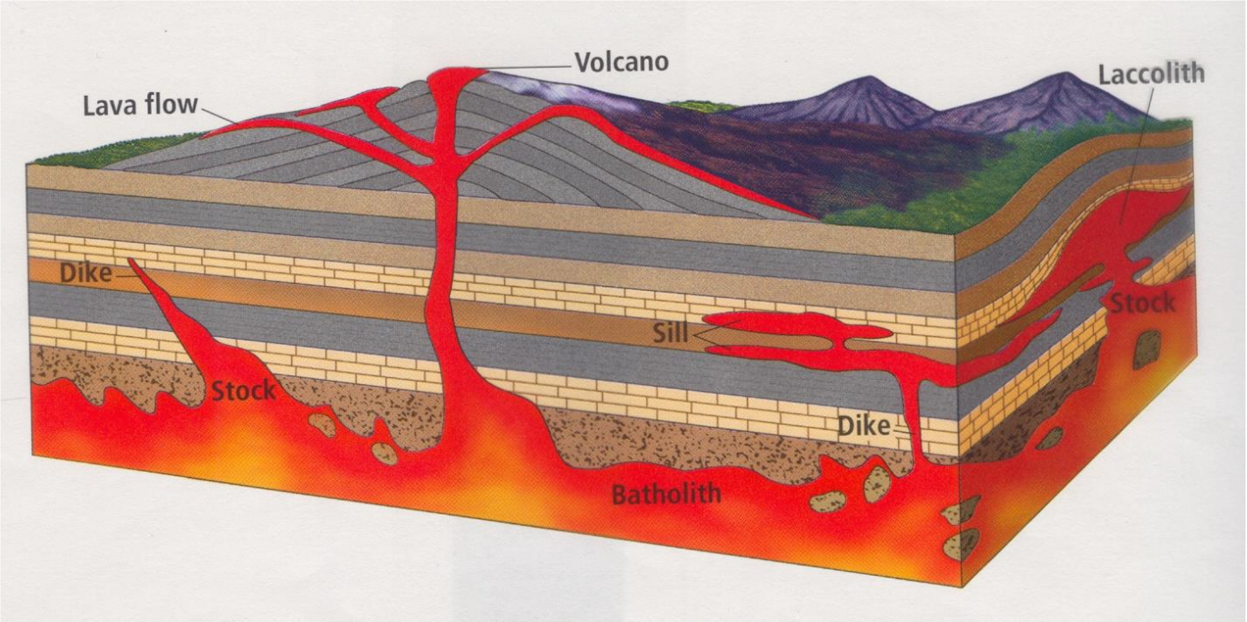


Figure 2.4 Formation of dike or dyke and sill

- **Volcanic / Extrusive igneous rocks**
  Volcanic or extrusive rocks formed from magma reaching the surface either as lava or fragmental ejecta, forming rocks such as Pumice, Basalt and Rhyolite. They are crystalline rocks and the size of crystals are relatively smaller, and dark-coloured

On the basis of percentage of silica content, igneous rocks are classified into four groups, viz., ***Acidic, Intermediate, Basic and Ultrabasic***. The first rocks to form are relatively low in silica (<55%), and include Basalt and Dolerite. These are known as ultrabasic rocks, because of their relatively high content of basic cations, such as Mg, Fe and Ca. The silica content increases as crystallisation proceeds (**Table 2.2).**

Table 2.2: Classification of igneous rocks

Types of igneous rocks		***Descriptions***	***Examples***
Based on mode of the origin	Intrusive or plutonic	Solidification takes place at moderate depth of the earth	Granite, Gabbro, Syenite
	Extrusive or Volcanic	Solidification takes place on the surface of the earth	Basalt, Rhyolite
Based on the chemical (Silica) composition	Acidic	>65% Silica content; Light in colour	Granite
	Intermediate	55 – 65% Silica content; Variable in colour	Andesite, diorite
	Basic	45 – 55% Silica content; Dark in colour	Basalt, Dolerite, Gabbro
	Ultrabasic	<45% Silica content; Dark in colour	Basalt, Peridotite

2.4.2 Sedimentary rocks (Latin *sedimentas*, means settling)

As soon as igneous rocks are exposed to weathering processes, they start breaking down physically and chemically into soluble and insoluble products. These products when transported by water or glaciers form new deposits which in time become cemented and solidified into new forms of rocks called the ***sedimentary rocks***.The rocks are mostly deposited in characteristic layers or strata and stratification is the most common feature of these rocks – so called as ***stratified rocks***, e.g., lime stone, sand stone, silt stone, shale and conglomerate.They are also known as ***Aqueous rock***, since water plays important role in the formation of sedimentary rocks (**Figure 2.5**).

Based on the grain size, sedimentary rocks are classified as:

- **Rudaceous:** If the individual grains forming rocks are of the size of boulders and pebbles, called *rudaceous*. *Grit*is composed of sharp and angular pebbles, *Shingle* is composed of large rounded pebbles, *Conglomerate* consist of rounded or sub angular pebbles, and *Breccia* consists angular fragments.

- **Arenaceous:** These rocks have individual grains of sand size, e.g., Sand stone

- **Argillaceous:** These rocks have individual grain size of clay particles. These may either loose or consolidated rocks. ***China clay***is formed from decomposition of feldspar, ***Pipe clay*** is Iron free clay, ***Fire clay***is Free from lime and alkalies and ***Laterite*** isred-coloured clay formed by decomposition of basalt and granite.

The sedimentary rocks are formed by the action of water, glacier, wind, etc. The rocks are, therefore, divided according to the agent of erosion that have played the major role in the formation of rocks.

On the basis of formation by different agencies, sedimentary rocks are classified as:

- **Aqueous rocks:** Water transports weathered rock particles from one place to another and formed the sedimentary rocks. The aqueous rocks are classified according to water reservoirs.

- **Lacustrine rocks:** Rivers and winds bring weathered rock particles to the lakes. The particles accumulate at its floor. Finer rock material is found in the lakes situated in plains than on mountains. The nature of sediment deposited depends upon the stage of river valley development and the causes of lake formation. When the lake is filled up with sediment or its water is dried, the sediment can be seen deposited in the lakes in form of the stratified rocks.

- **Riverine rocks**: When the rivers enter plains, its speed of flow is reduced and the sediment which it brings with it is deposited at the floodplains and deltas and formed the riverine rocks.

- **Chemically formed rocks:**The rock mixture which is dissolved in water gets deposited when its water evaporates. For an example, Gypsum is formed through this process.

- **Glacial rocks:** Glaciers scour the floor and adjoining areas and transport rock-mixture with them. The glaciers usually leave this material on its floors, on both the sides and at their terminals. The rock material, thus lift, forms glacial rocks.

- **Aeoline rocks (also called ventifacts)**: Wind also transports weathered rock-mixture from one place to another. The fine particles flown by winds are carried to great distances and are deposited into rocks. Such rocks are formed only in those areas where the climate is arid (dry).

2.4.3 Metamorphic rocks

Metamorphic rocks are formed from the igneous and sedimentary rocks by a process of change (termed '*metamorphism*') due to intense temperature, pressure or chemically active liquids and gases. Metamorphism may change both, physicl and chemical compositiono of the original rocks. For example, igneous rock granite metamorphosed into *Gneiss* and sedimentary rocks sandstone and shale respectively modified to *marble* and *slate*. The changes due to water is called ***hydro-metamorphosis*** and due to pressure is called ***dynamo-metamorphosis*** **(Figure 2.5).**

Original rocks	Agents of metamorphism	Metamorphic rocks
Sand stone	→ *Temperaure (heat) & Pressure* →	Quartzite
Shale	→ *Pressure* →	Slate
Lime stone	→ *Temperature (heat)* →	Marble
Granite	→ *Pressure* →	Gneiss (distinct layers)
Basalt	→ *Pressure* →	Schist (indistinct layers)

The ***action of water*** tends to remove some material or introduce new materials. By the introduction of a cementing material like silica, lime or iron oxide, loose sand may be turned into sandstone or *sandstone into a quartzite*. By the removal of certain constituents by percolating waters, *basalt or granite may be converted into a laterite*.The ***action of heat*** hardens the rock and develops new crystals in it. Crystalline marble is produced this way from amorphous limestone by the action of heat and pressure.

Types of metamorphic rocks

- **Foliated metamorphic rocks** such as gneiss, phyllite, schist, and slate have a layered or banded appearance that is produced by exposure to heat and directed pressure. Foliation represent a distinct plane/layer, is caused by the re-alignment of minerals. The layering within metamorphic rocks is called ***foliation*** (Latin word *folia*, meaning "leaves") when they are subjected to high pressure and temperature. Foliated metamorphic rocks often break easily along foliation planes, are identified on the basis of their texture: (i) ***Slate*** formed at very low temperatures and pressures, rock breaks along nearly perfect parallel planes; (ii) ***Phyllite*** formed at low to intermediate temperatures and pressures, slightly more crystallized with shiny appearance; (iii) ***Schist***formed at intermediate to high temperatures and pressures, crystals are larger with the grains aligned in parallel to subparallel layers; (iv) ***Gneiss***formed at very high temperatures and pressures; coarse grained texture of alternating light and dark mineral bands.

  As the grade of metamorphism increases (more temperature and pressure), both crystal size and the coarseness of foliation increase. Therefore, ***gneiss*** represents more intense metamorphism (or a higher grade) than does ***schist***.

- **Non-foliated metamorphic rocks** such as hornblende, marble, quartzite, and novaculite do not have a layered or banded appearance.They do not have a platy or sheet-like structure.

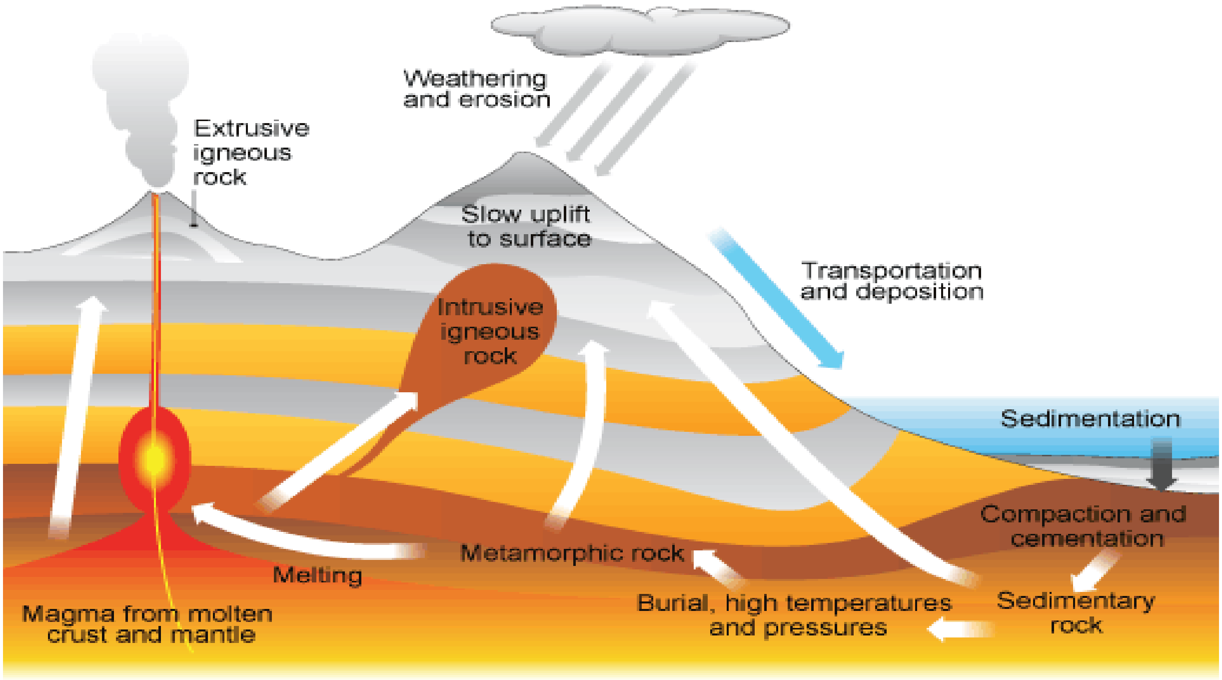


Figure 2.5 : Rock cycle

2.4.4 Occurrences of soil forming rocks

The occurrences of rocks in the upper 5 km of the Earth's crust is given in **Table 2.3**.

Table 2.3: Composition of the upper 5 km of the Earth's crust

Sedimentary (74%)	Shales Sandstones Limestone and Dolomite	52% 15% 7%
Igneous(18%)	Granites Basalt	15% 3%
Others, i.e., ***Metamorphic***		8%

2.5 Minerals

Minerals are naturally-occurring inorganic substances composed of atoms having an orderly and regular arrangement with difinite chemical composition and characteristic geometic form such as Quatz (SiO_2), Orthoclase ($KAlSi_3O_8$), Calcite ($CaCO_3$), Olivine [$(Mg, Fe)_2SiO_4$] and gypsum ($CaSO_4{\cdot}2H_2O$). Minerals that are the original components of rocks are called ***primary minerals***. (e.g., feldspar, mica, etc.). Minerals that are formed from changes in primary minerals and rocks are called ***secondary minerals*** (e.g., clay minerals).

2.5.1 Classification of soil minerals

Minerals are classificed on basis of mode of origin, composition and specific gravity as follows.

On the basis of origin and mode of formation

- ***Primary minerals*:** When a mineral arises form the cooling and solidification of a molten mass is called ***primary minerals***. They are inherited from the parent rock, make-up main part of the sand and silt fractions of soil.

Name of Primary Minerals	**Chemical Formula**
Quartz	SiO_2
Orthoclase / Feldspar	$KAlSi_3O_8$
Plagioclase / Feldspar	$(Ca, Na)\cdot AlSi_3O_8$
Muscovite / Mica	$KAlSi_3O_{10}(OH)_2$
Biotite / Mica	$KAl(Mg, Fe)_3Si_3O_{10}(OH)_2$
Hornblende / Amphibole	$Ca_2Al_2Mg_2Fe_3Si_6O_{22}(OH)_2$
Augite / Pyroxine	$Ca_2(Al, Fe)_4(Mg, Fe)_4Si_6O_{24}$
Olivine	$(Mg, Fe)_2SiO_4$

- ***Secondary minerals*****:**It arises through the metamorphism or weathering of primary or other pre-existing minerals, it is called ***secondary minerals***. Most common example is Silicate clay minerals.

Name of secondary mineral	**Chemical Formula**
Oxides	
Hematite	Fe_2O_3
Goethite	$FeO(OH)$
Gibbsite	$Al(OH)_3$
Carbonates	
Calcite	$CaCO_3$
Dolomite	$CaMg(CO_3)_2$
Sulphates and Sulphides	
Gypsum	$CaSO_4\cdot 2H_2O$
Pyrites	FeS_2, CuS_2

On the basis of chemical composition

According to their chemical composition, minerals are divided into eight groups.

- **Silicates:** These are the salts of silicic acid (H_4SiO_4). e.g. muscovite, biotite, epidote, orthoclase feldspar, zeolite, olivine and amphibole
- **Native elements:** The minerals of this group are made up of only one element. e.g., graphite – C, diamond – C, sulphur – S
- **Oxides and hydrooxides:** e.g., quartz, hematite, geothite, limonite– $Fe_2O_3\cdot 3H_2O$, magnetite– Fe_3O_4, gibbsite – $Al_2O_3\cdot 3H_2O$.
- **Sulphates:** e.g. Gypsum – $CaSO_4\cdot 2H_2O$, Barite – $BaSO_4$, Gypsum anhydrite – $CaSO_4$
- **Carbonates:** e.g., Calcite, magnesite – $MgCO_3$, Dolomite – $CaMg(CO_3)_2$
- **Sulphides:** e.g., Copper pyrite – CuS_2, Iron pyrite – FeS_2
- **Phosphates:** e.g., apatite – $Ca_5(F,Cl,OH,O)(PO_4)_3$ – is the source of phosphorus in soils.
- **Halides:** e.g., Flurorite (flurospar) - CaF_2, Rock salt (halite) – NaCl, Sylvite – KCl

On the basis of specific gravity (g cm^{-3}; **gram per cubic centimeter**)

- **Light minerals**: having specific gravity <2.85 g cm^{-3}. e.g. quartz (2.6 g cm^{-3}), feldspar (2.65 g cm^{-3}), muscovite (2.50-2.75 g cm^{-3})
- **Heavy minerals:** having specific gravity >2.85 g cm^{-3}. e.g., hematite (5.3 g cm^{-3}), pyrite (5.0 g cm^{-3}), limonite (3.8 g cm^{-3}), augite (3.1-3.6 g cm^{-3}), hornblende and amphiboles (2.9- 9.8 g cm^{-3}), olivine (3.5 g cm^{-3})

2.5.2 Clay minerals

Clay minerals in the soils are formed from *primary* and *secondary* minerals due to weathering processes. The clay fraction of the soil particles has a diameter less than 0.002 mm (2 µm). The mineral present in the clay fraction of the soil are called as *clay minerals.*Clay minerals are the most important secondary minerals. They are colloidal and crystalline in nature. They carry a negative electrical charge on their surface. Most of the physical, chemical and morphological properties of soils are influenced by these clay minerals.

Table 2.4: Relative occurrence of minerals in soils

Name of minerals	**~ Distribution (%)**
Feldspars	60
Quartz	12
Amphiboles and pyroxenes	17
Micas	4
Silicates	6
Rest of the minerals	1

The three most important groups of silicate clay minerals are kaolinite, montmorillonite and illite. Among different minerals present in soil, Feldspars and Quartz dominates by about 72 %, followed by Amphiboles and pyroxenes about 17% (**Table 2.4).**

CHAPTER 3: WEATHERING AND SOIL FORMATION

3.1 Weathering of rocks and minerals

Weathering is a natural process of breakdown and transformation of rocks and minerals into unconsolidated residues, called ***regolith*** – from which true soil formed. In simplest manner, the process of transformation of solid rocks into soils is known as ***weathering***. Weathering refers to disintegration and decomposition of rocks and minerals.

Weathering processes are of two types: **(i) Physical weathering**, brought about by the mechanical action of the various weathering agents, is designated as ***disintegration***. Disintegration breaks down the rocks into small pieces without affecting their original composition **(ii) Chemical weathering** is designated as ***decomposition***.The minerals decompose chemically, releasing soluble materials and synthesizing new minerals (**Figure 3.1**).

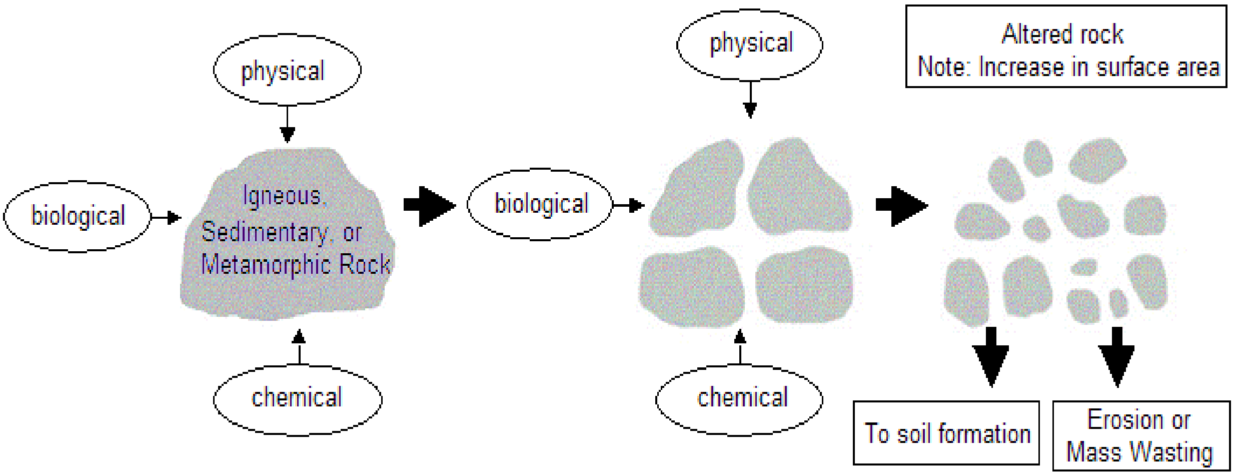


Figure 3.1: Weathering and synthesis of rocks

Weathering leads to the formation of *regolith* (i.e., unconsolidated residues of the weathered rock on the earth's surface or above the solid rock). ***Soil formation*** is caused by the action of atmospheric agents at or near the surface of the earth. When the rocks and minerals are exposed to the action of atmospheric agents. For example, formation of clay in soil,and hydrated aluminum silicates and free silica as a result of decomposition of feldspars.Biological agencies also accelerate physical and chemical weathering.

Thus, weathering is a combination of destruction and synthesis. Rocks are first broken down into smaller particles of which they are composed (*destructive processes*). The mineral are attacked by chemical forces, result in the release of soluble constituents. The soluble constituents may either be lost in drainage waters or recombine to form new minerals (*constructive process*).

Physical disintegration agent	**Chemical decomposition process**
• Temperature	• Solution
• Water	• Hydration
• Wind	• Hydrolysis
• Ice	• Oxidation
• Plants and animals	• Reduction
	• Carbonation

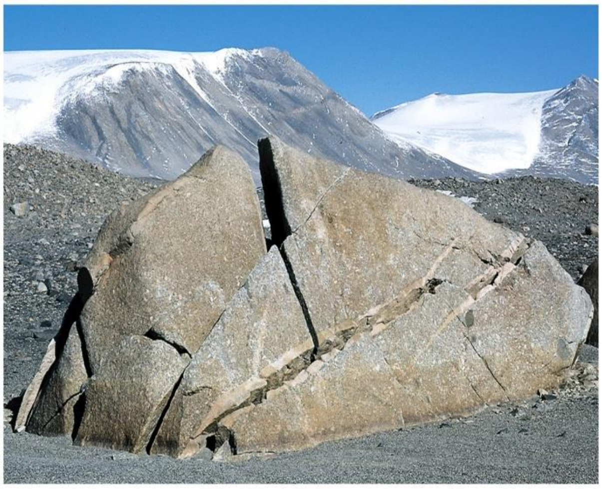
3.2 Physical weathering

It is a mechanical process, causing disruption of consolidated massive rocks into smaller bits without any corresponding chemical change.

- **Temperature**: The alternate expansion and contraction of rocks due to variation in temperature produce cracks. The number of cracks increases and the rock gets broken into pieces. This phenomenon is referred to as '***exfoliation***'. The dark coloured rocks are subjected to fast changes in temperature as compared with light coloured rocks.

- **Water**: In cold regions, water freezes in rock joints and cracks. On freezing, the water expands in volume by about 9% with a force of ***150 tonnes per square feet or 1465 Mg per square metre***. Due to such tremendous pressure, the rock splits up into a loose mass of stones. The moving water has a tremendous transport capacity which by rolling action further grinds the rocks into smaller pieces. Water through its erosion forces removes weathered parts of rock, thereby exposing fresh surface to weathering. The excavation and destructive action of water is called ***denudation*.** The amount material carried by water varies as the fifth power of its velocity, while the size of material carried varies as the sixth power of its velocity. Thus doubling the velocity increases the amount of material carried 32 times ($2^5 = 32$) and the size of materials by 64 times ($2^6 = 64$).

Physical Weathering



- **Wind:** Wind carrying particles in suspension and blowing constantly over the rock at great speed exerts a grinding action, thereby the rock disintegrated. Loosely balanced rock boulders sometimes roll down by the action of wind and break into pieces. At a velocity of 5 metre per seccond, particles of 0.25 mm size are transported, while at a velocity of 10 metre per seccond, the wind can carry particles of 1 mm size.

- **Ice:** The moving ice is an erosive detachment and transporting agency with tremendous capacity. Snow received at higher elevations or polar regions accumulates and starts moving in the form of glaciers. Glaciers movement causes great deal of cutting and crushing of the bedrocks. Although glaciers are not so extensive in the present day environments; in the recent geological past, they had transported and deposited parent materials over millions of hectares on this planet. At present, glaciers are active in upper parts of the Himalayas.

- **Plants and Animals:** Some plants, like mosses and lichens, grow on the exposed rock. They accumulate dust, which further encourages plant growth, and a thin film of highly organic material is formed. Sometimes, roots of higher plants exert a prying effect on rocks (as the root girth increases with plant growth), which results in rock disintegration.

Burrowing by rodents, movement of animals, and human activities (cultivation, quarrying, land levelling, construction of roads, buildings, railway lines, etc.) also result in physical weathering. Such influences, however, are of relatively limited importance in producing parent material when compared to the drastic physical effects of water, ice, wind, and temperature changes.

3.3 Chemical weathering

While, the physical weathering is accentuated in very cold or very dry environments, the chemical weathering (reactions) are more intense where the climate is hot and humid (Wet). However, both types of weathering occur together, and each tends to accelerate the other. Chemical weathering is enhanced by such geological agents as the presence of water and oxygen, as well as by such biological agents as the acids produced by microbial and plant-root metabolism. That is why the term ***biogeochemical weathering*** is often used to describe the process. Below are basic types of chemical weathering reactions discussed: Hydration, Hydrolysis, Dissolution, Acid reactions, Oxidation-Reduction and Complexation.

- **Hydration:** Hydration means chemical combination of molecules with a particular mineral. Soil forming minerals occurring in rocks undergo hydration when exposed to humid condition. For example,

  $$\underset{\text{(Hematite)}}{2Fe_2O_3} \quad + \quad \underset{\text{(Dissociated water)}}{3HOH} \quad \rightarrow \quad \underset{\text{Limonite (Yellow)}}{2Fe_2O_3\cdot 3H_2O}$$

  Due to this reaction, the minerals increase in the volume and become soft and more readily weatherable.

- **Hydrolysis:** It is one of the important processes in chemical weathering. This reaction depends on the partial dissociation of water into H- and OH-ions. Increases in the H-ion concentration resulting in the accelerated hydrolytic action of water. Water thus, acts like a weak acid on silicate minerals.For example,

  $$\underset{\text{(Orthoclase)}}{KAlSi_3O_8} \quad + \quad \underset{\text{(Dissociated Water)}}{HOH} \quad \Leftrightarrow \quad \underset{\text{(Acid silicate)}}{HAlSi_3O_8} \; + \; \underset{\text{(Potassium)}}{KOH}$$

  $$\underset{\text{(Acid silicate)}}{2HAlSi_3O_8} \; + 8\,HOH \quad \Leftrightarrow \quad \underset{\text{(Al-oxide clay)}}{Al_2O_3\cdot 3H_2O} \quad + \quad \underset{\text{(Silicic acid)}}{6H_2SiO_3}$$

  The products of hydrolysis are either entirely or partially leached by percolating water. They may also recombine with other constituents to form clay. Hydrolysis may be considered as ***principal agents of clay formation***.

- **Dissolution:** Water is capable of dissolving many minerals by hydrating the cations and anions until they become dissociated from each other and surrounded by water molecules. For an example, Gypsum dissolves in water.

  $$\underset{\text{(Solid Gypsum)}}{CaSO_4\cdot 2H_2O} \quad + \quad \underset{\text{(Water)}}{2H_2O} \;\Leftrightarrow\; \underset{\text{(Solution)}}{Ca^{2+} + SO_4^{2-}} \quad + \quad \underset{\text{(Water)}}{4H_2O}$$

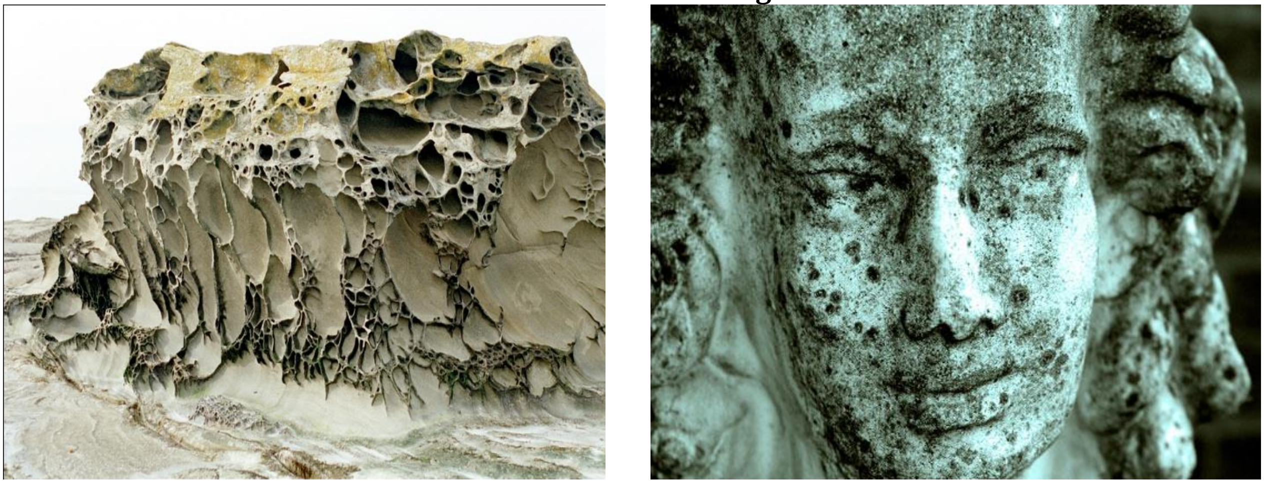
- **Oxidation:** Oxidation means addition of oxygen to minerals. Oxidation is more active in the presence of moisture and results in hydrated oxides. Soil-forming minerals containing iron, manganese are more subjected to oxidation. For example,

  $$\underset{\text{(Ferrous oxide)}}{4FeO} \quad + \quad \underset{\text{(Oxygen)}}{O_2} \Leftrightarrow \quad \underset{\text{(Ferric oxide; Hematite)}}{2Fe_2O_3}$$

  $$\underset{\text{(Magnetite)}}{4Fe_2O_4} + \quad \underset{\text{(Oxygen)}}{O_2} \Leftrightarrow \quad \underset{\text{(Ferric oxide; Hematite)}}{2Fe_2O_3}$$

A rusty-looking (red) crust is formed on the surface of the rock. The crust thickens and then slowly gets separated from the parent rock. As process continues, the change produced in the mineral weakens the rock and ultimately the rock itself crumbles to pieces.

Chemical Weathering



- **Reduction:** This means the removal of oxygen. Under condition of excess water (less or no oxygen), reduction takes place e.g.

$$2Fe_2O_3 \Leftrightarrow 4FeO + O_2$$

(Ferric oxide; Hematite) (Ferrous oxide) (Oxygen)

- **Carbonation (acid reactions):** Carbon dioxide dissolved in water, it forms carbonic acid:

$$H_2O + CO_2 \Leftrightarrow H_2CO_3$$

(Carbonic acid)

The carbonic acid or carbonated water attacks many rocks and minerals and brings them into solution. Limestone, which is insoluble in water, is dissolved readily by carbonated water and is thus, removed from the parent rock.

$$CaCO_3 + H_2CO_3 \Leftrightarrow Ca(HCO_3)_2$$

(Calcite; slightly soluble) (Calcium bicarbonate; readily soluble)

- **Complexation:** Soil biological processes produce organic acids such as oxalic, citric, and tartaric acid, as well as the much larger fulvic and humic acid molecules, which tend to forms organic-complexes with elements, e.g., oxalic acid forms a soluble complex with Al from the mineral, muscovite. As the reaction proceed to the right, it destroy the muscovite structure and release dissolved K-ions as plant nutrient.

$$K_2[Si_6Al_2]Al_4O_{20}(OH)_4 + 6C_2O_4H_2 + 8H_2O$$

(Muscovite; solid) (Oxalic acid) (Water)

$$\Leftrightarrow 2K^+ + 8OH^- + 6C2O4Al^+ + 6Si(OH)_4^0$$

(K-hydroxide; Solution) (Complex) (Solution)

3.4 Soil formation factors

The concept of soil as natural bodies was put-forward by a team of Russian Soil Scientists led by **V. V. Dokuchaiev (1889)**, and they gave an equation for soil formation.

Soil formation = *Function of (P, Cl, O)*
Where, *P = Parent material; Cl = Climate; O = Organism*

The concepts concerning the factors of soil formation are derived from the work of American Scientist, **E. W. Hilgard (1921).** Later on**, Hans Jenny (1941)** modified the Dokuchaiev's equation as:

Soil formation = *Function of (Cl, O, P, R, T…)*
Where, *P= Parent material; Cl= Climate; O= Organism; R= Relief / Topography; T=Time* *where dots…. represents unspecified unidentified factors*

Joffe categorized above factors into passive and active factors.
Active factors → Climate and Biosphere/Organisms/Vegetation
Passive factors → Parent material, Relief/Topography, Time

Soil are often defined in terms of factors (below discussed) as: *Dynamic natural bodies having properties derived from the combined effects of climate and biotic activities, as modified by topography, acting on parent materials over periods of time".*

Five factors that control the formation of soils are:

- Parent materials (geological or organic precursors to the soil); ***Lithosequence***
- Climate (primarily precipitation and temperature); ***Climosequence***
- Biota (living organisms, plants, soil organisms, human beings); ***Biosequence***
- Topography (slope, aspect, and landscape position); ***Toposequence***
- Time (time since parent material began to undergo soil formation); ***Chronosequence***

These factors do not exert influences the soil formation independently. Indeed independence is the rule. For example, contrasting climate regimes are likely to be associated with contrasting types of vegetation, and perhaps differing topography and parent material as well. Nonetheless, in certain situation one of the factors has had the dominant influence in determining differences among a set of soils. Soil scientists refer to such set of soils as *lithosequence, climosequence, biosequence, toposequence, or chronosquence*.

3.4.1 Passive soil forming factors

(i) Parent materials (Geologic material in which a soil forms)

Parent material is the unconsolidated weathered mineral or organic matter from which soil is developed. Two groups of parent material: ***Sedentary*** – parent material formed in-situ, at original place, residual parent material; and ***Transported*** – transported from their place of origin. They are named according to the main force responsible for the transport and redeposition. Following various terms are defined to relate this placement of parent materials via various agents.

Terms used	**Transporting agent/force**
Colluvial	Gravitational force / gravity
Alluvial (flood-plains, Delta)	Water
Marine	Water/Sea
Lacustrine	Deposits settled into stagnant water of lakes
Glacial (Moraines)	Ice
Eolian (Sand dunes, loess)	Wind
Peat	Organic deposits

The material transported and deposited by water is ***alluvium***, found along major stream courses, at the bottom of slopes of mountains, and along small streams flowing out of drainage basins. ***Colluvium*** is used for poorly sorted materials near the base of strong slopes transported by the action of gravity. ***Lacustrine*** consists of materials that have settled out of the quiet water of lakes. ***Glacial*** consist of all the materials picked up, mixed, disintegrated, transported and deposited through the action of glacial ice or of water resulting primarily from melting of glaciers. The wind blown materials are termed ***loess*** when the texture is silty and ***eolian*** sand when these are primarily sand. The materials deposited by the melting glaciers vary widely in particle size called as ***till*** or ***moraine***. If the parent material is transported by water and fine sediments deposited at the bottom of the sea and get exposed at the surface due to change in sea level named as ***marine***. The soils developed on such transported parent materials bear the name of the parent material, viz. alluvial soils from alluvium, colluvial soils from colluvium.

(ii) Relief or topography

The topography refers to the differences in elevation of the land surface. Topography largely determines the drainagecondition and the groundwaterlevel in the soil. On level topographic positions, almost the entire water received through rain percolates through the soil. Under these conditions, the soil formed may be considered asrepresentative of the regional climate. They have normal solum with distinct horizons. The soils on steep slopes are shallow, stony and have weakly-developed profiles with less distinct horizons. Soils on steep terrain tend to have rather shallow, poorly developed profile in comparison to soils on nearby, more level sites. On the steep terrain, water runoff and soil erosion removes surface material before it has time to develop, hence no distinct horizon observed at steep slopes. ***Red soils*** mostly developed at ***higher topographic position***, while the ***black cotton soil*** developed at ***lower topographic position***. In India black and red soils occur in close proximity, it is observed that red soils occupy higher elevated levels while the black soils are found at lower elevation levels.

(iii) Time

Soil formation is a very slow process requiring thousands of years to develop a mature pedon. The period taken by a given soil from the stage of weathered rock (i.e. regolith) up to the stage of maturity is considered as time. By matured soils, we mean soils with fully developed horizons (A, B, C). Soil formation is very slow process, takes hundreds of years to develop an inch of soil. The time that nature devotes to the formation of soils is termed as ***pedological time*** **(Figure 3.2)**.

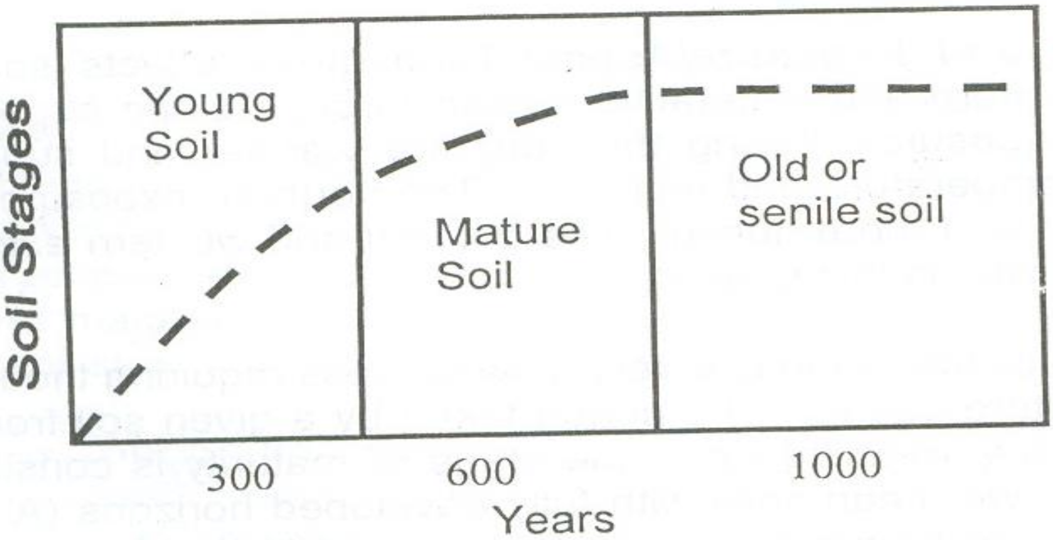


Figure 3.2: Stages of soil development

3.4.2 Active soil forming factors

The active soil forming factors are those which supply energy that acts on the mass for the process of soil formation. They are (1) *climate* and (2) *biosphere – vegetation & organism.*

(i) Climate

Climate is perhaps the most influential of the four factors acting on parent material because it determines the nature and intensity of the weathering that occurs over large geographical areas. The principal climatic variable influencing soil formation are ***effective precipitation*** and ***temperature***, both of which affect the rates of chemical, physical and biological processes. The greater the depth of water penetration, the greater the depth of weathering soil and development. Percolating water stimulates weathering reactions and helps differentiate soil horizons. For every 10 °C rise in temperature, the rates of biochemical reactions more than double.

(ii) Biosphere (vegetation and organisms)

Organic matter accumulation, biochemical weathering, profile mixing, nutrient cycling, and aggregate stability are all enhanced by the activities of organisms in the soil. Vegetative cover reduces soil erosion rates, thereby slowing down the rate of removal of surface soil-minerals. Organic acids produced from certain plants bring Fe and Al into solution by complexation and accelerate the downward movement of these metal and their accumulation in the 'B' horizon.

Burrowing animals (fauna) such as moles, earthworms, ants, termites, and rodents are highly important in soil formation. Old animal burrows in the lower horizons often become filled with soil materials from the overlying 'A' horizon, creating profile features known as ***crotovinas***. The organisms cause constant mixing within the soil profile. Ants and termites, as they build mounds, also transports soil materials from one horizon to another, and this mixing activities of animals called ***pedoturbation***.

The vegetation controls the erosion, thereby facilitates percolation as well as drainage and brings greater dissolution of minerals. Their role as soil formers is related to humification and mineralization.

3.5 Soil formation process (Pedogenic process)

Most natural processes, such as the upliftment of a mountain mass and the filling of an island in sea, take place rather slowly. In contrast, the pedogenic processes, work faster than the geological processes in changing lifeless parent material into true soil full of life. The pedogenic processes are extremely complex and dynamic involving many chemical and biological reactions, and usually operate simultaneously in a given area. One process may counteract another, or two different processes may work simultaneously to achieve the same result. The ultimate result of soil formation is profile development.

The pedogenic processes are grouped in two major categories as:

(A) Fundamental soil forming processes

(1) Humification

Humification is the process of decomposition of raw organic matter into humus. It is extremely a complex process involving various organisms. First, simple organic compounds such as sugars and starches are decomposed by microorganisms followed by proteins and cellulose and finally very resistant compounds, such as tannins, are decomposed and the dark coloured substance, known as humus, is formed.

Humification is the process of decomposition of organic matter and synthesis of new organic substances. It is the process of transformation of raw organic matter into formation of surface humus layer, called A_0- horizon. The percolating water passing through this layer dissolves certain organic acids and affects the development of the lower A-horizon and the B- horizon.

(2) Eluviation and illuviation

Eluviation is the process of removal of constituents by percolation from upper layers to lower layers. This layer of loss is called ***eluvial*** and designated as the A-horizon. The eluviated producers move down and become deposited in the lower horizon which is termed as the ***illuvial*** or B-horizon. The eluviation produces textural differences. The process of illuviation leads to the textural contrast between A_2 and B_1 horizon.

Eluviation: It is the mobilization and translocation of certain constituent's viz. Clay, Fe_2O_3, Al_2O_3, SiO_2, humus, $CaCO_3$, other salts etc. from one point of soil body to another. Eluviation means washing out. It is the process of removal of constituents in suspension or solution by the percolating water from the upper to lower layers. The eluviation encompasses mobilization and translocation of mobile constituents resulting in textural differences. The horizon formed by the process of eluviation is termed as eluvial horizon (A_2 or E horizon). The degree of translocation depends upon relative mobility of elements and depth of percolation.

Illuviation: The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer (or horizon of gains having the property of stabilizing translocated clay materials) is termed as Illuviation. The horizons formed by this process are termed as illuvial horizons (B-horizons, especially Bt). The process leads to textural contrast between E and Bt horizons, and higher fine total clay ratio in the Bt horizon.

(B) Specific soil forming processes

(1) Podsolisation

It is a type of eluviation in which humus and sequioxides become mobile, leach out from upper horizons and become deposited in the lower horizons. This process is favoured by cool and wet climate. It requires high content of organic matter and low alkali in the parent material. The process increases the proportion of silica, sesquioxide in A-horizons and accumulation of clay, iron and aluminium in B-horizons.

(2) Laterisation

In this process, silica is removed while iron and alumina remain behind in the upper layers. Laterisation is favoured by rapid decomposition of parent rocks under climates with high temperature and sufficient moisture for intense leaching, such as found in the tropics. The soil formed in this process is acidic in nature.

(3) Calcification

In this process, there is usually an accumulation of calcium carbonate in the profile. This process is favoured by scanty rainfall and alkali in parent material.

(4) Gleization

The term *glei* is of Russian origin, which means blue, grey or green clay. The ***gleization*** is a process of soil formation resulting in the development of a glei (or gley horizon) in the lower part of the soil profile above the parent material due to poor drainage condition (lack of oxygen) and where waterlogged conditions prevail. Under such condition, iron compounds are reduced to soluble ferrous forms. This is responsible for the production of typical bluish to grayish horizons with mottling of yellow and / or reddish brown colours.

(5) Salinization

Salinization is the process of accumulation of salts, such as sulphates and chlorides of calcium, magnesium, sodium and potassium, in soils in the form of salty (salic) horizons. It is quite common in arid and semi arid regions. It may also take place through capillary rise of saline ground water and by inundation with seawater in marine and coastal soils. Salt accumulation may also result from irrigation or seepage in area of impeded drainage.

(6) Desalinization

It is the removal by leaching of excess soluble salts from horizons or soil profile by ponding water and improving the drainage conditions by installing artificial drainage network.

(7) Solonization (Alkalization)

The process involves the accumulation of sodium ions on the exchange complex of the clay, resulting in the formation of sodic soils (***solonetz***).

(8) Solodization (dealkalization)

The process refers to the removal of Na^+ from the exchange sites. This process involves dispersion of clay. Dispersion occurs when Na^+ ions becomes hydrated. Much of the dispersion can be eliminated if Ca^+ and Mg^{++} ions are concentrated in the water, which is used to leach the ***solonetz***. These Ca and Mg ion can replace the Na on exchange complex, and the salts of sodium are leached out.

(9) Pedoturbation

Another process that may be operative in soils is pedoturbation. It is the process of mixing of the soil. For example argillipedoturbation is observed in deep black soils. Mixing to a certain extent takes place in all soils. The most common types of pedoturbation are:

- ✓ **Faunal pedoturbation:** Mixing of soil by animals such as ants, earthworms, moles, rodents, humans
- ✓ **Floral pedoturbation :** Mixing of soil by plants as in tree tipping that forms pits and mounds
- ✓ **Argillic pedoturbation:** Mixing of materials in the solum by the churning process caused by swell shrink clays as observed in deep Black Cotton Soils.

CHAPTER 4: SOIL PROFILE

4.1 Soil profile

The soil formation results in the formation of distinct characteristic layers or horizons in the soil. *The ultimate result of soil formation is the development of soil profile*. The development of soil profile is constructive processes where in disintegrated material resulted from weathering of rocks and minerals get converted into different soil layers.

Soil profile may be defined as a vertical section of the soil showing the various layers from the surface to the unaffected parent material. The various layers are known as ***horizons***. Soil profile represents sequence of horizons or layers differentiated from one another, but genetically related and included to the parent materials from which soil profile developed. Master soil horizons are commonly recognized and are designated using capital letter O, A, E, B, C, and bed rocks (unweathered parent materials) as letter R **(Figure 4.1).** In general, organic matter is concentrated in the O and A horizons, making them the most critical for agriculture.The ***subordinate horizons*** may occur within a master horizon and these are designated by lowercase following the capital master horizon letter, e.g., Bt, Ap, or Oi **(Table 4.1)**.

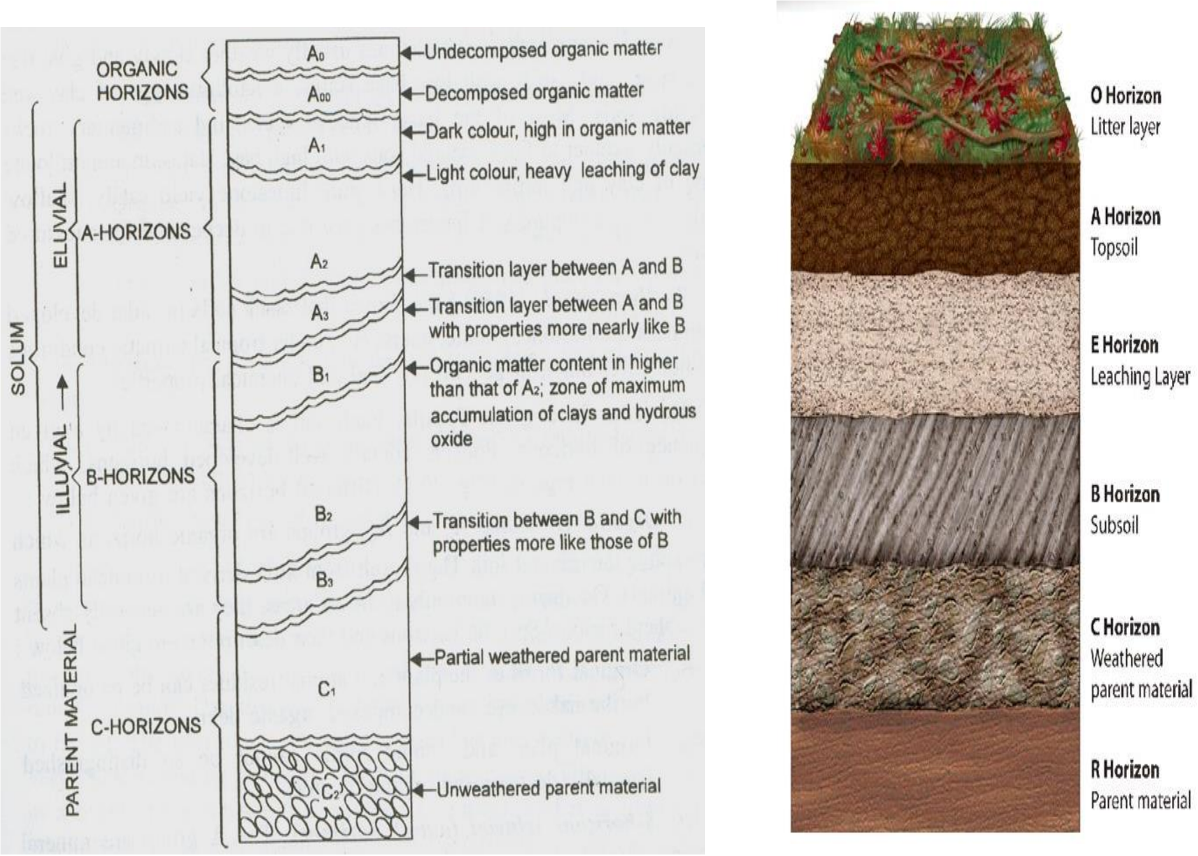


Figure 4.1: Hypothetical well-developed soil profile showing the major horizons.

The parent material from which the soil developed is horizon 'C'. The 'A' (***eluvial***) horizon is present at or near the surface, and it is characterized as zone of 'washing-out or maximum ***leaching*** or ***eluviation***'. The 'B' (***illuvial***) horizon is the zone of '***washing-in*** or ***illuviation***', or accumulation of materials such as iron and aluminium oxides and silicate clays, from above horizon.

4.2 Soil horizons

Each soil is characterized by a sequence of horizons; ***podsols*** contain well-developed horizons, which develop in cool regions. Different horizons are discussed below:

- **'O' horizon:** The 'O' group is comprised of organic horizons that generally form above the mineral soil or occur in an organic soil profile. They derived from dead plant and animal residues. Absent in grassland soil, O horizons usually occur in forested area and are referred as forest floor. Three subordinate O horizons can be distinguished.
  - ✓ ***Oi horizon:*** organic horizon of ***fibric*** material – recognized plant and animal parts, only slightly decomposed. The Oi horizon is referred to as the **litter** or **L layer**.

  - ✓ ***Oe horizon:*** consists of ***hemic*** material – finely fragmented residues intermediately decomposed, but still much fibers recognized. This layer corresponds to the **fermentation** or **F layer**.

  - ✓ ***Oa horizon:*** contains of ***sapric*** materials – highly decomposed, smooth, amorphous residues that do not retain much fiber or recognizable tissue structure. This layer is the **humidified** or **H layer**.

- **'A' horizon:** The top-most mineral horizons, generally contain enough partially decomposed (humified) organic matter to give the soil a darker colour than lower horizons. This layer are often coarse in texture, having lost some of the finer materials by translocation to lower horizons and by erosion.Thesubordinatesof A-horizon are designated by numericals as A_1, A_2 and A_3.

  - ✓ **A_1:** Topmost mineral horizons, dark coloured horizon, usually contains a high proportion of organic matter.

  - ✓ **A_2:** Light coloured horizons than horizon A_1, maximum leaching or eluviation of clay, iron and aluminium oxides and a corresponding concentration of resistant minerals such as quartz.

  - ✓ **A_3:** Transition layer between horizons A and B with properties more resemble to those of horizon A than of the underlying horizon B. Sometimes,horizon A_3 is absent.

- **'E' horizon:** These are zones of maximum leaching or eluviation (from Latin *ex* or *e*, out) of clay, iron, aluminium oxides, which leaves a concentration of resistant minerals, such as quartz, in the sand and silt sizes. The ***E horizon***is common in soils developed under forests, but they rarely occur in the soils developed under grassland.

- **'B' horizon:** Form below O, A, or E horizon, and have undergo sufficient changes during soil genesis. In this layer, materials have accumulated, typically by washing-in from the above horizons, a process termed *illuviation* (from Latin *il*, in). B horizonis the layers of maximum accumulation of materials such as Fe- and Al-oxides (Bo or Bs horizons) and silicate clays (Bt horizons). The B-horizon is also referred to as the ***subsoil***. The subordinates of B horizon are designated as B_1, B_2 and B_3.

  - ✓ **B_1:** A transition layer between A and B with properties more nearly like B than A. Also referred to as **E-horizon** as discussed above.

- ✓ **B_2:** Zone of maximum accumulation of clays and hydrous oxides. Organic matter content is generally higher than horizon A_2. Maximum development of blocky or prismatic soil structure or both.

- ✓ **B_3:** Transition layer between horizons B and C with properties more resemble to horizon B, than those of horizons C underneath.

- **'C' horizon:** This layer is the unconsolidated materials underlying the solum (horizons A and B are collectively referred as ***solum***). It may or may not be the same as the parent material from which the *solum* formed. The subordinates of C horizon are designated as C_1 and C_2.

  - ✓ **C_1:** Partially weathered parent material, contains accumulation of lime and gypsum in some soils.

  - ✓ **C_2:** Unweathered parent material. It is also referred to as R horizon as discussed under.

- **'R' horizon:** These are consolidated rock, with little evidence of weathering.

Table 4.1 Lowercase letter symbols to designate subordinate distinctions within horizons.

Letter	***Distinction***	***Letter***	***Distinction***
a	*Organic matter, highly decomposed*	**n**	*Accumulation of sodium*
b	*Burried soil horizon*	**o**	*Accumulation of Fe- and Al-oxides*
c	*Concentration or nodules*	**p**	*Ploughing or other disturbance*
d	*Dense unconsolidated materials*	**q**	*Accumulation of silica*
e	*Intermediate decomposed OM*	**r**	*Weathered or soft bedrock*
f	*Frozen soil*	**s**	*Illuvial OM and Fe/Al-oxides*
ff	*Dry-permafrost*	**ss**	*Slickensides (shiny clay wedges)*
g	*Strong gleying (mottling)*	**t**	*Accumulation of silicate clays*
h	*Illuvial accumulation or OM*	**u**	*Present of human artifacts*
i	*Slightly decomposed OM*	**v**	*Plinthite (high iron, red material)*
j	*Jarosite (yellow sulphate mineral)*	**w**	*Structure without clay accumulation*
ij	*Cryoturbation (frost churning)*	**x**	*Fragipan (high bulk density, brittle)*
k	*Accumulation of carbonates*	**y**	*Accumulation of gypsum*
m	*Cementation or induration*	**z**	*Accumulation of soluble salts*

By way of illustration, Bt horizon is a 'B' horizon characterized by silicate clays accumulation (t from the German *ton*, meaning clay). Similarly, in a Bk horizon, carbonates (k) have accumulated.

CHAPTER 5: SOIL TAXONOMY AND SOIL CLASSIFICATION

The primary objective of soil taxonomy is to establish hierarchies of classes that permit us to understand, as fully as possible, the relationship among soils and between soils and the factors responsible for their character. A second objective is to provide a means of communication for the discipline of soil science. Soil taxonomy was originally developed to serve the purposes of soil survey. Taxonomy is a narrower term than classification. Classification includes taxonomy, but it also includes the grouping of soils according to limitations that affect specific practical purposes. So, Taxonomy is the part of classification that is concerned primarily with relationships.

The study of indigenous soil classification system is called ***Ethnopedology*** .It studies with an interest in soils that have documented earlier by local people. This system most commonly classify the soil using soil colour, texture, hardness, moisture, organic matter, and topography.

5.1 Soil classification – Concept and history

The Russian scientist **V. V. Dokuchaiev** and his associates first conceived the idea that soils exist as natural bodies in nature. Dokuchaiev (1900) divided soils into three categories: Normal, Transitional and Abnormal. These categories were later termed as ***Zonal***, ***Intrazonal*** and ***Azonal*** soils, respectively.Russian soil scientist soon developed a system for classifying natural soil bodies, but poor international communications and the unwillingness of some scientist to acknowledge such fundamental ideas, delayed the universal acceptance of the natural bodies concept. In the **United States, in 1920s**, **C. F. Marbut of the USDA**, who grasped the concept of soils a natural bodies, developed a soil classification scheme based on these principles.

Principles of soil classification:

- There is really no soil '*individual*' as a self-standing object.
- Thus, the emphasis is on defining mappable classes rather than on optimal classification ofindividuals.
- There is no true inheritance or genetics as it is understood in biology.

5.1.1 Dokuchaiev's genetic system

V. V. Dokuchaiev is considered as the founder of modern soil pedology. In later 19th century, he observed an uniform loess parent material extended for hundreds of kilometres with increasing temperature gradient from north to south, and with increasing rainfall and moisture gradient from east to west. These differences in climatic conditions were associated with important vegetation patterns, varying from forest to prairie, which left their imprint on the parent materials, producing distinct soil differences. Such observations led Dokuchaiev to establish the concept of soil as an independent natural body and develop a series of publications on soil genesis and classification. The Russian approach tends to emphasize on soil genesis, and hence is termed as ***genetic system of soil classification***.

5.1.2 Marbut's morphogenetic system

Although the Dokuchaiev's approach was based on sound principles of soil genesis, it had weakness of putting excessive emphasis on climate and vegetation rather than on the intrinsic properties of the soils. **Marbut** in the USA was greatly influenced by the Dokuchaiev's approach and he accepted the concept of the Russian *soil type,* but gave it the name of ***great soil group***. **Joffe** and **Marbut** classified soil on the basis of zonality, their own properties, and morphological characters like soil colour, texture, structure, consistency, drainage conditions etc. They also emphasized on the concept of *pedalfers (Accumulation of Fe/Al Oxides)* and *pedocals (Accumulation of* $CaCO_3$*).*

5.1.2 Baldwin and his assoiciate’s genetic system

The major limitation of Marbut's system was that it was based on assumptions concerning soil genesis. As such, many of the soil series, recognized in the USA, could not find a place in the system. Hence, the morphogenetic system was revised and elaborated by **Baldwin et al. (1938)** and **Kellogg and Thorp (1949)**. The system marked the beginning of a comprehensive approach. The important characteristics of this system are:

- A return to the Russian’s zonality concept.
- The *pedocal & pedalfer* concept was not given emphasis.
- More emphasis was given on soil as a three-dimensional body with its characteristics.
- A new category, viz. soil family, was introduced between great goil group and soil series; but neither soil families nor the higher categories were defined was defined in relation to soil properties.

5.1.3 Zonality concept of genetic approach

After modification, the soils can be grouped into three orders namely, *Zonal*, *Intra-zonal* and *Azonal* based on the zonality concept developed by V. V. Dokuchaiev.

- **Zonal soils:** *Zonal soils* were groups of soils developed under similar climate conditions and distributed in a climatic belt. Soils in this group possess well developed profiles reflecting the influence of climate and vegetation. The only differences due to the parent material are rendered subordinate by dominating climate influences. For example, *laterite soil, podzol soil, chernozem soil, Seirozem soil* etc.

  > ***Podzol*** is a term given to the soils that are infertile and have a light-brown colour due to poor humus. ***Chernozem*** soil is a term given to the soils that are rich in humus and thus are fertile. *Chernozem* soil is black coloured because of the rich humus. ***Sierozem*** soil is a calcereous soil with low organic content. *Sierozem soil* is characteristic of temperate to cool arid regions with mixed shrub vegetation.

- **Intrazonal soils:**The soils occur within a zone, but reflect the influence of some local conditions, such as topography and/or the parent material. Under these conditions, the characteristics of soils imparted by the local conditions and dominant viz., excess of water, salt, calcium carbonate etc. For example, saline soil, sodic soil etc.

- **Azonal soils:**The soils have poorly developed profiles because of time as limiting factor. The group include young soils without horizon differentiation. For example, alluvial soils.The soils formed in regions, where time has been a limiting factor to produce fullydeveloped horizons

5.1.4 Soil Taxonomy: Comprehensive soil classification system

In 1951, in the USA, the soil survey staff of USDA began to collaborate with soil scientists from many countries to devise classification system to address all soils in the world. The 7th Approximation was published in 1960 with supplements in 1964 and 1967. As a result, Soil Taxonomy: A basic system of soil classification for making and interpreting soil survey was published in 1975, and revised in 1999, is used in USA and approximately 50 other countries.

Salient features of 7th approximation

The 7th approximation system of soil classification has an edge over the earlier systems in the following respects:

- Unlike the genetic systems, this system is based on measurable soil properties that exist today.
- It considers all soil properties which affect soil genesis or are the outcome of soil genesis.
- The common definition of a class of taxonomic system is type or orthotype.
- The nomenclature, using coined words, is derived mainly from Greek and Latin languages. Although it appears difficult, once understood, it is the most logical nomenclature and helps in relating the place of taxon in the system and in making interpretations.
- A new category, viz.,*subgroup,* has been introduced to define the central concepts of *great groups* and their intergrades in order to express and recognize more clearly that soils are in continuum and show gradual change in many properties.

5.2 Pedon

There are seldom sharp demarcations between one soil individual to another. Soils in the field are heterogeneous, i.e., the profile characteristics are not exactly same in any two points within the soil individual you may choose to examined. Consequently, it is necessary to characterize a soil individual in terms of an imaginary three-dimensional unit called a ***pedon*** (from Greek word '*pedon*' means ground). ***Pedon*** is the smallest 3-dimentional sampling unit that displays the full range of properties of a particular soil. *Pedon* serves as the fundamental unit of soil classification.

5.3 Diagnostic horizons of soils

A ***diagnostic horizon*** is defined as one, formed through pedogenic processes and having distinct properties or features that can be described in terms of measurable soil properties. The *diagnostic horizons* are largely used for identifying soils and also in classifying them at various categoric levels, especially great groups. A number of *diagnostic horizons* have been defined in soil taxonomy. Based on their soil profiles, these horizons are of two types, viz., *diagnostic surface* and *subsurface horizons*.

The diagnostic surface horizons are called ***epipedons*** (Greek *epi*, over, upon and *pedon*, soil). The epipedons are simply the upper most soil horizons and include the upper part of the soil darkened by organic matter. They are not synonymous with A-horizon. Nine epipedons, viz. folistic, histic, melanic, mollic, anthropic, umbric, ochric, plaggen and grossarenic are recognized **(Table 5.1)**, but generally speaking, three of these, viz. *mollic, ochric* and *umbric,* are of importance in India.

The diagnostic subsurface horizons are called ***endopedons*** (Greek *endodermis,* subsurface or deep-seated and *pedon,* soil). The endopedon includes the lower part of the soil where soil materials accumulate. Nineteen endopedons, viz. argillic, natric, agric, spodic, sombric, cambic, kandic, oxic, sulphuric, salic, placic, albic, glossic, calcic, gypsic, duripan, fragipan, petrocalcic and petrogypsic are recognized **(Table 5.2)**. Of these, eight, viz. argillic, natric, cambic, kandic, oxic, salic, calcic and gypsic are commonly observed in India.

Table 5.1. Major features of ***epipedons*** in mineral soil used at higher levels of Soil Taxonomy

Diagnostic horizons	Major features
Surface horizons (Epipedons)	
Anthropic	Human-modified mollic-like horizon, high in available P
Folistic	Organic horizon saturated for less than 30 days per normal year
Histic	Very high in organic content, wet during some part of year
Melanic	Thick, black, high in organic matter (>6% Organic C), common in volcanic ash soil
Mollic	Thick, dark-coloured, high base saturation, strong structure
Ochric	Too light-coloured, low organic content or thin Mollic; may be hard and massive
Plaggen	Human-made sod-like horizon created by years of manuring
Umbric	Same as Mollic except low base saturation
Grossarenic	Sandy (loamy fine sand or coarser) horizon, 100 cm thick over an argillic horizon

Table 5.2. Major features of ***endopedons*** in mineral soil used at higher levels of Soil Taxonomy

Diagnostic horizons	Major features
Subsurface horizons (Endopedons)	
Agric (A or B)	Organic and clay accumulation just below plough layer resulting from cultivation
Albic (E)	Light-coloured, clay and Fe- and Al-oxides mostly removed
Argillic (Bt)	Silicate clay accumulation
Calcic (Bk)	Accumulation of $CaCO_3$ or $CaCO_3 \cdot MgCO_3$
Cambric(Bw, Bg)	Changed or altered by physical movement or by chemical reactions, generally non-illuvial
Duripan (Bqm)	Hard pan, strongly cemented by silica
Fragipan (Bx)	Brittle pan, usually loamy textured, dense, coarse prisms
Glossic (E)	Whitish eluvial horizon that tongues into a Bt horizon
Gypsic (By)	Accumulation of gypsum
Kandic (Bt)	Accumulation of low-activity clays
Natric (Btn)	Argillic, high in sodium, columnar or prismatic structure
Oxic (Bo)	Highly weathered, primarily mixture of Fe, Al oxides and non-sticky type silicate clays
Petrocalcic (Ckm)	Cemented calcic horizon
Petrogypsic (Cym)	Cemented gypsic horizon
Placic (Csm)	Thin pan cemented with Fe alone or with Mn or organic mater
Salic (Bz)	Accumulation of salts
Sombric (Bh)	Organic matter accumulation
Spodic (Bh, Bs)	Organic matter, Fe and Al oxide accumulation
Sulfuric (Cj)	Highly acid with Jarosite mottle

5.4 Categories and Nomenclature of Soil Taxonomy

There are six hierarchical categories of classification in Soil Taxonomy: (i) ***order***, the highest or broadest category, (ii) ***suborder***, (iii) ***great group***, (iv) ***subgroup***, (v) ***family***, (vi) ***series***, the most specific category. Thus, each order has several suborder, each suborder has several great groups, and so on (**Figure 5.1**).

Figure 5.1: The categories of *Soil Taxonomy* and appropriate number of units in each category.

5.5 Nomenclature of Soil Taxonomy

The names of the classification units are combination of *syllable*, most of which are derived from Latin or Greek, and are root words in several modern language. Since each part of a soil name conveys a concept of soil character or genesis, the name automatically describes the general kind of soil being classified. For example, soils of the order ***Aridisols*** (from the Latin *aridus*, dry and *solum*, soil) are characteristically dry soils in arid regions. Those of the order ***Inceptisols*** (from Latin, *Inceptum*, beginning, and *solum*, soil) are soils with only beginnings or inception of profile development. Thus, the names of orders are combinations of (i) formative elements, which generally defines the characteristics of the soils, and (ii) the ending ‘***sols***’.

The names of suborders automatically identify the order of which they are a part. For example, soils of the suborder **Aquolls** are the wetter soils (from Latin *aqua*, water) of the **Mollisols** order. Likewise, the name of the great group identifies the suborder and order of which it is part. **Argiaquolls**are **Aquolls** with clay or *argillic* (Latin *agrilla*, white clay) horizons. In following illustration, note that the three letters ‘**oll**’ identify each of the lower categories as being in the M**oll**isols order. So, if one is given only the subgroup name, the great group, suborder and order to which the soil belongs are automatically known.

M**oll**isols	Order
Aqu**oll**s	Suborder
Argiaqu**oll**s	Great group
Typic Argiaqu**oll**s	Subgroup

5.2.1 Soil order

Each of the world’s soils is assigned to one of 12 orders (A VAGAMI HOUSE – phrase to facilitate in remembering names of soil orders), is largely on the basis of soil properties that reflects a major course of development, with considerable emphasis placed on the presence or absence of major diagnostic horizons (**Table 5.2**). Note that all order names have a common ending, *sols* (from the Latin *solum*, soil). The general conditions that enhance the formation of soils in the different orders are shown in **Figure 5.2.**

Table 5.2: Names of soil orders in *soil taxonomy* with their derivation and major characteristics.
(*Source: N. C. Brady, The Nature and Properties of Soil*)

Name	**Formative element**	**Origin**	**Major characteristics**
Alfisols	***alf***	–	Agrillic, natric, or kandic horizon; high-medium base saturation
Andisols	***and***	Jap. ando, black soils	From volcani ejecta, dominated by allophane/Al-humic complex
Ar**id**isols	***id***	L. aridus, dry	Dry soil, ochric epipedon, sometimes argillic or natric horizon
Entisols	***ent***	–	Little profile development, ochric epipedons common
G**el**isols*	***el***	Gk. gelid, very cold	Permafrost, often with cryoturbation (frost churning)
H**ist**osols	***ist***	Gk. histos, tissue	Peat or bog; >20% organic matter
Inc**ept**isols	***ept***	L. inceptum, start	Embryonic soils with few diagnostic features, ochric or umbric epipedon, cambic horizon
M**oll**isols	***oll***	L. mollis, soft	Mollic epipedon, high base saturation, dark soils, some with argillic or natric horizon
Oxisols	***ox***	Fr. oxide, oxide	Oxic horizon, no argillic horizon, highly weathered
Sp**od**osols	***od***	Gk. spodos, wood ash	Spodic horizon usually with Fe, Al oxides, humus accumulation
Ultisols	***Ult***	L. ultimus, last	Argillic or kandic horizon, low base saturation
V**ert**isols	***Ert***	L. verto, turn	High in swelling clays, deep cracks when soil is dry

L. = Latin; Gk. = Greek; Fr. = French; Jap. = Japanese. The bold letters in the order names indicate the formative element used as the ending for suborders and lower taxa within that order. *recently added soil order.

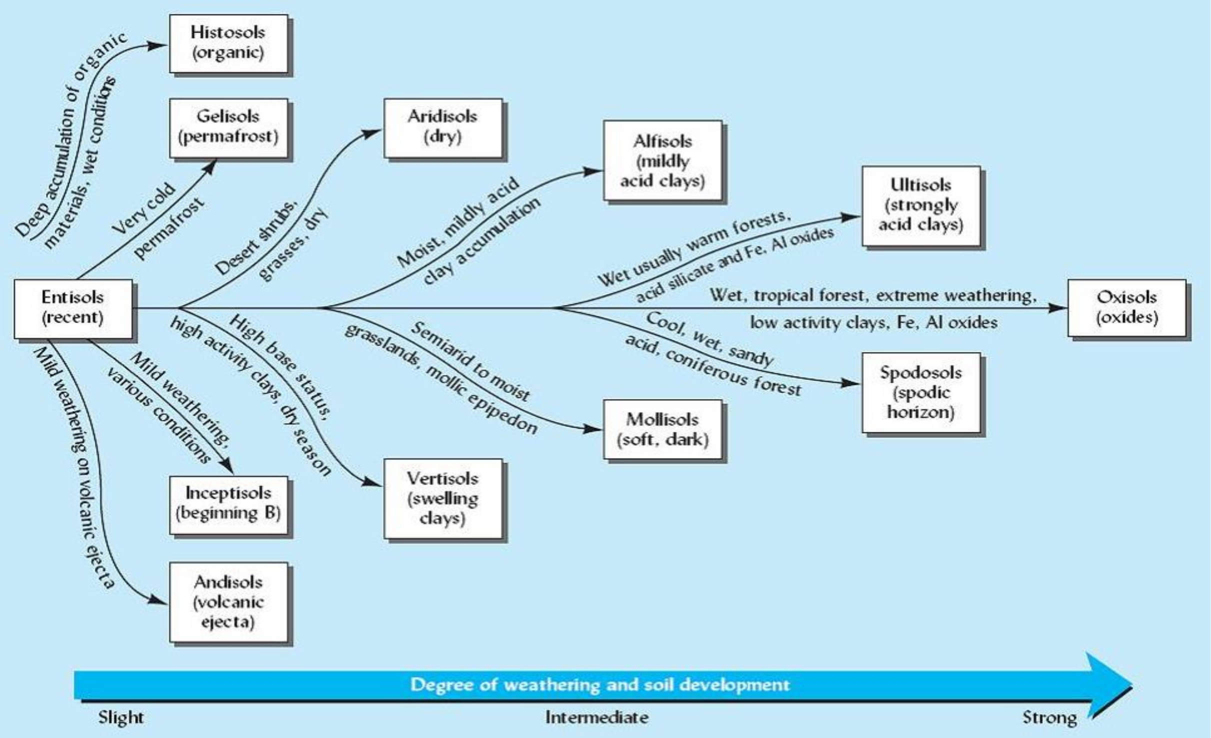


Figure 5.2: Degree of weathering and soil development in different soil orders.
(*Source: N. C. Brady, The Nature and Properties of Soil*)

5.2.2 Soil suborder

Soils within each order are grouped into suborders (as mentioned above in each order detail) on the basis of soil properties that reflect **major environmental control on current soil-forming processes**. It is composed of formative element of order + any differentiating character like temperature, moisture, drainage, diagnostic horizon etc. For example, Aquolls–wet soil in order Mollisols (oll), Aquents– wet soil in order Entisols (ent), Argid – white clay soils in Aridisol (id)

5.2.3 Great groups

The great groups are subdivisions of suborders. More than 400 great groups are recognized. They are **defined largely by the presence or absence of diagnostic horizons** and the arrangement of those horizons.

5.2.4 Subgroups

Subgroups are subdivisions of the great groups. More than 2500 subgroups are recognized. The central concept of a great group makes one subgroup, termed *Typic*. Thus, the Typic Hapludolls subgroup typifies the Hapludolls great group.

Table 5.3: Names of soil suborders in *soil taxonomy* with their derivation and major characteristics. (*Source: N. C. Brady, The Nature and Properties of Soil*)

Formative elements	Derivation / origin	Description of formative element
alb	L. *albus*, white	Presence of albic horizon (a bleached eluvial horizon)
anthr	Gk. *anthropose*, human	Presence of anthropic or plaggen epipedon
aqu	L. *aqua*, water	Characteristics associated with wetness
ar	L. *arare*, to plough	Mixed horizons
arg	L. *argilla*, white clay	Presence of argillic horizon (horizon with illuvial clay)
calc	L. *calcic*, lime	Presence of calcic horizon
camb	L. *cambriare*, to change	Presence of cambic horizon
cry	Gk. *kryos*, icy cold	Cold
dur	L. *durus*, hard	Presence of a duripan
fibr	L. *fibra*, fiber	Least decomposed stage
fluv	L. *fluvius*, river	Floodplains
fol	L. *folia*, leaf	Mass of leaves
gel	Gk. *gelid*, cold	Cold
gyps	L. *gypsum*, gypsum	Presence of gypsic horizon
hem	L. *hemi*, half	Intermediate stage of decomposition
hist	Gk. *histos*, tissue	Presence of histic epipedon
hum	L. *humus*, earth	Presence of organic matter
orth	Gk. *orthos*, true	The common ones
per	L. *per*, throughout time	Of year-round humid climates, perudic SMR
psamm	Gk. *psammos*, sand	Sand textures
rend	Rendzina modified	Rendzina-like high in carbonates
sal	L. *sal*, salt	Presence of salic (saline) horizon
sapr	Gk. *sapros*, rotten	Most decomposed stage
torr	L. *torridus*, hot and dry	Usually dry
turb	L. *turbidus*, disturbed	Cryoturbation
ud	L. *udus*, humid	Of humid climates
ust	L. *ustus*, burnt	Of dry climates, usually hot in summer
vitr	L. *vitreus*, glass	Resembling glass
xer	Gk. *xeros*, dry	Dry summers, moist winters

5.2.5 Families

Within, a subgroup, soils fall into a particular family, if at a specified depth, they have similar physical and chemical properties affecting the growth of plant roots. About 8000 families have been identified. The criteria used include broad classes of particles size, mineralogy, cation exchange activity of the clay, temperature, and depth of the soil penetrable by roots. Table 5.3gives examples of the classes used.

5.2.6 Series

The series category is the most specific unit of the classification system. It is a subdivision of the family, and each series is defined by a specific range of soil properties involving primarily the kind, thickness, and arrangement of horizons. Some examples of the soil series identified and taxonomically grouped is shown below.

Soil Series	**Subgroup**	**Great group**	**Suborder**	**Order**
Bodali	*Vertic Ustorthents*	*Ustorthents*	*Orthents*	*Entisols*
Eru	*Typic Chromusterts*	*Chromusterts*	*Usterts*	*Vertisols*
Ilav	*Typic Ustorthents*	*Ustochrepts*	*Orthents*	*Inseptisol*
Dandi	*Typic Halaquepts*	*Halaquepts*	*Aquepts*	*Inseptisol*

Differentiating characteristics and description of soil classification system

Order (12)	There are 12 Orders "A VAGAMI HOUSE*" phrase suggested to facilitate naming of all the Orders. These are based largely on morphology, as produced by soil-forming processes, and indicated by the presence or absence of major diagnostic horizons.
Suborder (63)	There are 63 Suborders within 12 Orders. These emphasize genetic homogeneity, wetness, climatic environment, parent material and vegetational effects. The differentiate used vary, but most tend to emphasize wetness and moisture regime.
Great Group (240+ approximately)	There are 240 Great Groups within 63 Suborders of 12 Orders. The major emphasis is on the diagnostic horizons (except in Entisols which have no such horizon) and presence or absence of diagnostic layers, base status, soil temperature and moisture regimes. There are more than 1,000 Subgroups. The Typic is used to define the central concept of a great group; the others are used to indicate intergraded to great groups, suborders and orders, and the extra-graded to 'not soil'.
Subgroup (1000+)	
Family	The soil properties that are most important for plant growth (like texture, mineralogical class (dominant of solum), soil temperature class (based on MAST at 50 cm depth) and pH are used to differentiate families. They meet the need for making practical prediction for land-use planning.
Series (Approximately 200+ in India; and 12,000 in the USA)	It is the lowest category in the system. The series is a collection of soil individuals, essentially uniform in differentiating characteristics (like colour, texture, structure, consistence, pH and EC) and in arrangement of horizons. It is the series which is most useful for making land-use plans of a small area. The series are named after the geographic name of the place where it was first recognized or where they have wide extent of distribution, e.g. Jodhan loam, Tigris silt loam. The textural name, along with the series name, suggest the surface phase.

CHAPTER 6: SOILS OF INDIA AND GUJARAT

6.1 Soils of India

India is a country of vast dimensions with varied conditions of geology, relief, climate and vegetation. Therefore, India has a large variety of soil groups, distinctly different from one another. Soils of India have been divided into the following major groups (**Figure 6.1**).

1. Alluvial soils
2. Tarai soils
3. Black soils
4. Red soils
5. Laterites and lateritic soils
6. Arid and desert soils
7. Forest and mountain soils
8. Peaty and marshy soils
9. Saline and alkalinesoils

Alluvial soils (soil order: Entisols, Inceptisols and Alfisols)

Alluvial soils are by far the largest and the most important soil group of India. Covering about 15 lakh square km (~45.6% of the total land area of the country), these soils contribute the largest share of our agricultural wealth and support the bulk of India's population.Most of the alluvial soils are derived from the sediments deposited by rivers as in the Indo-Gangetic plain. Although some alluvial soils in the coastal areas have been formed by the sea waves. Thus, the parent material of these soils is all of transported origin (**Figure 6.1**).

Geologically, the alluvium of the Great plain of India is divided into younger *khādir* or *khadar* soils(sandy, generally light coloured and less calcareous) and older *bhangar*or *bangar* soils (More clayey, generally dark and calcareous). The *khadar* soils are found in the low areas of valley bottom which are flooded almost every year. *Bhaggar* soils, on the other hand, is found on the higher reaches about 30 metres above the flood level.

In general alluvial soils are low in nitrogen except in Brahmaputra valley. Alluvial soils are found in Indo-gangetic plains of Uttar Pradesh, West Bengal, Bihar, Gujarat, Brahmaputra valley of Assam and along the coastal regions of India. Alluvial soils are fertile and suitable for most of the agricultural crops like lowland rice, wheat, oilseeds, pulses, sugarcane, banana, etc.

Tarai soils (soil order: Mollisols)

Along the Shiwalik foothills, there are alluvial fans having coarse, often pebbly soils. This zone is called ***bhabar***. To the south of the *bhabar* is a long narrow strip of swampy lowland with silty soils. It covers an area of 56,600 square km and is called ***tarai***.

The *tarai* soils are rich in nitrogen and organic matter but are deficient in phosphate. These soils are generally covered by tall grasses and forests but are suitable for a number of crops such as wheat, rice, sugarcane, jute and soyabean under reclaimed conditions.

Black soils (soil order: Entisols, Inceptisols, Vertisols)

The black soils are also called ***regur*** (from the Telugu word *Reguda*) and black cotton soils because cotton is the most important crop grown on these soils. These soils have been formed due to the solidifaction of lava spread over large areas during volcanic activity in the Deccan Plateau, thousands of years ago.Most of the black soils are derived from two types of rocks, the

Deccan and the Rajmahal trap, and ferruginous gneisses and schists occurring in Tamil Nadu. The soils formed from the trap rocks are sufficiently deep while the soils formed from gneiss and schists are generally shallow.In some parts of Gujarat and Tamil Nadu, the origin of black cotton soils is ascribed to old lagoons in which the rivers deposited the materials brought down from the interior of Peninsula covered with lava.

Geographically, black soils are spread over 5.46 lakh square km (~16.6% of the total geographical area) encompassed between 15°N to 25°N latitudes and 72°E to 82°E longitudes, characterized by high temperature and low rainfall regions. These soils are mainly found in Maharashtra, Madhya Pradesh, parts of Karnataka, Andhra Pradesh, Gujarat and Tamil Nadu. Black soils are dark grey in colour, which is due to the presence of clay-humus complex (**Figure 6.1**).

Characteristics of black soils:

- Black soils have higher water retension capacity. It swells greatly and becomes sticky when wet in rainy season. Under such conditions, it is almost impossible to work on such soil because the plough gets stuck in the mud.
- However, in the hot dry season, the moisture evaporates, the soil shrinks and is seamed with broad and deep cracks, often 10-15 cm wide and upto a metre deep.
- Black soils are characterized by Impeded drainage and low permeability of water.
- Highly clayey soil (35-60%). A typical black soil is highly argillaceous with a large clay factor, 62% or more, without gravel or coarse sand.
- Potash is variable (<0.5%) and phosphates, nitrogen and humus (organic matter) are low in black soils. Soil structure is cloddish but occasionally friable.
- They are calcareous with high cation exchange capacity of 30-50 cmol/kg of soil).
- Major crops grown in black soils are: cotton, sugarcane, groundnut, millets, maize, sorghum, pulses, safflower, sunflower, Virginia tobacco, castor, etc.

Red soils (soil order: Alfisols, Inceptisols, Ultisols)

Most of the red soils have come into existence due to weathering of ancient crystalline and metamorphic rocks (main parent rocks are acid granites, gneiss, quartzitic) either in-situ or from decomposed rock materials.The red colour is due to the coating of ferric oxides on soil particles.

The red soils occupy a vast area of about 3.5 lakh square km (~10.6% of the total geographical area. These soils are spread on almost the whole of Tamil Nadu, parts of Karnataka, south-east of Maharashtra, eastern parts of Andhra Pradesh and Madhya Pradesh, Chhattisgarh, Orissa and Chota Nagpur in Jharkhand.

Properties of red soils:

- Red soils have argillic subsurface horizon.
- The texture of these soils varies from sand to clay, the majority being loams.
- Red soils are well-drained with moderate permeability.
- By and large, the red soils are poor in lime, magnesia, phosphates, nitrogen and humus, but are fairly rich in potash.
- The red soils respond well to the proper use of fertilizers and irrigation and give excellent yields of cotton, wheat, maize, rice, pulses, millets, tobacco, oil seeds, potatoes, pigeon pea and fruits.

Laterites and Lateritic soils (soil order: Ultisols, Oxisols, Alfisols)

The word ‘laterite’ from Latin meaning brick, and term used for soils having 90-100% of iron, aluminium, titanium and manganese oxides concentration. The laterite soil is formed under conditions of high temperature and heavy rainfall with alternate wet and dry periods.It is probably the end product of decomposition found in regions of heavy rainfall, >200 cm. Such climatic conditions promote leaching of soil whereby lime and silica are leached away and a soil rich in oxides of iron and aluminium compounds is left behind (i.e., laterization process).

Laterite and lateritic soils are widely spread in India and cover an area of 2.48 lakh square km. They are mainly found on the summits of Western Ghats at 1000-1500 metre above mean sea level, Eastern Ghats, the Rajamahal Hills, Vindhyas, Satpuras and Malwa Plateau.They also occur at lower levels and in valleys in several other parts of the country. They are well developed in south Maharashtra, parts of Karnataka, Andhra Pradesh, Orissa, West Bengal, Kerala, Jharkhand, Assam and Meghalaya.

Properties of laterites:

- Almost all laterite soils are very poor in lime and magnesia, and deficient in nitrogen.
- Typical laterite soils generally lack fertility and are of little use for crop production.
- Low silica/sesquioxide ratio.
- Low in Ca and Mg, but well drained and porous.
- When manured and irrigated, some laterites and lateritics are suitable for growing plantation crops like tea, coffee, rubber, cinchona, coconut, arecanut, etc. In low lying areas paddy is also grown.

Arid and desert soils (soil order: Aridisols, Entisols)

A large part of the arid and semi-arid region in Rajasthan and adjoining areas of Punjab and Haryana lying between the Indus and the Aravalis, covering an area of 1.42 lakh square km (~4.32% of total geographical area) and receiving less than 50 cm of annual rainfall, is affected by desert conditions.The Rann of Kuchchh in Gujarat is an extension of this desert.Barren sandy soils without clay factor are also common in coastal regions of Orissa, Tamil Nadu and Kerala. The desert soils consist of aeolian sand (90-95%) and clay (5-10%).

Properties of desert soils:

- Sand dunes and undulating sandy plains.
- Accumulation of alkaline earth carbonates.
- Clay content is very low.
- These soil contains high percentages of soluble salts, are alkaline (pH 8.0-8.8) with varying degree of calcium carbonate and are poor in organic
- Moderate to high phosphates and nitrates content make them fertile soils wherever moisture is available.
- However, in large areas of desert soils, only the drought resistant and salt tolerant crops such as barley, rape, cotton, wheat, millets, maize and pulses are grown.

Forest and mountain soils (soil order: Histosols)

Such soils are mainly found on the hill slopes covered by forests. These soils occupy about 2.85 lakh square km (~8.67% of the total land area of India). The formation of these soils is mainly governed by the characteristic deposition of organic matter derived from forest growth.

In the Himalayan region, such soils are mainly found in valley basins, depressions, and less steeply inclined slopes. Apart from the Himalayan region, the forest soils occur on Western and Eastern Ghats as well as in some parts of the Peninsular plateau.

The forest soils are very rich in humus but are deficient in potash, phosphorus and lime. They are especially suitable for plantations of tea, coffee, spices and tropical fruits in Karnataka, Tamil Nadu and Kerala and wheat, maize, barley and temperate fruits in Jammu and Kashmir, Himachal Pradesh and Uttaranchal.

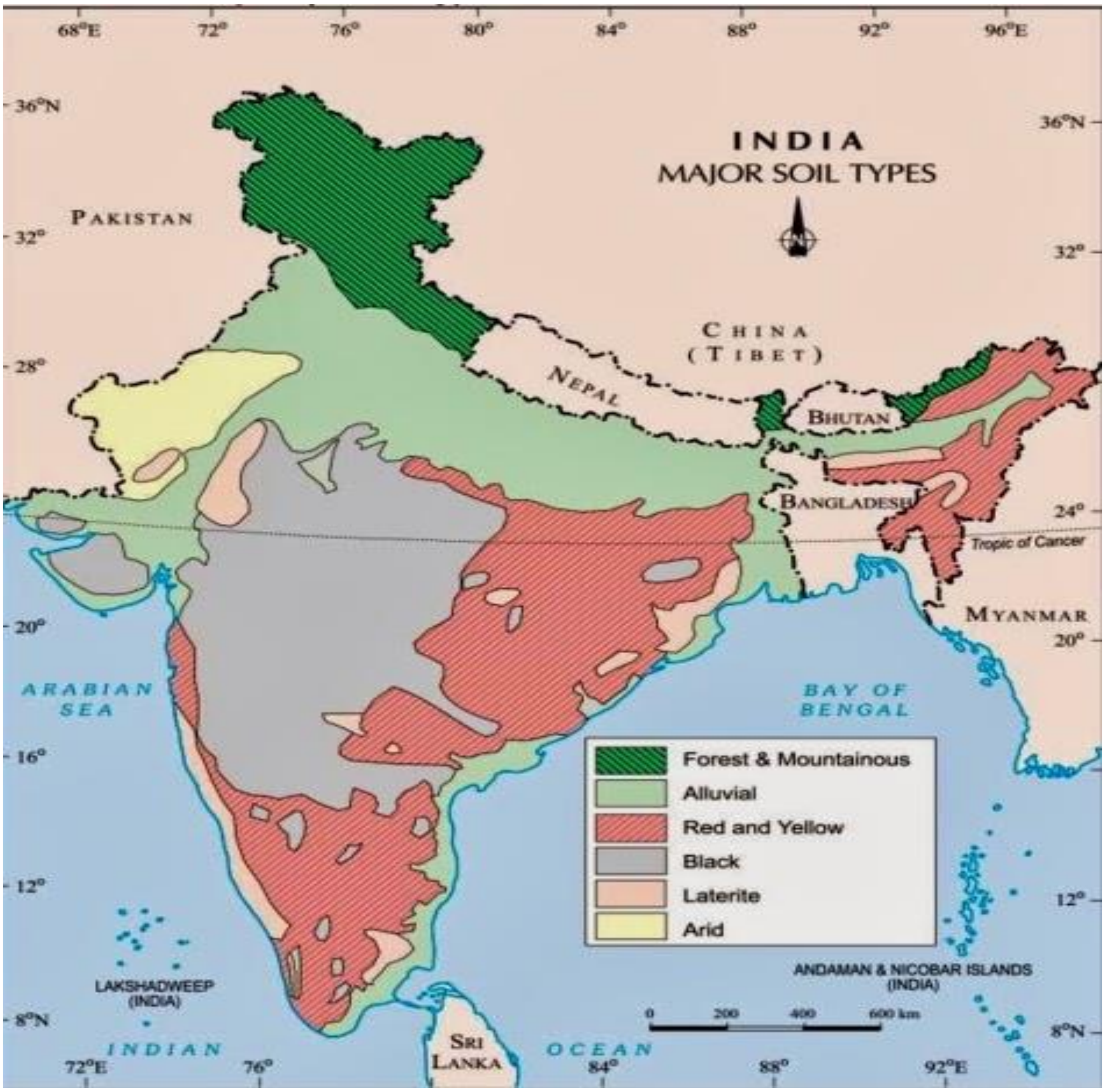


Figure 6.1: Major soil groups of India

Peaty and marshy soils

Peaty soils originate in humid regions as a result of accumulation of large amounts of organic matter in the soils. These soils contain considerable amount of soluble salts and 10-40% of organic matter. Soils belonging to this group are found in Kottayam and Alappuzha districts of Kerala. Marshy soils with a high proportion of vegetable matter also occur in the coastal areas of Orissa and Tamil Nadu, Sunderbans of West Bengal, in Bihar and Almora district of Uttaranchal.

The peaty soils are black, heavy and highly acidic. They are deficient in potash and phosphate. Most of the peaty soils are under water during the rainy season but as soon the rains cease, they are put under paddy cultivation.

Saline and alkaline soils (soil order: Aridisols, Inceptisols, Alfisols, Entisols, Vertisols)

These soils are found in Andhra Pradesh and Karnataka. In the drier parts of Bihar, Uttar Pradesh, Haryana, Punjab, Rajasthan and Maharashtra, there are salt-impregnated or alkaline soils occupying 68000 square km of area. These soils are liable to saline and alkaline efflorescences. It has been estimated that about 1.25 million hectares of land in Uttar Pradesh and 1.21 million hectares in Punjab has been affected by salts. In Gujarat, the area round the Gulf of Khambhat is affected by the sea tides carrying salt-laden deposits. Vast areas comprising the estuaries of the Narmada, the Tapi, the Mahi and the Sabarmati have thus become infertile.

6.2 Soils of Gujarat

Gujarat has total geographical area of 19.6 millionhectares with about 1600 km of coastal belt. About 10.9 millionhectares land is cultivated out total geographical area. About 2 miilion hectares (about 10.5%) area is under forest.Gujarat lies on the west coast of India between 21.1-24.7 °N latitude and 68.4-74.4 °E longitude. The state can be broadly divided into two natural regions: Main land (i.e., plains, north-eastern hill, and coastal regions) and Kutch-Saurashtra peninsula.

The soils of Gujarat are classified into nine broad groups of which black and alluvial soils are predominently found in major areas of the state (**Figure 6.1**).

1. Black soil
2. Mixed red and black soils
3. Residual sandy soils
4. Alluvial soils
5. Lateritic soils
6. Hilly soils
7. Desert soils
8. Forest soils.
9. Saline and alkali soils

According to National Bureau of Soil Science and Land Use Planning (NBSS & LUP), Nagpur, the soil of Gujarat belongs to: 5 soil orders, 11 suborders, 20 great groups, 45 subgroupds, 124 families, 145 soil series. Among the 5 orders 51% of soil are of Inceptisols, 13.8% of Entisols, 10.6% of Aridisols, 8.9% of Vertisols, and 0.6% Alfisols.

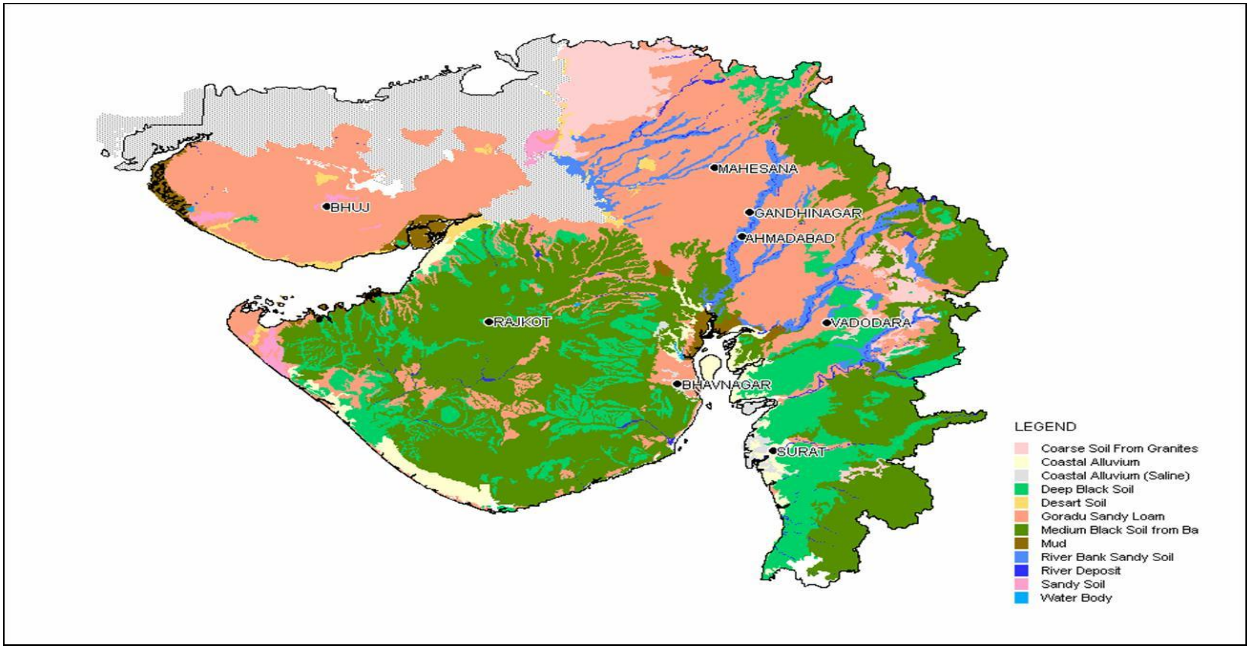


Figure 6.2: Major soil groups of Gujarat state.

Black soils

There are three types of black soils namely: shallow, medium and deep soils.

- ***Shallow black soils***
  - Shallow black soils have been developed from basaltic trap in Saurashtra, Deccan trap in extreme eastern part and the remaining strips in Chhotaudepur and Saurashtra districts have been developed from granite and gneiss parent material.
  - The depth of soil ranges from a few cm to 30 cm.
  - These soils do not have sub surface diagnostic horizon and soils are light grey in colour.
  - In some places they are gravelly but mainly they are sandy clay loam in texture.
  - Soil structure is weak, mainly subangular blocky and occasionally crumb.
  - Generally, these soils are poor in fertility.

- ***Medium black soils***
  - ✓ These residual soils with medium depth of 30-60 cm.
  - ✓ Theses soils are derived from basaltic trap parent material in Saurashtra except in coastal belt, from granite and gneiss in some parts of Sabarkantha, Panchmahals and Ahmedabad districts and a narrow strip form Chhotaudepur to Vansada and Dharampur in South Gujarat.
  - ✓ Calcium is the dominant exchangeable cation followed by magnesium.These soils are calcareous in nature in Saurashtra. Free lime content varies between 15-45% in Junagadh district.
  - ✓ The soil profile has A-C horizon with having moderate subangular blocky structure plastic, sticky and hard consistency.
  - ✓ These soils are silty loam to clay in texture, with neutral to alkaline in reaction.
  - ✓ These are poorly supplied with nitrogen and phosphorus with adequate supply of potassium.

- ***Deep black soils***
  - ✓ These soils are also known as '***regurs***' or black cotton soils and have their origin in trap.
  - ✓ The depth varies from 60 cm to as much as few metre.
  - ✓ These soils occur mainly in Bharuch, Surat and Valsad districts of South Gujarat.
  - ✓ The tract known as '*Bhal*' comprising area between Dhandhuka and Bhavnagar has typical deep black soils formed due to deposition of trap parent material transported through flow of rivers.
  - ✓ Similarly, in the '*Ghed*' tract covering mainly the talukas of Porbander, Kutiyana and Manavadar and part of Mangrol taluka, the deep black soils have been formed due to deposition of basaltic trap materials transported by rivers Bhadar, Minsar, Ozat Madhuvanti etc., and faced the problem of salinity and alkalinity.
  - ✓ These soils contain 40-70% clay dominated by smectite group of clay minerals.
  - ✓ These soils are natural to alkaline in reaction, poor in drainage.
  - ✓ The soil exchange complex is dominated by calcium followed by magnesium, nitrogen and potassium.
  - ✓ These soils are comparatively more fertile than the shallow and medium black soils.
  - ✓ These soils are grouped under *Chromusterts*.

Mixed red and black soils

- ✓ These soils are localized in small areas in Junagadh district.
- ✓ These soils are shallow in depth, red or grayish brown coloured with A-C profile.
- ✓ These solis are clay loam to clay in texture, provides ideal drainage condition.
- ✓ These are soils are highly calcareous and alkaline in reaction.

- ✓ These soils are low in nitrogen, medium in phosphorus, and high in potassium.

Residual sandy soils

- ✓ Residual sandy soils have developed in-situ from the parent material originated from red sandstone and shale. These soils occur in some parts of Kutch, Surendranagar and Rajkot districts. The similar soils have developed due to weathering of granite and quartzite parent rocks along the north-eastern border of Banaskantha and Sabarkantha districts.
- ✓ All these residual soils are shallow in depth, red brown in colour with A-C profile characteristics.
- ✓ These soils are sandy to loamy sand in texture dominated by coarse sand.
- ✓ These soils are non-calcareolls, neutral to alkaline in reaction with poor base saturation.
- ✓ From fertility point of view, these soils are poorly supplied with plant nutrients and as such support the crops with short duration and less water requirement.
- ✓ These are classified as Ustorthents and Ustipsamments of Entisols order.

Alluvial soils

Alluvial soils have been formed due to silting by the Indus river system. These soils are very deep. The river flowing through its bed, deposited the coarse material first giving rise to coarse sandy type of soils which are found in Banaskantha and part of Mehsana districts while comparatively finer material was deposited at a further distance near the sea. These soils are further divided as alluvial sandy to sandy loam soils, alluvial sandy loam to sandy clay loam and coastal alluvial soil.

- ***Alluvial sandy to sandy loam soils***
  - ✓ These soils cover the entire northern districts, namely, Banaskantha and Mehsana except its southern part and the area of Sabarkantha bordering Kheralu and Vijapur talukus of Mehsana district.
  - ✓ The original alluvial material in the Banaskantha and some parts of the Mehsana district has been overlain by the sandy material which has been brought by the winds blowing through the desert of Kutch.This sand which is impregnated with salt has imparted salinity to the area where it has been deposited.
  - ✓ These soils have much less base saturation compared to black soils.
  - ✓ These soils are neutral to alkaline in soil reaction.
  - ✓ From fertility point of view, these soils are low in available nutrients.

- ***Alluvial sandy loam to sandy clay loam***
  - ✓ These soils are found in Kheda and Gandhinagar districts, eastern part of Ahmedabad district, southern part of Mehsana district and western part of Vadodara district. In addition to this, they are also found in low lying areas.
  - ✓ These soils may be considered to be two types, are locally known as *Goradu* or *Gorat* soils and *Bhatta* soils. The *Goradu* soils are nothing but alluvial soils of older origin, while *Bhatta* soils are of recent origin deposited chiefly along the banks of river.
  - ✓ In some places even a third type of soil locally known as *Besar* soils is found which has a reddish brown colour. These soils are silty clay loam to clay loam in texture, very deep and well drained. These soils are the most productive in the whole of the State and well supplied with potassium due to presence of illite type of clay mineral.

- ***Coastal alluvial soils***
  - ✓ These soils are situated along the sea coast extending in length to more than 1600 km.
  - ✓ They are fairly deep, and normally medium in fertility.

- ✓ These soils are sandy clay loam to clay texture.
- ✓ The soil reaction varies from neutral to highly alkaline.
- ✓ These are classified as Halaquents, Fluvaquents of Entisols order and Halaquepts and Haplaquepts of Inceptisols order.

- ***Lateritic soils***
  - ✓ There are no true laterites exists in Gujarat.
  - ✓ However, in Dangs district, with abundant forest vegetation and high annual precipitation of about 250 cm lateritic soils have developed.
  - ✓ These soils are yellowish red in colour in the upper horizon. Colour changes to dark reddish brown in the lower horizons.
  - ✓ The thickness of solum ranges from 22-40 cm.
  - ✓ The surface horizon is moderately porous having weakly developed sub-angular blocky to crumb structure.
  - ✓ The soil reaction is neutral to slightly acidic.
  - ✓ These soils are highly susceptible to erosion.

- ***Hilly soils***
  - ✓ Hill soils occur in the hilly areas of Surendranagar, Amreli, Jamnagar, Bhavnagar and Junagadh district in Saurashtra, Kutch and eastern strip of the mainland Gujarat. These soils are found in the Dang and Panchmahalas districts.
  - ✓ Because of the steep slope and erosion the soil profile is not well developed.
  - ✓ They are shallow in depth composed of undecomposed rock fragments and poor in fertility.
  - ✓ These soils can be classified into Ustorthents.
- ***Desert soils***
  - ✓ These soils are the two Ranns (Deserts) of Kutch namely, little desert and greater desert.
  - ✓ The alluvial deposits due to the river system flowing through the area have subsequently been overlain by the aeolian deposits.
  - ✓ These soils are fairly deep, light grey in colour with no definite structure.
  - ✓ The soil texture is sandy to sandy loam with silty clay loam in some areas.
  - ✓ The salt content is very high with the sodium chloride as the dominant salt.
  - ✓ Sufficient amount of the gypsum is available in the profile.
  - ✓ These soils fall mainly under two order, namely Aridisols and Entisols.

- ***Forest soils***
  - ✓ Of the total arable land in Gujarat about 10.5 % is under forest.
  - ✓ These soils are clayey in texture.
  - ✓ Junagadh forest soils have higher percentage of sand fraction and those of Dangs forest soils have higher silt fraction.
  - ✓ Junagadh forest soils have high organic matter and lime contents compared to those of Dangs forest soils.
  - ✓ Junagadh forest soils are neutral in soil reaction, whereas Dangs forestsoils are acidic.

- ***Problematic soils (saline and alkali soils):***
  - ✓ Generally, saline soils are encountered along the coastal area.
  - ✓ The major areas affected are due to the desert soils in Kutch and those affected along the sea coast due to ingress of sea water, i.e., Bhal tract with flat topography.
  - ✓ Water logging for a long time has created saline and alkaline conditions in these regions.
  - ✓ The soils of the Bhal are clayey with a high percentage of lime.
  - ✓ The irrigation projects have raised the water table and have contributed to the problem of salinity in the areas of Kheda, Ahmedabad, Surat and Valsad districts.

CHAPTER 7: PHYSICAL PROPERTIES OF SOIL

7.1 Components of soil

Soil is an extremely complex and variable material, but all soil consists of four major components (**Figure 2.3**).

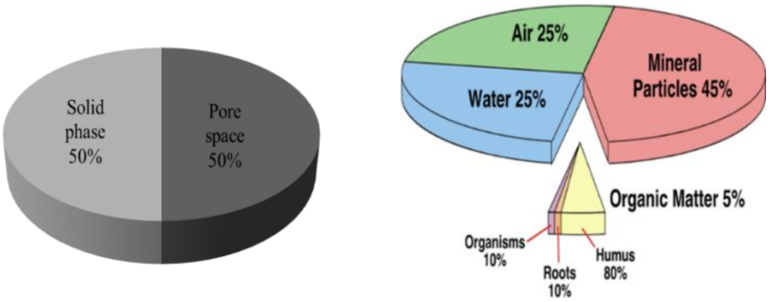


Figure 2.3 Proporation of Soil Components (by volume)

1. ***Mineral matter (~45%)*** – clays, silicates, cations and anions.
2. ***Organic matter (~5%)*** – decomposed organic matter, humus.
3. ***Soil Water (~25%)*** – chemically bound to various compounds, physically bound by adsorption or as free-to move moisture.
4. ***Soil Air (~25%)***– provides channels for movement of water and organisms.

Soil contains about 50% solid space and 50% pore space. The total pore space of the soil is occupied and shared by air and water on roughly equal basis. The proportion of air and water will vary depending upon the weather and environmental factors.

Mineral matter in soils

Generally, it is composed of very fine broken rock fragments and minerals either dominated by inorganic constituents or dominated by distinct minerals like quartz and feldspars. The **primary minerals** viz., quartz, biotite, muscovite, etc., dominate the coarser fractions of soil i.e. sand and silt particles, on the other hand, the **secondary minerals**, viz., silicate clays and hydrous oxide clays of iron and aluminium etc., are present as very fine fraction, i.e. clay particles in the soils.

Organic matter in soils

It exists as partly decayed and partially synthesized plant and animal residues, being broken down as a result of microbial activity in soil. The organic matter content in a soil is very small and varies from only 3 – 5% by weight in a top soil. Organic matter is a store house of nutrients in soils. Besides theses, organic matter is responsible for desirable surface soil structure, promotes a greater proportion of micro pore sizes; improves water holding capacity and also soil aerations.

Soil water

Water is held within the soil pores with varying degrees of forces. Soil water also presents along with dissolved salts and makes up the soil solution. This soil solution (water plus dissolved salts) is an important medium for supplying different essential nutrients to the growing plant through exchange phenomena between soil solid surface and soil solution and finally between soil solution and the plant roots.

Soil air

Air spaces or pore spaces (voids) in a soil consists of that portion of the soil volume not occupied by soil solids, either mineral or organic. Under field conditions, pore spaces are occupied at all time by air and water. The more the water, the less room of air and vice-a-versa. Soil air contains various gases like carbon dioxide, oxygen and nitrogen etc. Generally soil air contains much more carbon dioxide and small amount of oxygen than that of atmospheric air due to microbial respiration where large amount of carbon dioxide release into the soil and the oxygen is taken up by them.

7.2 Important of physical properties of soils

Soil is comprised of mineral matter, organic matter, water and air. The composition and proportion of these components greatly influence soil physical properties listed below. In turn, these properties affect air and water movement in the soil, and thus the soil's ability to function. The plant support, root penetration, drainage, aeration, retention of moisture, and plant nutrients are linked with the physical conditions of the soil. Physical properties also influence the chemical and biological behaviour of all soils.The physical properties of a soil depend on the amount, size, shape, arrangement and mineral composition of the soil particles, kind and amount of organic matter and the volume and form of its pores and the way they occupied by water, air at a particular time.

Features of the soil profile and the soil horizons are often described in the field in terms of the physical properties of soils. Horizons are defined based on difference in the soil physical properties. Major physical properties of soils are discussed hereunder:

- Soil separate
- Soil texture
- Soil specific surface area
- Soil aggregate
- Soil structure
- Soil density and porosity
- Soil consistency
- Soil colour
- Soil water / soil moisture (discussed in chapter 8)
- Soil air and soil temperature (discussed in chapter 9)

7.2.1 Soil separates

The mineral component constituents the largest volume of soil mass (~45%) and plays a vital role in determining most of the physical properties of soil. This mineral portion consists of particles of various sizes. Soil scientists usually separate them into convenient groups according to size. The various groups like gravels, sands, silts, clays are termed as ***soil separates or fractions***. The process of determining soil separate below 2 mm in diameters is called ***mechanical analysis***.

Classification of soil separates

Soil separates have been classified differently by various soil related national agencies or institutions. They are:

- United State Department of Agriculture soil separate classification **(Table 7.1)**
- British Standard Institution soil separate classification
- International Union of Soil Science (ISSS) soil separate classification
- United State Public Roads Administrative (USPRA) soil separate classification

Characteristics and physical nature of soil separates

Sand separates are large sized particles and have the large size of pore spaces. Hence, they facilitate easy percolation and encourage aeration, and their water holding capacity is low. They do not possess plasticity. **Clay** separates are smaller in size and possess fine pore spaces. With the decrease in particle sizes, there is a decrease in aeration and percolation rate. The water holding capacity of clay is very high. Properties such as plasticity, swelling, cohesion etc., are very high.

Silt separates are intermediate in size. Silts also show properties somewhat intermediary between sands and clays. **Table 7.3** present the comparison of characteristics of all three soil separates.

Table 7.1: USDA system of soil separate classification

Diameter / size (mm)	Name of soil separates
<0.002	Clay
0.002 – 0.05	Silt
0.05 – 0.10	Very Fine Sand
0.10 – 0.25	Fine Sand
0.25 – 0.50	Medium Sand
0.50 – 1.00	Coarse Sand
1.00 – 2.00	Very Coarse And
>2.00	Gravel

Table 7.2: International system of soil separate classification (commonly followed in India)

Diameter / size (mm)	Name of soil separates
<0.002	Clay
0.002 – 0 .02	Silt
0.02 – 0.2	Fine Sand
0.2 – 2	Coarse sand
>2	Gravel

Table 7.3: Characteristics of soil separates

Characteristics	**Sand**	**Silt**	**Clay**
Size (mm)	2.0-0.02	0.02-0.002	<0.002
Visibility	Visible by naked eye	Visible by microscope	Visible by ultra microscope
Water holding capacity	Low	Medium	High
Total pore space	Least	Medium	Highest
Size of pore space	Larger	Medium	Very small
Air & water movement	Very rapid	Moderate	Slow
Plasticity, swelling, cohesion etc	Very low	Moderate	Very high
Feel while rubbing between thumb and fingers	Gritty feel	flour or talcum powder like feel	Very plastic and sticky feel when wet and become hard under dry condition
Tillage	Easy	Moderate	Difficult
Minerals	Quartz	Feldspar, Mica, hematite, Quartz	Kaolinite, montmorillonite, illite
Chemical activity	Chemically inactive	Slightly active	Chemical activity

Soil particle size determination (Mechanical analysis)

The mineral component constitutes the soil mass. This mineral portion consists of particles of various sizes. According to the size, the soil particles are grouped into gravels, sands, silts and clays which are termed as soil separates.

The process of determining the amounts of individual soil separates below 2 mm in diameter is called ***mechanical analysis***. It is based on **Stokes's law (1851)** which states that when soil particles are suspended in water they tend to sink and their velocity (V) of settling is proportional to the square of the radius (r) of each particle.

The relation between the diameter of a particle and its settling velocity is given below:

$$V = \frac{2}{9}\frac{(D_p - D_w)gr^2}{\eta}$$

Where,

V = Velocity of particle fall (cm sec^{-1})
g = Acceleration due to gravity (cm sec^{-2})
D_p = Density of the particle (g cm^{-3})
D_w = Density of the liquid (g cm^{-3})
r = radius of the particle (cm)
η = Absolute viscosity of the liquid (poise)

- **Assumptions of stokes's law**
  - ✓ The particles must be large in comparison of liquid molecules, so that Brownian movement will not affect the fall.
  - ✓ The extent of the liquid must be great in comparison with the size of the particles.
  - ✓ The fall of the particle must not be affected by the proximity of the wall of the vessel or of the adjacent particles.
  - ✓ Partilce must be rigid and smooth
  - ✓ There must be no slipping between the particle and the liquid.
  - ✓ The particle greater than silt size fractions of a soil cannot be separated accurately with the help of the Stokes's law.

To conduct a mechanical analysis, a sample of soil is crushed lightly in a wooden mortar. The material is next passed through the sieve is taken for mechanical analysis. The organic matter and other binding materials are removed from the soil before the mechanical separation.There are several methods of mechanical analysis viz., sieve method, sedimentation method, decantation method, centrifugal method, pipette method and hydrometer method. Pipette method is universally employed for carrying out mechanical analysis of soil.

7.2.2 Soil texture

Natural soils are made-up of soil particles of varying sizes. Texture is an important soil characteristic because it will partly determine water intake rates (absorption), water storage in the soil, the ease of tillage operation, aeration status and altogether it greatly influence the soil fertility.

"***Soil texture*** refers to the relative percentage of sand, silt and clay in a soil"or *"**Soil texture*** is relative proportion of soil separates of various sizes in a given soils".

For instance, a coarse sandy soil is easy to cultivate, has enough aeration for good root growth and easily get wetted, but it also dries rapidly and easily loses plant nutrient through leaching. Whereas clayey soils (>35% clay) have very small particles the fit tightly together, leaving very little pore spaces which permits very little room for water to flow into the soil. This condition makes soil difficult to wet, drain and till.

Soil texture is a basic property of a soil and it cannot be altered or changed like ploughing or puddling; but can be improved through addition of organic matter like FYM, tank silk, etc.

Soil textural classes

Textural names are given to soils based upon the relative proportion of each of the three soil separates – sand, silt, and clay. Soil that are predominately clay, are called clayey (textural class), those with high silt content are silty (textural class), and those with high sand percentage are sandy (textural class). Three broad and functional groups of soil textural classes are recognized:

• ***Sandy***	Soils of which the sand separates make up 70% or more of the materials by weight
• ***Loam***	An ideal *loam* soil may be defined as a mixture of sand, silt and clay particles which exhibits light and heavy properties in about equal proportions. **Note** the loam doesn't contain equal percentages of sand, silt and clay separates. It does, however, exhibit approximately equal properties of sand, silt and clay.
• ***Clayey***	A clay soil must carry at least 35% of clay separate and it most cases not <40%.

The textural triangle (**Figure 7.2**) is used to determine the soil textural name after performing mechanical analysis in the laboratory. Based on the proportion of sand, silt and clay particles, classification was made and standardized into twelve classes as shown in a triangular diagram. This triangle is known as USDA soil textural triangle. The twelve classes are as follows: (i) Sand (i) Silt (iii) Clay (iv) Loam sandy (v) Clay silty (vi) Clay (vii) Clay-loam (viii) Loamy sand (ix) Sandy loam (x) Silty loam (xi) Sandy clay loam, and (xii) Silty clay loam.

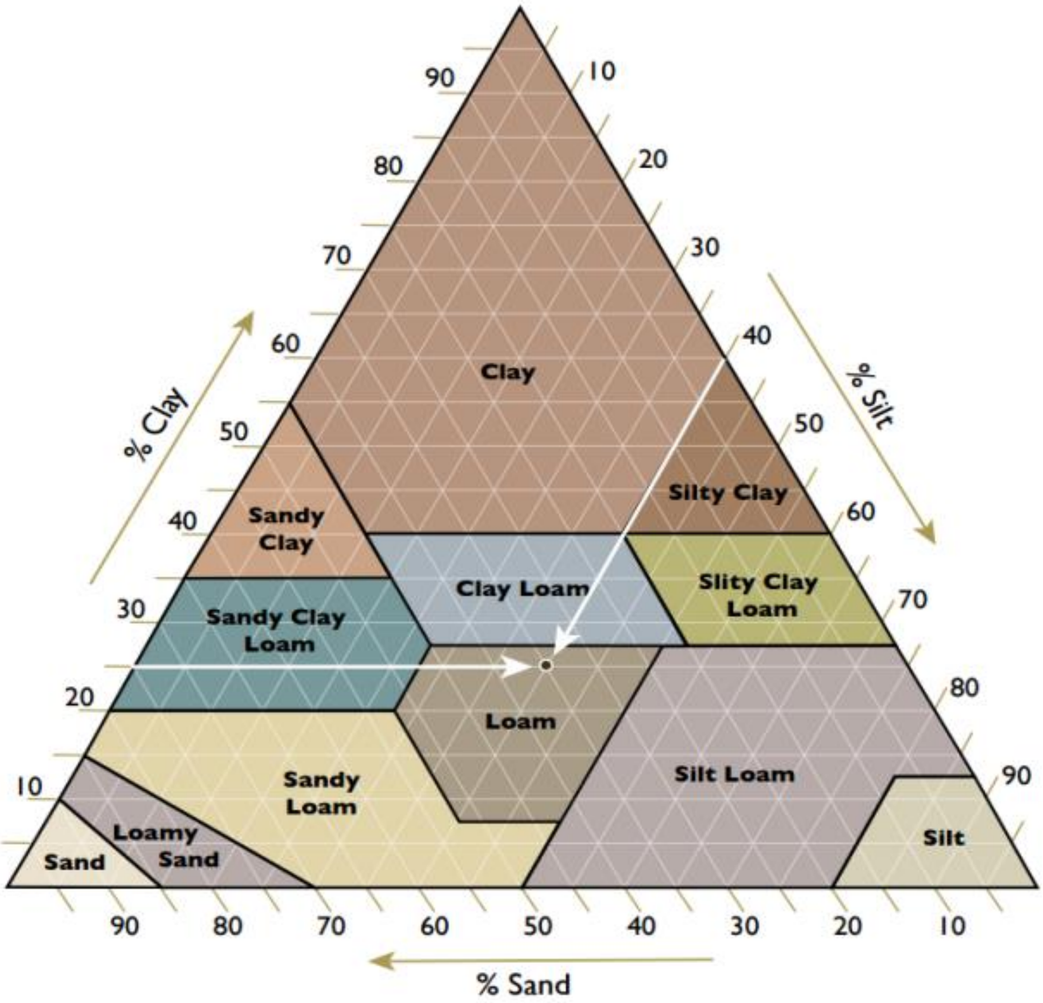
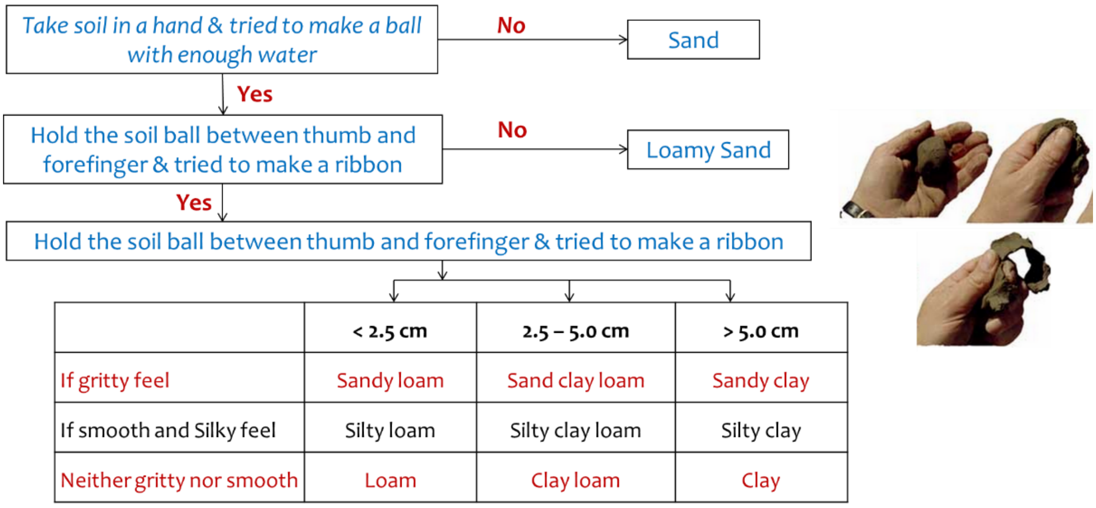


Figure 7.2: Soil textural class triangle

Soil texture by 'Feel method'

This is the simplest technique and all you need bottle of water, a rule and texture flow chart **(Figure 7.3)**. Each soil separate has distinct texture that you can distinguish by touch. Sand feels gritty and you can see individual grain with the naked eyes. Silt will feel smooth almost like silky, but you can only see individual particles under a microscope. Clay is the smallest particle, however, when wet it will feel sticky and can easily be moulded into long ribbons.

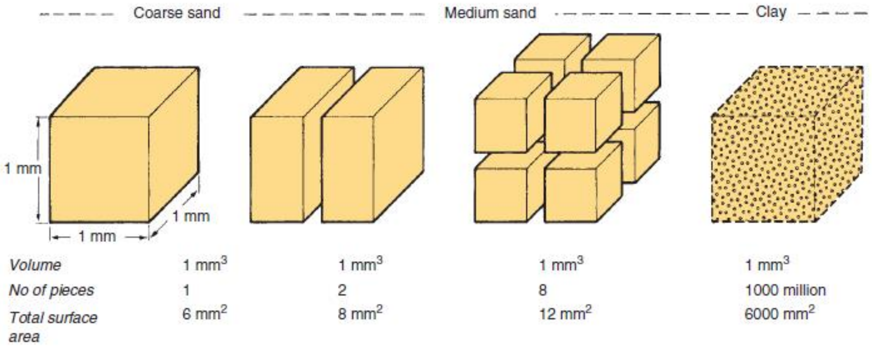


	< 2.5 cm	2.5 – 5.0 cm	> 5.0 cm
If gritty feel	Sandy loam	Sand clay loam	Sandy clay
If smooth and Silky feel	Silty loam	Silty clay loam	Silty clay
Neither gritty nor smooth	Loam	Clay loam	Clay

Figure 7.3: Soil texture by Feel Method

7.2.3 Soil specific surface area

Soil specific surface area refers to the surface area for a given mass (or volume) of particles. When particle size decreases, specific area increases geometrically **(Figure 7.4)**. Soil specific surface area depends on shape and size of soil particle, for instance if spherical, it depend on r = radius and ρ = density.



Volume	1 mm^3	1 mm^3	1 mm^3	1 mm^3
No of pieces	1	2	8	1000 million
Total surface area	6 mm^2	8 mm^2	12 mm^2	6000 mm^2

Figure 7.4 Subdivision particles, increases surface area

$$Surface\ Area\ (A) = 4\pi r^2 \qquad Density\ (\rho) = \frac{Mass\ (M)}{Volume\ (V)} = \frac{Mass\ (M)}{\frac{4\pi r^3}{3}}$$

$$\therefore Mass\ (M) = \rho \times \frac{4\pi r^3}{3}$$

$$Specific\ Surface\ Area = \frac{A}{M} = \frac{4\pi r^2}{\rho \times \frac{4\pi r^3}{3}} = \frac{3}{\rho \times r}$$

That implies that specific surface area inversely proportional to the radius of soil particles.

Surface area of soil affects its physical and chemical properties and is largely determined by amount of clay present in soil. Clay is the smallest mineral particle in soil and are the active portion of a soil, because chemical reactions occur at their surface. Clay particles have about 1000-times as much external surface area as the particles in an equal weight of sand.

Importance of specific surface area in soil

- Maintain water films
- Chemical attachment and adsorption at the surface
- Weathering at the surfaces
- Surface electromagnetic charges as forces of soil aggregation
- Microbes tend to grow on particle surfaces

7.2.4 Soil aggregates

"***Soil aggregates*** *are groups of soil particles that bind to each other more strongly than to adjacent particles. Aggregate stability refers to the measure of resistance of soil aggregates to break down or disruptive forces associated with tillage and water or wind erosion are applied*".

Soil aggregates is a general term for any distinct lump or clumping of soil particles, including ped, clods or fragment. ***Ped*** is an aggregate formed in the soil and may be an aggregation of smaller peds and is separated from other similar aggregates by an obvious pattern of cracks or partings. **Clod** is an aggregate of 100 mm or more in length and formed by soil disturbance such as cultivation. **Fragment** is an aggregate less than 100 mm in length and formed by soil disturbance such as cultivation

Formation of soil aggregation

There are several factors that influences the formation of soil aggregates **(Figure 7.5)** and they are:

- Fungi filaments, called hyphae, which extend into soil and tie soil particles together.
- Roots also excrete sugars into the soil that help bind minerals.
- Oxides also act as glue and join particles together. This aggregation process is very common to many highly weathered tropical soils.
- Finally, soil particles may naturally be attracted one another through electrostatic forces, much like the attraction between hair and a balloon.

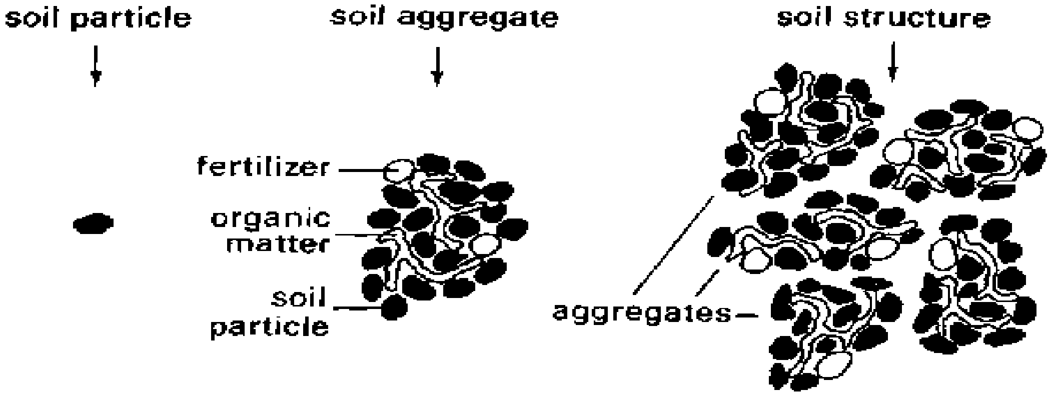


Figure 7.5: Formation of soil aggregates and soil structure

Soil aggregate stability

Aggregate stability refers to the ability of soil aggregates to resist disintegration when disruptive forces associated with tillage and water or wind erosion are applied. ***Wet aggregate stability*** suggests how well a soil can resist raindrop impact and water erosion, while size distribution of ***dry aggregates*** can be used to predict resistance to abrasion and wind erosion.

Ideal aggregates are stable against rainfall and water movement. Aggregates that break down in water or fall apart when struck by raindrops release individual soil particles that can seal the soil surface and clog pores. This breakdown creates crusts that close pores and other pathways for water and air entry into a soil and also restrict emergence of seedlings from a soil.

Aggregate stability is an indicator of organic matter content, biological activity, and nutrient cycling in soil. Greater amounts of stable aggregates suggest better soil quality. When the proportion of large to small aggregates increases, soil quality generally increases. Stable aggregates can also provide a large range in pore space, including small pores within the aggregates and large pores between aggregates. Pore space is essential for air and water entry into soil, and for air, water, nutrient, and biota movement within soil.

Practice that improve soil aggregation

- Practices that keep soil covered physically, protect it from erosive forces that disrupt aggregation, while also building organic matter. Any practice that increases soil organic matter, and consequently biological activity, improves aggregate stability.
- Aggregates form readily in soil receiving organic amendments, such as manure.
- They also form readily where cover and green manure crops and pasture and forage crops are grown, and where residue management and/or reduced tillage methods are practised.
- Pasture and forage plants have dense, fibrous root systems that contribute organic matter and encourage microbial activity.

7.2.5 Soil structure

"The arrangement of soil particles and their aggregate into certain defined patterns is called ***soil structure****"* or *"The arrangement and organization of primary and secondary particles in a soil mass is known as* ***soil structure****".*

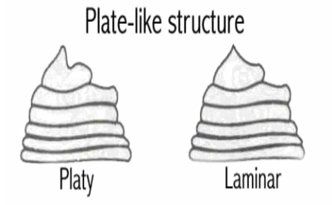
Most soils are having a mixture of single grain structure or aggregate structure. These groups of soil aggregates are combined together by the binding effect of organic and inorganic soil colloids. The formation of soil structure is promoted by chemical (flocculation) processes, physical processes (e.g., freezing, drying), and, especially, biological processes (e.g., binding of particles by microbial glues and fungal hyphae, as well as by fine plant roots).

Soil structure can be changed or improved by operations like ploughing, puddling, addition of organic matter, etc. The management practices like proper land use, suitable tillage practice at optimum moisture level, addition of organic matter, crop rotation, optimum fertilization, mulching, drainage, controlled irrigation, soil conservation, protection against compaction and use of soil conditioner may be tried for better soil structure management.

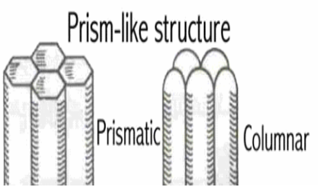
Classification of soil structures

There are four principal forms of soil structure.

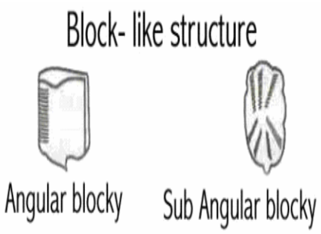
- **Plate-like (Platy)**
  The aggregates are arranged in relatively thin horizontal plates or leaflets. The horizontal axis are larger than the vertical axis. When the units/layers are thick, they are called ***platy***. When they are thin, called ***laminar***. Platy structure is most noticeable in the surface layers of virgin soils, and it may be present in the subsoil.



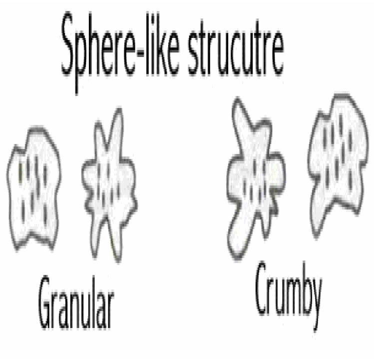
- **Prism-like**
  The vertical axis is more developed than horizontal, giving a pillar like shape. Vary in length from 1-10 cm; commonly occur in sub-soil horizons of arid and semi-arid regions. When the tops of pillar are rounded, the structure is termed as ***columnar***, and when the pillar tops are flat plane, level and clear cut called ***prismatic***.



- **Block-like**
  In this structure type, all three dimensions are about the same size. The aggregates have been reduced to blocks. When the faces are flat and distinct and the edges are sharp angular, the structure is named as ***angular blocky***. When the faces and edges are mainly rounded it is called ***sub-angular blocky***. These types usually are confined to the sub-soil and characteristics have much to do with soil drainage, aeration and root penetration.



- **Spheroidal (Sphere-like)**
  All rounded aggregates (peds) may be placed in this category. Not exceeding an inch in diameter. These rounded complexes usually loosely arranged and readily separated. When wetted, the intervening spaces generally are not closed (by swelling) as in the case with a blocky structural condition. Therefore, in sphere like structure, infiltration, percolation and aeration are not affected by wetting of soil. The aggregates of this group are usually termed as ***granular*** which are relatively less porous. When the granules are very porous, it is termed as ***crumb***. This is specific to surface soil particularly high in organic matter/grass land soils.



Factors affecting soil structure

The development of soil structure in arable soil depends on the following factors:

- **Climate:** In arid regions, there is very little aggregation of primary particles. In semi-arid regions, the degree of aggregation is greater.

- **Organic matter:** Organic matter improves the structure of a sandy soil as well as of a clay soil. In case of a sandy soil, the sticky and slimy material produced by the decomposing organic matter and the associated microorganism cement the sand particles together to form aggregates. In case of clayey soil, it modifies the properties of clay by reducing its cohesiveness. This helps making clay more crumby.

- **Tillage:** Cultivation implements break down the large clods into smaller fragments and aggregates. For obtaining good granular and crumby structure, optimum moisture content in the soil is necessary. If the moisture content is too high, it will form large clods on drying. If it is too low, some of the existing aggregates will be broken down.

- **Plants, roots and residues:** Excretion of gelatinous organic compounds and exudates from roots serve as cementing agents for aggregation. Root hairs make soil particles to cling together. Pressure exerted by the roots also held the particles together. Plant residues serve as a food to microbes which are the prime agents of aggregate builders.

- **Animals:** Among the soil fauna, small animals like earthworms, moles and insects etc., that burrow in the soil are the chief agents that take part in the aggregation of finer particles.

- **Microbes:** Algae, fungi, actinomycetes and fungi keep the soil particles together. Fungi and actinomycetes exert mechanical binding by mycelia, cementation by the products of decomposition and materials synthesized by bacteria.

- **Fertilizers:** Fertilizer like sodium nitrate destroys granulation by reducing the stability of aggregates. Few fertilizers for example, CAN (Calcium Ammonium Sulphate) help in development of good structures.

- **Wetting and drying:** When a dry soil is wetted, the soil colloids swell on absorbing water. On drying, shrinkage produces strains in the soil mass gives rise to cracks, which break it up into clods and granules of various sizes.

- **Exchangeable cations:** Ca, Mg cations are flocculating agents facilitate soil aggregation and hence good soil structure. Whereas H, Na cations are act as deflocculation agents, disperses the soil separates, and so poor soil aggregation and soil structure.

Role of soil structure in relation to plant growth

- ***Good soil structure*** for plant growth is one that has stable aggregates between 0.5 and 2mm in diameter that creates enough pore spaces.
- Soil structure influences the amount and nature of soil porosity (=total pore spaces).
- Soil structure controls the amount of water and air present in the soil. Not only the amount of water and air dependent on soil structure, but their movement and circulation are also controlled by soil structure.
- It affects tillage practices.
- Structure controls runoff and erosion.
- ***Platy structure*** normally hinders/reduces free drainage whereas sphere like structure (granular and crumby) helps in drainage.
- ***Crumby and granular structure*** provides optimum infiltration, water holding capacity, aeration and drainage. It also provides good habitat for microorganisms and supply of nutrients.

7.2.6 Soil density

Density represents weight (mass) per unit volume of a substance, expressed in g cc^{-1} (gram per cubic centimeter; i.e., g cm^{-3}) or Mg m^{-3} (Mega gram per cubic meter). Both the units are numerically equal.

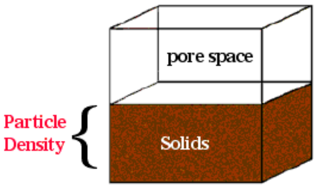
$$Density = \frac{Mass\ (Weight)}{Volume}$$

Soil density is expressed in two well accepted concepts as ***particle density*** and ***bulk density***.

Particle density or density of solids or true density

"It is defined as the ratio of weight (mass) of solids to volume of solids only"

$$Particle\ Denisty = \frac{Mass\ (weight)\ of\ Solids}{Volume\ of\ Soloids} = \frac{W_s}{V_s}$$



The chemical composition and crystal structure of a mineral matter determines soils' particle density. ***Particle density*** is not affected by pore space and therefore is not related to particle size or to the arrangement of particles (soil structure). Particle density for most mineral soils varies between the narrow limits of 2.60-2.75 Mg m^{-3} or g cm^{-3}. The particle density of soils with very high organic matter content may vary from 0.9-1.3 Mg m^{-3}. Particle density of soils is almost a permanent character which is not influenced by addition of organic matter, tillage or depth. Particle density of important soil materials given in **Table 7.4**.

Table 7.4: Particle density of importance soil materials

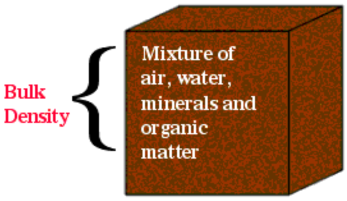
Soil materials	Particle Density (Mg m^{-3})	Soil materials	Particle Density (Mg m^{-3})
Humus	1.3 − 1.5	Clay	2.2 − 2.6
Orthoclase	2.5 − 2.6	Quartz	2.5 − 2.8
Calcite	2.6 − 2.8	Muscovite	2.7 − 3.0
Biotite	2.8 − 3.1	Apatite	3.2 − 3.3
Pyrites	4.9 − 5.2	Hematite	4.9 − 5.3

Bulk density or Apparent density

"It is the mass (weight) per unit volume of dry soil (volume of solid and pore spaces)".

$$Bulk\ Density = \frac{M_{solids}}{V_{total}} = \frac{M_{solids}}{V_{air} + V_{water} + V_{solids}}$$

$$\therefore Bulk\ Density = \frac{M_{solids}}{V_{pores} + V_{solids}}$$



*The **bulk density** of a soil is always smaller than its particle density* (**Figure 7.6**).

Loose and porous soils have low bulk densities as compared to compacted soils. *Bulk density* is more important than particle density in understanding physical behaviour of soils. Generally in normal soils, bulk density ranges from 1.0-1.60 Mg m^{-3}. Finer the texture of the soil, lesser is the bulk density.

Bulk density of soils having different composition are:

Compacted soils = 2.0 Mg m^{-3}; Sandy soils = 1.7 Mg m^{-3}; Organic peat soils = 0.5 Mg m^{-3}

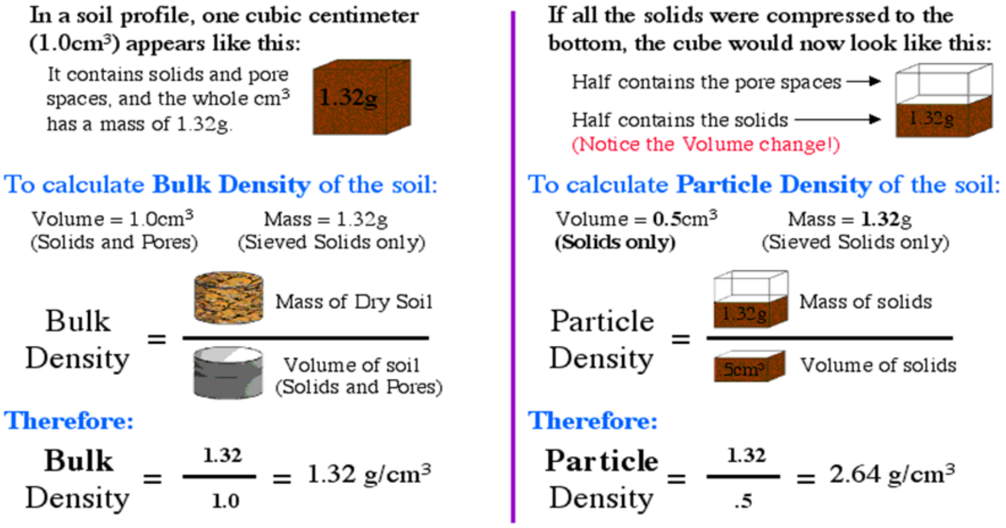


Figure 7.6: Comparison of bulk density and particle density

Importance of bulk density

- Soil bulk density determines not only total pore space but the macro pore and micro pore space also, which governs the soil-water-air relationship, thereby facilitate better crop growth.
- Infiltration, permeability, percolation of water and water retention in soil system, all these have direct relation with bulk density of soil.

Factors affecting bulk density

- **Pore space:** More is the pore space per unit volume of soil, less is the bulk density.
- **Soil compactness:** Higher is the compactness; more will be the bulk density.
- **Soil depth:** Higher is the depth of soil, more will be the bulk density.
- **Soil texture:** Finer is the texture of the soil, lesser is the bulk density.
- **Organic matter:** High organic matter contents, lead to reduced bulk density.
- **Soil structure:** Crumb soil structure shows low bulk density than that of platy structure.
- **Cultivation operations:** Tillage temporarily reduces the bulk density. While, cropping increases the bulk density of top soils.

Numerical:
Calculate the weight of a hectare field soil up to the soil depth of 15 cm. The bulk density of soil is 1.48 Mg m^{-3}.

Area of the a hectare field (i.e., length × breath; 100 m × 100 m) = 10000 m^2
Soil depth = 15 cm = 0.15 m. (Hence, the volume of field at 0.15 m depth is 1500 cubic metre).

Weight of soil depends on the bulk density of soil.

Bulk density of 1.48 Mg m^{-3}meaning soil filled in a cubic metre container weight 1.48 Mg. So, How much does it weight for 1500 cubic meter volume?

$$\therefore \text{Weight of soil} = \text{Volume of field at 0.15 m depth } \times \text{bulk density of soil}$$

$$\therefore \text{Weight of soil} = 1500\ \text{m}^3\ \times 1.48\ \text{Mg m}^{-3} = 2200\ \text{Mg}$$

OR

$$\text{Weight of soil} = \text{Area of the field } \times \text{depth of soil} \times \text{bulk density of soil}$$

$$\therefore \text{Weight of soil} = 1000\ \text{m}^2\ \times 0.15\ \text{m} \times 1.48\ \text{Mg m}^{-3}$$

$$\therefore \text{Weight of soil} = 2200\ \text{Mg}$$

Now, $1\ \text{Mg} = 10^6\ \text{g} = 10^3\ \text{kg} = 1\ \text{tonne}$

So, the weight of hectare filed soil up to the depth of 15 cm will be 2200 Mg or tonnes.

7.2.7 Soil porosity

"*Porosity refers to the percentage of soil volume occupied by pore space*".

Pore spaces (voids) in a soil are portions of soil volume that neither occupied by solids, mineral nor organic. The pore spaces under field conditions are occupied at all times by air and water. Pore spaces directly control the amount of water and air in the soil and indirectly influence the plant growth and crop production. Soil pores are of two types:

- **Macro pores** arelarge sized pores (>0.06 mm) invariably exist in between sand sized granules and allow air and water movement readily.
- **Micro or capillary pores** aresmaller sized pores (<0.06 mm) in which movement of air and water are restricted to some extent. These pores are very important for crop growth. Generally clays and clayey soils have a greater number of capillary pores.

The existence of approximately equal number of macro and micro pores would facilitate better aeration, permeability, drainage, and water retention.

Calculation of soil porosity

$$\text{Particle Density}(\mathbf{D_p}) = \frac{\text{M}_{\text{solids}}}{\text{V}_{\text{solids}}} \quad \therefore\ \text{M}_{\text{solids}} = \text{D}_\text{p} \times \text{V}_{\text{solids}}$$

$$\text{Bulk Density}(\mathbf{D_b}) = \frac{\text{M}_{\text{solids}}}{\text{V}_{\text{solids}} + \text{V}_{\text{pore}}} \quad \therefore\ \text{M}_{\text{solids}} = \text{D}_\text{b} \times (\text{V}_{\text{solids}} + \text{V}_{\text{pores}})$$

$$\therefore\ \text{D}_\text{p} \times \text{V}_{\text{solids}} = \text{D}_\text{b} \times \left(\text{V}_{\text{solids}} + \text{V}_{\text{pores}}\right)$$

$$\therefore\ \frac{\text{D}_\text{b}}{\text{D}_\text{p}} = \frac{\text{V}_{\text{solids}}}{\left(\text{V}_{\text{solids}} + \text{V}_{\text{pores}}\right)}$$

$$\therefore\ \frac{\text{D}_\text{b}}{\text{D}_\text{p}} \times 100 = \frac{\text{V}_{\text{solids}}}{\left(\text{V}_{\text{solids}} + \text{V}_{\text{pores}}\right)} \times 100$$

$$\frac{V_{solids}}{(V_{solids} + V_{pores})} \times 100 \text{ is nothing but \% Solid space}$$

$$\therefore \text{ \% Solid space} = \frac{D_b}{D_p} \times 100$$

$$\textbf{Now, we know that } \text{ \% Pore sapce } + \text{ \% Solid space} = 100$$

$$\therefore \text{ \% Pore sapce } = 100 - \text{ \% Solid space}$$

$$\therefore \text{ \% Pore sapce} = 100 - \frac{\text{Bulk Density } (D_b)}{\text{Particle Density } (D_p)} \times 100$$

$$\therefore \text{ \% Pore sapce} = \left[1 - \frac{\text{Bulk Density } (D_b)}{\text{Particle Density } (D_p)}\right] \times 100$$

***Numerical*:**

A soil core was taken for the determination of bulk density. Calculate the percentage pore space from the given the measurements:

Cylinder core volume = 73.6 cm^{-3}
Dry soil weight = 87.8 g
Particle density = 2.65 g cm^{-3}

$$\textbf{Bulk Density} = \frac{M_{solids}}{V_{total}} = \frac{M_{solids}}{V_{air} + V_{water} + V_{solids}} = \frac{87.8 \text{ g}}{73.6 \text{ cm}^{-3}} = 1.19 \text{ g cm}^{-3}$$

$$\text{\% Pore sapce} = \left[1 - \frac{\text{Bulk Desntiy } (D_b)}{\text{Particle Density } (D_p)}\right] \times 100$$

$$\therefore \text{ \% Pore sapce} = \left[1 - \frac{1.19}{2.65}\right] \times 100 = 55.10\%$$

Exercise:

- Calculate % pore space of a soil with a bulk density of 1.55 & particle density of 2.65 Mg m^{-3}.
- Calculate % pore space of a soil with a bulk density of 1.45 & particle density of 2.65 Mg m^{-3}.
- Calculate % pore space of a soil with a bulk density of 1.33 & particle density of 2.65 Mg m^{-3}.
- Calculate % pore space of a soil with a bulk density of 1.22 & particle density of 2.65 Mg m^{-3}.
- Calculate particle density, bulk density and porosity of the soil, using given values of soils.
  (a) Weight of dry soil = 62.50 g
  (b) Volume of pore space = 17 cm^3
  (c)Total soil volume = 40 cm^3

Factors affecting soil porosity

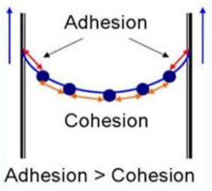
- **Soil structure**: A soil having granular or crumb structure contains more pore spaces than that of prismatic and platy soil structure. A well aggregated soil structure has more porosity than that of structure less or single grained soils.
- **Soil texture:** In sandy soils the total pore space is small; where as in fine textured clay and clay loams total pore space and micro pores are higher (**Table 7.5**).
- **Organic matter:** Organic matter facilitates more aggregation thereby more porosity.
- **Soil depth:** With increase in soil depth, porosity will decrease due to compactness in sub-soil.
- **Organisms:** Macroorganisms like earth worms, rodents, and insects increase macro pores.
- **Cultivation:** Intensive cultivation tends to lower the porosity of soil as compared to fallow soils. The decrease in porosity is due to reduction in organic matter content.

Table 7.5: Relation between textural class and pore space

Textural class	Clay content	Average pore space (%)
Heavy Clayey	>55	51.09
Clayey	40-55	48.45
Sandy Clay Loam	20-30	45.45
Sandy	<10	42.54

7.2.8 Soil consistency

*"Soil consistency refers to degree and kind of **cohesion** and **adhesion** forces between the soil particles as they related to the resistance of the soil to deform or rupture".*



Cohesion is the attraction of one water molecule to another resulting from hydrogen bonding (water-water bond; attraction between similar molecules).

Adhesion involves the attraction of a water molecule to a non-water molecule (water-solid bond; attraction between dissimilar molecules).

*Soil consistency*is the strength with which soil materials are held together or the resistance of soils to deformation and rupture. Soil consistency is measured for wet, moist and dry soil samples. For wet soils, it is expressed as both stickiness and plasticity

The physical properties of clays (fine-grained soil particles) greatly differ at different water contents. A soil which is very soft at a higher percentage of water content becomes very hard with a decrease in water content. However, it has been found that the same water content, two samples of clay of different origin may possess different consistency. One clay sample may be relatively soft while other may be hard. Further, a decrease in water content may have little effect on one sample of clay but may transform the sample from almost a liquid to a very firm condition.

For slightly wet condition of the soil (moisture content between air dry and field capacity) consistency is described in the following terms.

Type	**Characteristics**
Loose	Non coherent
Very friable	Coherent but easily crushed
Friable	Easily crushed
Firm	Crushed under moderate pressure
Very firm	Crushed only under strong pressure
Extremely Firm	Resist crushing between thumb and forefinger

Under dry condition of the soil (air dry) consistency is characterized by rigidity and hardness.

Type	**Characteristics**
Loose	Non coherent
Soft	Breaks under slight pressure to a powdery mass
Slightly hard	Breaks under pressure
Hard	Breaks with difficulty under pressure
Very hard	Resistant to pressure
Extremely hard	Extremely resistance to pressure

Atterberg limits for soil consistency

Atterberg, a Swedish scientist, studied the consistency of soils in 1911, and proposed a series of tests for defining the properties of cohesive soils. Strength decreases as water content increases. At very low moisture content, soil behaves more like a solid. When the moisture contents is very high, the solid and water may flow like a liquid. Hence, on arbitrary basis, depending on the moisture content, the behaviour of soil can be divided into 4 basic states: Solid, Semi-solid, Plastic, and Liquid.

Atterberg limits are the limits of water content used to define soil behaviour (**Figure 7.7**).

- **Liquid Limit (LL)** is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow.

- **Plastic Limit (PL)** is defined as the moisture content at which soil begins to behave as a plastic material.

- **Shrinkage Limit (SL)** is defined as the moisture content at which no further volume change occurs with further reduction in moisture content.

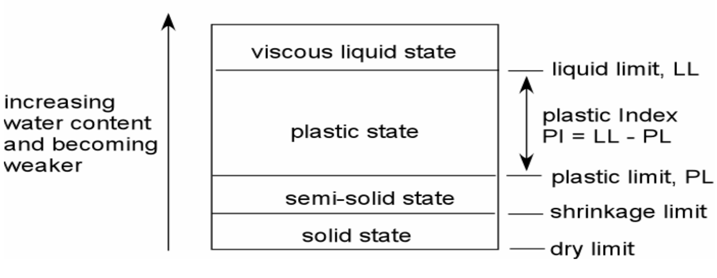


Figure 7.7: Atterberg limits for soil consistency

7.2.9 Soil colour

Soil colour is the most obvious and easily determined soil characteristic. Although it has little known direct influence on the functioning of the soil. Soil colour signifies soil conditions and some important properties. A soil attains certain colour depending on physico-chemical reactions, organic matter and mineral materials. A rough indication of soil colour is given in **Table 7.5**.

Table 7.5: Important indication of the soil colour

Colours	**Indication of the soils**
Dark colours	Dark topsoil indicates high organic matter content, which is linked to better drainage, good soil structure and nutrient levels.
Red brown and orange	Good drainage, well aerated, free movement of air and water. With enough water these soils are generally fertile. Acidity may be a problem.
Dull yellow and wet blue mottles	Some seasonal drainage problems (water logging) where air is lacking in the soil, especially in the rainy season.
Grey	Poor drainage, too much water and not enough air.

Factors affecting soil colour

- **Mineral matter:** Rocks are broken down to form soils, and sometimes these rocks give their colour to the soil. More usually the colour of the soil results from compounds such as iron.

- **Organic matter:** Humus, the final stage of organic matter breakdown is black. Throughout the stages of organic matter breakdown the colour imparted to the soil varies from browns to black. Sodium content influences the depth of colour of organic matter and therefore the soil. Sodium causes the organic matter (humus) to disperse more readily and spread over the soil particles, making the soil look darker (blacker).

- **Iron:** Red, yellow, grey and bluish-grey colours result from iron in various forms. Under average conditions of air and moisture, iron forms a yellow oxide imparting a yellow colour to the soil. Where soils are well draining or under dry conditions, iron forms red oxides imparting a red colour to the soil. Yet in waterlogged soil, with a lack of air, iron forms in a reduced state giving the soil grey/green/bluish-grey colours.

- **Water:** Soil colour darkens as the soil changes from dry to moist. But longer term colour changes are linked to water relations as well. Careful observation of colour can help to identify problems of waterlogging or leaching. Poorly drained soils are often dominated by blue grey colours often with yellow mottling. Well drained soils will usually have bright and uniform colours.

Munsell colour system

It was created by ***Prof. Albert H. Munsell*** in the first decade of the 20th century and adopted by the USDA as the official colour system for soil research in 1930s.

It specifies colours based on 3 colour dimensions:

- **Hue:** Dominant spectral wavelength of light, colour (red, yellow, green, blue, etc.)
- **Value:** Lightness or darkness; ranges from 0 (pure black) to 10 (pure white)
- **Chroma:** Colour intensity, Purity; ranges from 0 (natural grey) to 8 (highest purity or intensity of colour)

Soil colour and composition

- **Black and dark gray colour:** The variations from black to dark gray colour of soil are mainly due to organic matter.
- **Brown colour:** This is the most common soil colour and is due to a mixture of the organic matter and iron oxides.
- **Red yellow colour:** Red colour is associated with unhydrated ferric oxides, whereas yellow colour indicates some degree of hydration.
- **White colour:** Silica and lime generally impart white colour.
- **Bluish and greenish colour:** Some of the bluish and greenish colours are due to the presence of ferrous compounds. This reducing condition occurs in ill drained soil.
- **Mottling colour:** Colour variation or mottling in soils indicates alternating oxidizing and reducing conditions due to a fluctuating water table.

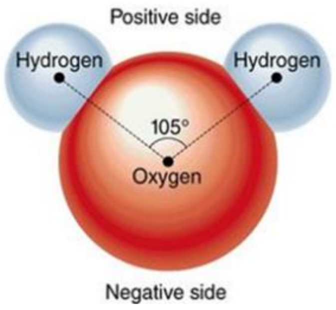
CHAPTER 8: SOIL WATER

8.1 Soil water

Water contained in soil is termed as ***soil moisture***. The water held within the soil pores. Soil water is the major component of the soil in relation to plant growth. If the moisture content of a soil is optimum for plant growth, plants can readily absorb soil water. Not all the water, held in soil, is available to plants. Much of water remains in the soil as a thin film. Soil water dissolves salts and makes up the soil solution, which is important as medium for supply of nutrients to growing plants.

8.1.1 Structure and related properties of water

- ***Structure of water molecule***
  Water participates directly and indirectly in most soil and plant reactions. This ability to do so is primarily determined by its structure. Water is a simple compound molecule containing one oxygen atom and two much smaller hydrogen atoms. The elements are bonded together covalently (each hydrogen atom sharing its single electron with the oxygen; H-bonding) in 'V' shaped at an angle of 105 degree, results into an asymmetric molecule. As seen in a given figure, in this asymmetric molecules, shared electron being closer to the oxygen than to the hydrogen. That's side on which hydrogen are located tends to be electropositive, and opposite side be electronegative, accounts for ***polarity or dipolar nature*** of the water, a most important in soil and plant science.



- ***Polarity***
  The property of polarity helps explain how water molecules interact with each other and with other electrostatically charged ions. Cations such as Na^+, K^+, and Ca^{2+}become hydrated through their attraction to the oxygen (negative end of the water molecules). Likewise, negatively charged clay surfaces attract water, through the hydrogen (positive, end of the water molecule).

  When water molecules become attracted to electrostatically charged ions or clay surfaces, they do so in closely packed clusters. In this state their free energy is lower than in pure water. Thus, when ions or clay particles become hydrated, energy must be released. The released energy is shown as ***heat of solution*** when ions hydrate, or as ***heat of wetting*** in the case of hydrating clay particles.

- ***Cohesion and Adhesion***
  Hydrogen bonding accounts for two basic forces responsible for water retention and movement in soils. One is the attraction of molecules for each other (***cohesion***). The other is the attraction of water molecules for solid surfaces (***adhesion***). By adhesion, solids hold water molecules rigidly at their soil-water surfaces.

- ***Surface tension***
  This phenomenon is commonly evidenced at liquid-air interfaces and is due to the greater attraction of water molecules for each other (cohesion) than for the air above. The net effect is an inward force at the surface that causes water to behave as a stretched elastic membrane. Because of the relatively high attraction of water molecules for each other, water has a high surface tension compared to that of most other liquids.

8.1.2 Factors affecting soil water

- **Texture:** Finer the texture, more is the pore space and surface area, greater is the retention of water.
- **Structure:** Well-aggregated porous structure favours better porosity, which in turn enhance water retention.
- **Organic matter:** Higher the organic matter more is the water retention in the soil.
- **Density of soil:** Higher the density of soil, lower is the moisture content.
- **Temperature:** Cooler the temperature, higher is the moisture retention.
- **Salt content:** More the salt content in the soil less is the water available to the plant.
- **Depth of soil:** More the depth of soil more is the water available to the plant.
- **Type of clay:** The 2:1 type of clay increases the water retention in the soil.

8.2 Soil water energy concepts

The retention and movement of water in soils, its uptake and translocation in plants, and its loss to the atmosphere are all energy-related phenomena. Different kinds of energy are involved, including ***potential***, ***kinetic***, and ***electrical***. For understanding, the soil water energy concepts, term '***free energy***' is used which means summation of all other forms of energy available to do work.

As we consider energy, we should keep in mind that all substances, including water, have a tendency to move from a higher free energy state to a lower free energy state. Water will move readily from a soil saturated with water (***high free energy***) to a dry soil (***low free energy***).

Forces affecting free energy

- Adhesion (the attraction of the soil solids; called matrix) for water, provides***matric force*** (responsible for capillarity) that markedly reduces the free energy of the adsorbed water molecules and even those held by cohesion.
- Likewise, the attraction of ions and other solutes for water results in ***osmotic forces*** tends reduce the free energy of soil solution. Osmotic movement of pure water across a semipermeable membrane into salt solution is evidence of lower free energy state of solution.
- The third major force acting on soil water is ***gravity***, which tends to pull the water downward. The free energy ofwater at a given elevation in the profile is thus higher than that of pure water at some lower elevation. Such a difference in free energy level causes water to flow.

Concept of pressure

The pressure (measured in unit 'atmosphere' or 'bar') required to remove water from soil. Opposite of pressure is ***moisture tension*** or ***suction***.

8.3 Soil water potential

Soil water potential may be defined as the work the water can do when it moves from its present state to a pool of water in the reference state. We know that movement of water is soil occurs from a higher free energy (called ***zero potential level***) to a lower free energy level (***negative potential***). Adsorbed water has less free energy to do work, hence always has negative water potential; work must be done to remove the water. The more tightly water is adsorbed, the more negative is the water potential value.

Soil water potential (denoted as Ψ_w; Ψ is a Greek alphabet pronounced as ***Psi***) is combined effects combined effects of gravitational force (called ***gravitational potential***; Ψ_g), matric force (adhesion; called ***matric potential***, Ψ_m), osmotic force (due to ions and other solutes; called ***osmotic or solute potential***, Ψ_s), atmospheric or gas pressure (called ***pressure potential***, Ψ_p). See, **Figure 8.1**.

Total Soil water potential (Ψ_w) = $\Psi_g + \Psi_m + \Psi_s + \Psi_p$

Ψ_g= Gravitational potential (+ve value)

- Determined by the height of water above reference points
- Water flows downward under gravity

Ψ_m= Matric potential (–ve value)

- Determined by the strength of the attraction of water to the soil matrix
- Most important for unsaturated soil water flow (dry soils)
- Water flows from zones of wet soils to zones of dry soils
  (Less negative potential to more negative potential)

Ψ_s = Solute or Osmotic potential(–ve value)

- Determined by the concentration of solutes/salts in the soils water
- More negative potential for high solute/salts concentration
- Water flows from zone of low solute to high solute concentration
- Most important for root-water interaction

Ψ_p= Pressure potential(–ve value)

- Determined by the amount of air pressure imposed on the soil water
- Usually zero, but there some exceptions as in case of flooded soils and soil with high water-tables (artesian wells)

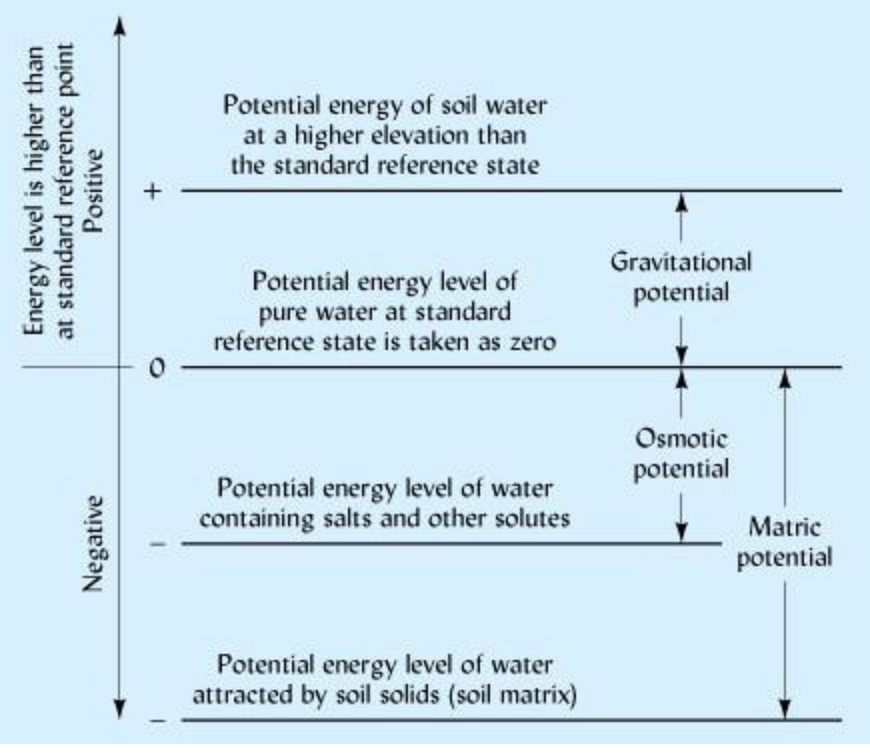


Figure 8.1: Relationship between the potential energy of pure water at a standard reference state (pressure, temperature, and elevation) and that of soil water

8.4 Units of soil water potential

Soil water potential is expressed in two ways: (i) pF scale and (ii) bar or atmosphere

- ***pF scale***

  The free energy is measured in terms of ***the height of a column of water required to produce necessary suction or pressure difference at a particular soil moisture level***. The pF, therefore, represents the logarithm of the height of water column (cm) to give the necessary suction.**Schofield (1935)** suggested the use of **pF scale**, which defined as a logarithm of the negative pressure (soil water potential) head in cm of water. *A tension of 10 cm of water = 1 pF; A tension of 1000 cm of water = 3 pF*(**Table 8.1**).

Table 8.1: Relationship between soil moisture tension, soil water potential, height of hydraulic head, and pF value

Soil water potential (atm/bars)	Soil moisture tension/Suction (atm/bars)	Height of hydraulic head (cm)	pF value	Remarks*
–0.01	0.01	10.2	1.0	At nearly saturated condition
–0.1	0.1	102	2.0	–
–0.33	0.33	337	2.52	At field capacity
–1.0	1.0	1023	3.0	–
–15.0	15.0	15345	4.2	At wilting point
–31.0	31.0	31713	4.5	Hygroscopic water

**pF value of saturated soil = zero, pF value of over dry soil = 7*

- ***Bar or atmosphere***

  Average pressure at mean sea level is expressed as units of bar or atmosphere.

1 bar = 0.9869 atm $\approx$ 1 atm
= 14.7 pounds per square inch
= 76 cm or 760 mm height of mercury head
= 10^5 Pascals = 10^3 hectopascals (hPa) = 10^2 kilopascals (kPa)

8.5 Physical classification of soil water

Soil water categorized into three groups based on water retention to the soil matrix (**Figure 8.2**): (i) Gravitation water, (ii) Capillary water, and (iii) Hygroscopic water.

- **Gravitational water**

  Soil water that is held at a potential **above –0.33** bar is called ***gravitational water***. Gravitational water occupies the larger soil pores (macro pores) and moves down readily under the force of gravity. Gravitational water is of little use to plant, as it causes poor soil aeration. Hence, removal of gravitational water should be advisable for good plant growth.

- **Capillary water**

  Soil water held in the micropores, between the water potential **–0.33 to –31 bar**, is called ***capillary water***. Capillary water retained on soil particles due to cohesive and adhesive forces. Capillary water held so rigidly that gravity force unable to pull it downwards. Part of the capillary water is available to the plant root.

- **Hygroscopic water**
  Soil water held at a potential **greater than –31 bar**, is called ***hygroscopic water***. This water is essentially held very rigidly to soil particle in a water vapour form, hence plant root are unable to extract it and so, hygroscopic water is of no use to plant.

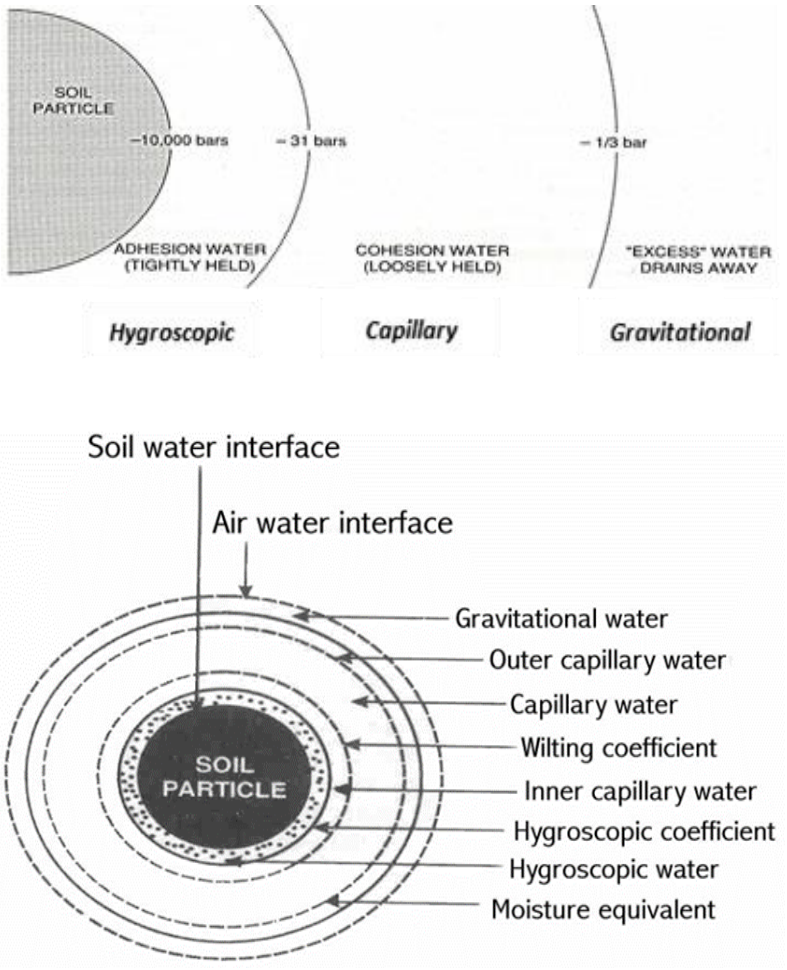


Figure 8.2: Different forms of soil water/soil moisture

8.5 Biological classification of soil water

There is a definite relationship between moisture retention and its utilization by plants. This classification based on the availability of water to the plant, can be divided into three groups.

- ***Available water***
  Available water is defined as the portion of water which is retained in the soil between field capacity (**−0.33 bars**) and the permanent wilting coefficients (**−15 bars**) or water which lies between wilting coefficient and field capacity. Portion of capillary water falls into an available water category.

- ***Unavailable water***
  It is defined as the water, which is held at soil water potential **lower than−15 bars**. This includes the entire hygroscopic water plus a part of the capillary water below the wilting point.

- ***Super available or superfluous water***
  Soil water held at a potential **greater than –31 bars** or beyond the field capacity, is called superfluous water. Gravitational water falls into a superfluous water category.

8.6 Soil moisture constants

Earlier classification divided soil water into gravitational, capillary and hygroscopic water. The hygroscopic and capillary waters are in equilibrium with the soil under given condition. The hygroscopic coefficient and the maximum capillary capacity are the two equilibrium points when the soil contains the maximum amount of hygroscopic and capillary waters, respectively. The amount of water that a soil contains at each of these equilibrium points is known as ***soil moisture constant***.

The soil moisture constant, therefore, represents definite soil moisture relationship and retention of soil moisture in the field. The three classes of water (gravitational, capillary and hygroscopic) are however very broad and do not represent accurately the soil-water relationships that exists under field conditions.

- Though the maximum capillary capacity represents the maximum amount of capillary water that a soil holds, the whole of capillary water is not available for the use of the plants.

- A part of it, at its lower limit approaching the hygroscopic coefficient is not utilized by the plants.Similarly, a part of the capillary water at its upper limit is also not available for the use of plants.

Hence, soil moisture constants, viz., ***field capacity*** and ***wilting coefficient*** have been introduced to express the soil-plant-water relationships as it is found to exist under field conditions.

- **Soil moisture content and oven dry soil weight**
  It indicates the amount of water present in the soil. It is commonly expressed as the amount of water (in mm of water depth) present in a depth of one meter of soil. Oven dry soil weight (determined by placing soil in oven at 105 °C temperature for 24 hours) is the basis for all soil moisture calculations. The equilibrium soil water potential is **–10000 bar** (or water tension of 10000 bar).

- **Air dry soil weight**
  Soil dried in air, and this value somewhat variable due to moisture in the air fluctuates. Water (or moisture) held at a potential of **–1000 bar** (or water tension of 1000 bar).

- **Hygroscopic coefficient**
  Hygroscopic coefficient can be determined by keeping an air-dried soil in a nearly saturated atmosphere at 25 °C temperature until soil absorbs no more water. The soil water (moisture) potential at this point is **–31 bar** (or water tension of 31 bar). Plant cannot use the moisture at hygroscopic coefficient, but certain microorganisms are able to utilize this moisture.

- **Wilting coefficient or Permanent wilting point (PWP)**
  Water or moisture held to the soil particle at water potential less than **–15 bar**, and it is held so rigidly that plants' roots cannot use it, is termed at ***wilting coefficient***. At water potential less than **–15 bar**, plant starts to wilt and it does not recover it turgidity inspite of addition of water, so the situation is called ***permanent wilting point***. Wilting coefficient and PWP both indicates the low moisture availability in soil for the plants.

- **Field capacity (FC)**
  The capacity of soil to retain water (moisture) against downward pull of gravity, and water (moisture) held at water potential between**–0.33 and –15 bar**, is called as field capacity.At field capacity, the water and air contents of the soil are considered to be ideal for crop growth.

- **Saturation**
  When all the soil pores (both, macro and micro) are filled with water, the soil is said to be saturated. At saturation, no air is present and the plant will suffer. Many crops cannot withstand saturated soil conditions for a period of more than 2-5 days, hence required proper drainage is necessary. In coarse-textured (sandy) soils, drainage is completed within a period of few hours. In fine textured (clay) soils, drainage may take some 2-3 days.

The types of water and their corresponding soil water potential, soil moisture constants are shown in **Figure 8.3**.

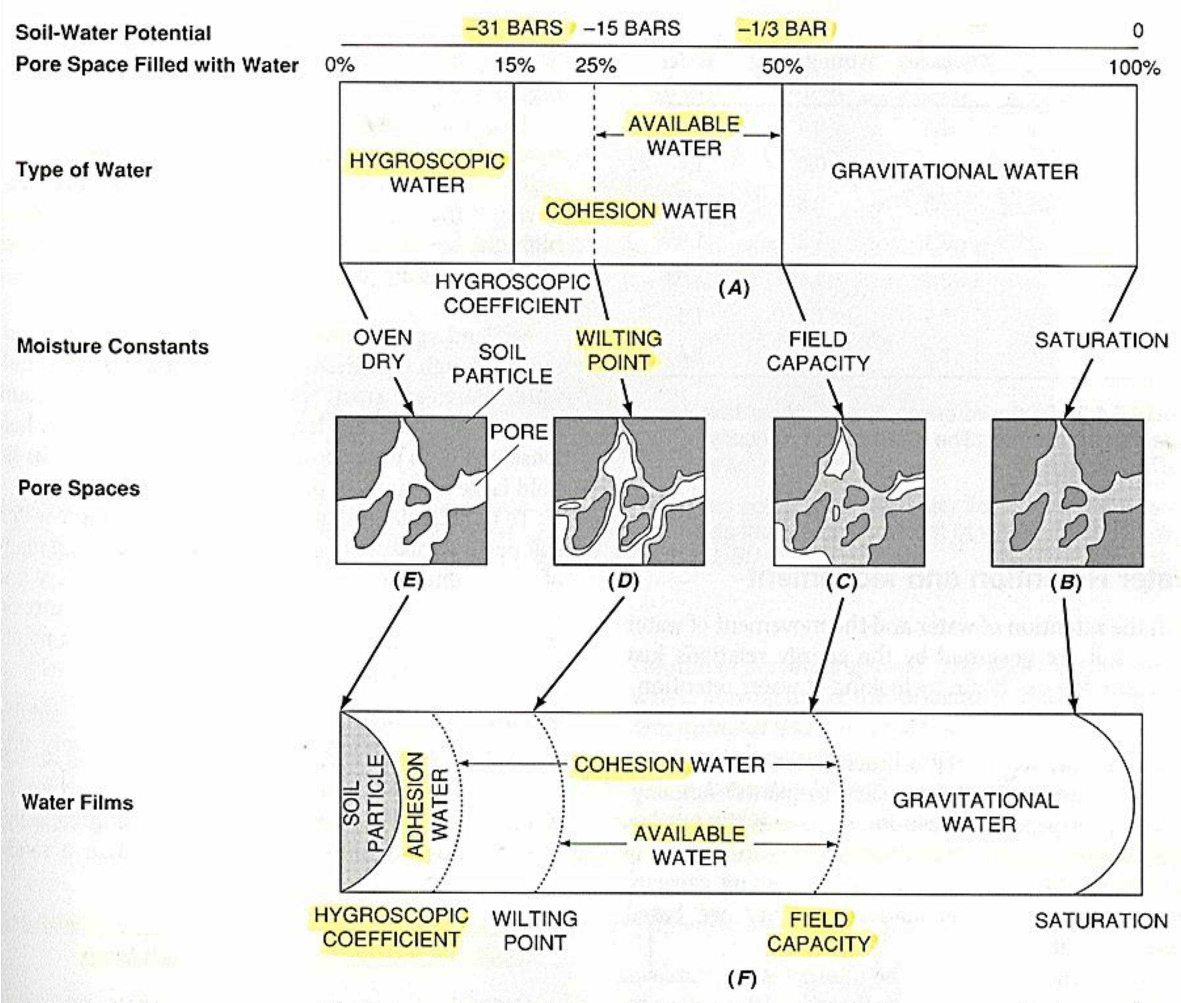


Figure 8.3: (A) Type of soil water, the moisture constants, the corresponding soil water potential, (B to E) the amount of average pore space, and (F) water films.

8.7 Soil moisture energy curve or soil moisture retention curve

The relationship between soil water tension and moisture content of three soils of different texture is shown in **Figure 8.4**. The curves indicates a gradual decrease in tension with increased soil water and *vice-versa*. The clay soil holds much more water at a given tension level than does loam or sand. Likewise, at a given moisture content, the water is held much more tenaciously in the clay as compared to the other two soils. As it can been see, much of the water held by clay soils in the field is held so tightly that it cannot be removed by growing plants. In any case, the influence of texture on soil moisture retention is obvious.

The soil structure also influences its soil moisture-energy relationships. A well-granulated soil has more total pore space than has a similar soil where the granulation has been destroyed and the soil has become compacted. The reduced pore space may be reflected in a lower water-holding capacity. The compacted soil may also have a higher proportion of small and medium-sized pores, which tend to hold the water with a greater suction/tension than do the larger pores.

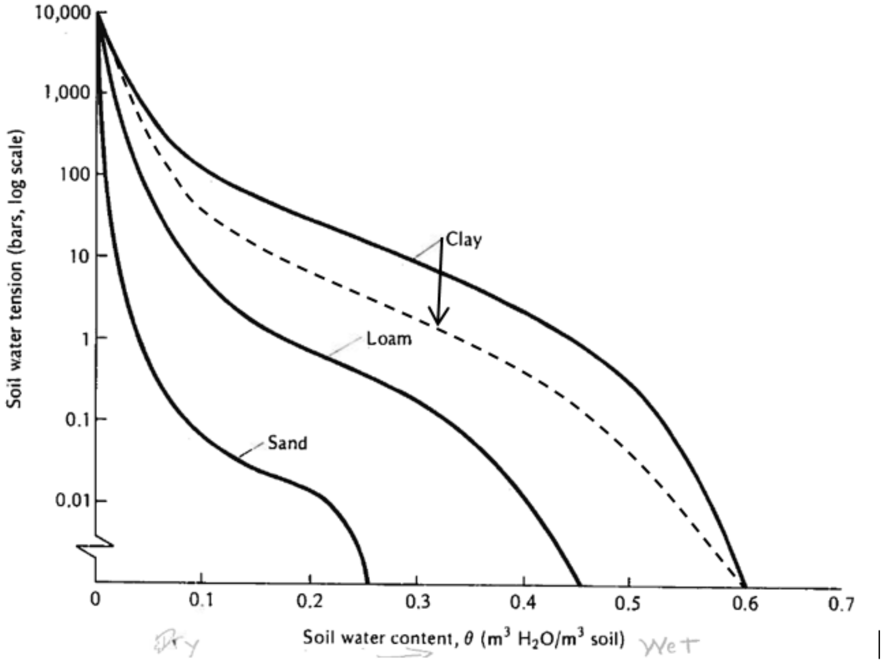


Figure 8.4: Soil moisture tension curves for three representative mineral soils

Hysteresis

An interesting phenomenon occuring when soils are alternately wetted and dried is illustrated in Figure 8.5. The upper solid line is termed as the ***desorption curve*** develops due to drying of a saturated soil. The lower dotted line is termed as ***sorption curve*** develops due to wetting an initially dry soil. The difference between the two curves is due to the ***phenomenon of hysteresis*** resulting from the presence of entrapped air in such soils.

Hysteresis phenomenon exists in soil minerals as a consequence of shrinking and swelling. This phenomenon is caused by number of factor such as shape and size of soil pores and their interconnectiion with other other, pore configuration, nature of soil colloids including both clay and organic colloids, bulk density of soil and entrapped air, etc.

8.8 Entry of water into soil

- **Infiltration**
  The downward entry or movement of water into the soil surface is called ***infiltration***. Infiltration is a surface characteristic so primarily influenced by the condition of the surface of soil. A compact surface permits infiltration. Soil surface with vegetative cover have more infiltration rate than bare soils. Warm soils absorb more water than cold one. Coarse surface texture (Sandy), granular structure and high organic matter content in surface soil, all help to increase infiltration. Infiltration rate is comparatively lower in wet soils than dry soils. An infiltration rate of 15 mm hr^{-1} means a water layer of 15 mm on the surface of the soil will take one hour to infiltrate. Infiltration rate is comparatively lower in wet soils than dry soils.

- **Percolation**

  The movement of water through a column of soil is called ***percolation***. It is important for two reasons (i) this is the only source of recharge of ground water which can be used through wells for irrigation (ii) percolating waters carry plant nutrients down and often out of reach of plant roots (leaching). Percolation is dependent of rainfall. In dry region, it is negligible and under high rainfall it is high. Sandy soils have greater percolation than clayey soil. Vegetation and high water table reduce the percolation loss.

- **Permeability**

  Permeability indicates the relative ease of movement of water within the soil. The characteristics that determine how fast air and water move through the soil are known as ***permeability***. The term ***hydraulic conductivity*** is also used which refers to the readiness with which a soil transmits fluids through it. The permeability is basically dependent on the pore-size distribution in the soil. The macro pores increases the permeability. The permeability of soil usually decreases with depth, as the sub-soil layers are more compact reduces the macro pores. More content of organic matter and vegetation increase permeability. Normally, permeability decreases with increasing fine texture, but the extent of aggregation in fine-textured (clay) soils may override the effects of texture. If irrigation water is high in sodium content, it would cause dispersion of soil (soil becomes compact) and thus reduce permeability.

- **Drainage**

  The purpose of drainage is to remove the excess water from the soil ensure proper soil aeration. When soil gets saturated with water, the entire pore space is occupied by water and soil aeration is cut off. Also, water ponded at soil surface cuts off gaseous exchange between atmospheric and soil air even if there are enough air-filled pores in the soil below. Draining out the excess water to create air porosity creates soil condition favorable for soil aeration.

  Drainage is of two type’s viz., **(i) *surface drainage*:** To ensure adequate soil aeration, the ponded water must be removed through gravity flow or pumping out and **(ii) *sub-surface drainage:*** In order to ensure adequate soil aeration and prevent soil salinization, water table must be kept below a certain level.

8.8 Soil-water movement

Three types of water movement within the soil are recognized: (i) saturated flow, (ii) unsaturated flow, and (iii) water vapour movement.

- **Saturated flow of water:** Condition of soil, when all large and small pores are filled with water is called saturated. Saturated flow takes place when the soil is saturated. The direction of flow is from a zone of higher moisture potential to a lower moisture potential. Generally, water percolates down (vertically) into the lower layers. But,horizontal flow also occurs with very less rapidly in comparison to vertical flow. Horizontal movement is much more evident in the clay soil, whereas vertical movement is much more evident in sandy loam.

- **Unsaturated flow of water:** Soil wherein the pore spaces contain air as well as water (macro pores filled with air, and micro pores with water + air) is called unsaturated soil, and unsaturated flow of water occurs where the soil pores are not completely saturated with water. Water movement under such conditions is relatively very slow compared to that of saturated flow. Water movement is from a zone of low suction (thick moisture film) to one of high suction (thin moisture film). The prominence of finer (capillary) pores in the clay soil encourages more unsaturated flow than in the sand.

- **Water vapour movement**: There are two type of water vapour movement: (a) *internal movement*, the change from the liquid to the vapour state takes place within the soil, that is, in the soil pores, and (b) *external movement*, occurs at the land surface and the resulting vapour is lost to the atmosphere by diffusion and convection (surface evaporation).

Saturated water flow	Unsaturated water flow
• Most pores are filled with water	• Pores are filled with water and air
• Soil water at zero bar tension	• Soil water at higher tension
• Driving force is positive pressure potential	• Driving force is negative pressure potential
• Most water is unavailable to plants under saturated condition	• Plant will take water mostly held under unsaturated condition
• Hydraulic conductivity under saturated condition Is: Sand> loams> clay	• HC in unsaturated condition is: Clay > loams > sands

8.9 Soil moisture determination

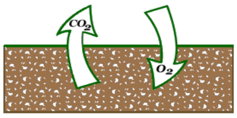
Four methods of soil moisture determination are described here: ***Gravimetrically***, using soil and water weight; by ***Tensiometer***, which measure soil sorption forces directly; by ***Bouyoucos moisture block***, which relates electrical conductivity to moisture content; and by ***Neutron probe***, in which emitted neutrons are deflected by water's hydrogen ions, giving a measure of water concentration by relating it to the number of deflected neutrons counted.

CHAPTER 9: SOIL AIR AND SOIL TEMPERATURE

9.1 Soil air / soil aeration

Soil is a three-phase, porous media, composed of solids, liquids, and gases.***Soil air*** *can be defined as the air that fills the soil pore spaces not occupied by water. That is the gaseous phase of the soil not occupied by solid or liquid.*

*"**Soil aeration** is the ability of soil (depends of type and amount of pore spaces) to exchange of carbon dioxide and oxygen gases (or other gases) with the atmosphere".*



Oxygen (O_2) and carbon dioxide (CO_2) exchange in the soil

Many biological and chemical processed are influenced or controlled by aeration, such as root growth, microbial activity, and transformation of nutrient elements and toxic chemicals, hence soil aeration is an important physical property to understand.

9.1.1 Gaseous composition of soil air

The soil air comprises with many gases likes oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2), water vapour, etc. Gaseous composition of soil air is quite similar to that of atmospheric air, but the content of CO_2 in soil air more than atmospheric air **(Table 9.1)**.

Table 9.1: Gaseous composition of soil and atmospheric air

Gas	**Percent distribution**	
	Soil air	**Atmospheric air**
Oxygen	<20	21
Nitrogen	78	78
Carbon dioxide	0.50	0.03

Soil air is consistently lower in oxygen. The oxygen content may be only slightly below 20% in the upper layers of a soil. Wet soils typically have low oxygen contents. Once the supply of oxygen is virtually exhausted, the soil environment becomes anaerobic. Drastic reductions in the oxygen content of soil air may occur following a heavy rain.

Carbon dioxide typically increases in soil air. Carbon dioxide may become toxic to plants when it is as high as 10% in soil air.

Soil air is usually higher in water vapour than in the atmosphere. Under waterlogged conditions, the concentrations of methane (CH_4), and hydrogen sulphide (H_2S) are particularly higher in soil air. Ethylene (C_2H_4) gas, a product of anaerobic microbial metabolism is toxic to plant roots, even in very small concentrations

9.1.2 Mechanisms for soil aeration

- ***Mass flow***
  This mechanism is dependent upon overall pressure gradients and is thus affected by soil water content, wind, and changes in barometric pressure. With rain and irrigation, soil air moves out; while with transpiration and evaporation, soil air enters into soils. Soil temperature plays important role mass flow of gaseous exchange

- ***Diffusion***
  Gases moves in the direction determined by its partial pressure. Consequently, the higher concentration of oxygen in the atmosphere will result in a net movement of this particular gas into the soil. Carbon dioxide and water vapour normally move in the opposite direction, since the partial pressure of these two gases are generally higher in the soil air than in the atmosphere **(Figure 9.1)**.

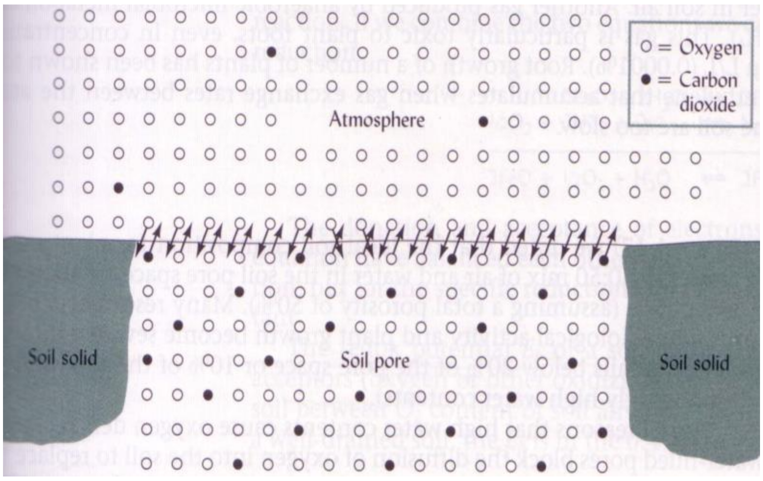


Figure 9.1: Diffusion mechanism of gases exchange between soil and atmospheric air

9.1.3 Influence of soil air on plant growth

- ***Plant and root growth*****:** When the supply of oxygen is inadequate, the plant growth either retards or ceases completely as the accumulated CO_2 hampers the growth of plant roots.
- ***Microorganism population and activity*****:** The deficiency of air (oxygen) in soil slows down rate of microbial activity, decomposition of organic matter, nitrification, sulphur oxidation.
- ***Formation of toxic material:*** Poor aeration results in the development of toxin and other injurious substances such as ferrous oxide, H_2S gas, CO_2 gas etc. in the soil.
- ***Water and nutrient absorption*****:** A deficiency of oxygen has been found to check the nutrient and water absorption by plants.
- ***Development of plant diseases*****:** Insufficient aeration of the soil also lead to the development of diseases. e.g.wilt of arhar and gram, dieback of citrus and peach.

9.1.4 Factors for poor soil aeration

- This refers to a condition in which the availability of oxygen in the root zone is insufficient to support optimal growth of most plants and aerobic microorganisms.
- Poor aeration becomes a serious impediment to plant growth when more than 80-90% of the soil pore space is filled with water, leaving less than 10-20 % of the pore space filled with air.
- The high soil water content not only leaves little pore space for air storage but, more important the water blocks the pathways by which gases could exchange with the atmosphere. The soil is said to be water saturated or waterlogged when all or nearly all of the soil pores are filled with water. Such conditions occur naturally in wetlands.
- Plants adapted to grow in waterlogged soils are known as hydrophytes (water-loving plants), e.g., grasses and rice. Respiration is via hollow structures in their stems and roots known as aerenchyma tissues.

When oxygen becomes depleted, soil conditions are said to be anaerobic. Methane, hydrogen sulphide, and ethylene are often evolved under these conditions.

9.2 Soil temperature and soil heat

Soil temperature is one of the most important soil properties that affect crop growth. Soil temperature controls the microbial activity and other plant growth process. It has been found that the decomposition of organic matter and mineralization of organic form of nitrogen increases with temperature. The soil colour, composition, and the water content in soils influence soil temperature. Dark and fine textured soil absorb more heat during the day and lost it during night more rapidly that coarse-textured soils, because later retain more water and the specific heat of water are 4-5 times more than that of soil particles.

9.2.1 Importance of soil temperature

- Soil temperature directly associated with plant growth directly. Most crops practically slow down their growth at soil temperature >9 °C and <50 °C.
- Most soil organisms function best at an optimum soil temperature of 25-35 °C.
- The optimum soil temperature for nitrification (mineralization process) is about 32 °C.
- Soil temperature influences soil moisture content, aeration and plant nutrients.

9.2.2 Sources of soil heat

- **Solar radiation:** The main source of soil heat is the energy of sun's rays (radiant energy) that reach the earth after they pass through the atmosphere. The exposure of the earth to the heat of the sun warms the surface of the soil.

- **Biochemical reactions:** Microbial and other biochemical reactions in soil generally liberates the heat. Likely, decomposition of organic matter and crop residues in the soil released heat to soil, increases soil temperature.

- **Conduction:** Transfer of subsoil heat to surface soil. The interior of the earth is very hot, the conduction of this heat to the soil is very slow. Generally, during night, the surface soil becomes cooler than subsurface soil. Thus, heat flows from subsoil (warm layers) to soil (cooler layers).

- **Rain:** The occurrence of rain during the winter months may raise the temperature of the soil.

9.2.3 Factros affecting soil heat absorption and loss

- **Slope:** If the incoming path of the rays is perpendicular to the soil surface energy absorption is greater than to the sloping surface, receiving the rays.The southern slope received more solar radiation per unit area than north facing slope. Therefore, the temperature of soil on southern exposure always higher than north-exposed soils.

- **Vegetative cover:** Acts as insulating layer, prevent heat loss as well as protect from direct sun rays heating.

- **Albedo/reflectivity of soil surface:** Dark soil (clay or high OM soil) less reflection than light coloured soil (sandy soil).

- **Colour of the soils:** Dark coloured soils absorbed more radiant energy than lighter coloured soils. This does not mean that dark soils are always warmer. In fact, dark soil usually are rich in organic matter and hold large amount of water, which requires comparatively more energy to be warmed.

- **Amount of soil moisture:** Presence of large amount of water in soil tends to stabilize the temperature due to high specific heat of water. Hence dry soil surface warms up rapidly than that of moist soils (clayey soils). Whereas, heat losses from dry soils (sandy soils) is quicker than moist/clayey soils

9.2.4 Soil thermal properties

- **Specific heat (Mass specific heat)**
  The amount of heat (in calories) required to raise the temperature of one gram of substance by 1 °C is called ***specific heat***. The specific heat of water = 1 cal g^{-1}, mineral soils = 0.18-0.20 cal g^{-1} and organic soils = 0.50 cal g^{-1}. It implies that one calorie of heat raises the temperature of water by 1 °C; the same calorie of heat raises the temperature of soil by 5 °C and of organic matter by 2 °C. The specific heat of soil increases with increase in moisture content. Thus, wet soil is cold while light/dry soil which hold less water warm up much more quickly.

- **Heat capacity (volume specific heat)**
  Heat capacity of a given material = specific heat × mass. It is the amount of heat required to raise the temperature of one cubic centimetre substance by 1 °C. Most soils have a heat capacity in the range of 0.30-0.60 cal cm^{-3}.

- **Thermal conductivity and thermal diffusivity**
  The flow of the temperature in the soil is expressed as***thermal conductivity***. It is defined as the quantity of heat transmitted through unit length of substance per unit cross section, per unit temperature gradient per unit time.

  The change in soil heat per unit time **(dQ/dt)** flowing into or out of soil depends on the temperature gradient **(dT/dz)** in the soil, and the ***thermal conductivity*** **(K)**, for a given soil can be given by:

$$\frac{dQ}{dt} = -\frac{K}{\rho c}\frac{d^2T}{dz^2}$$

Where, K = thermal conductivity expressed in J $°C^{-1}$ cm^{-1} sec^{-1}
z = temperature gradient in soil
c = specific heat of soil
ρ = density of soil
$K/\rho c$ = thermal diffusivity, expressed in cm^2 sec^{-1}

Thermal conductivity varies with porosity, moisture content and organic matter content of soil. In moist soil, with higher thermal conductivity heat flows into lower layers and surface temperature is therefore low. Tillage improves porosity and decrease thermal conductivity resulting in higher surface temperature.

Thermal diffusivity is the ratio of the thermal conductivity to volume specific heat. The thermal diffusivity of soil may either increase of decrease with increasing moisture content since **K, density (ρ),** and **specific heat (*c*)** all increase with it. It increased exponentially with the increasing bulk density, heat capacity, and the degree of saturation with soil moisture.

CHAPTER 10: SOIL COLLOIDS

10.1 Soil colloids – definition

Thomas Graham (1861) coined the term 'colloid' (Greek *Kolla* = glue *eidos* = like). In atrue solution as sugar or salt in water, the solute particles are dispersed in the solvent as singlemolecules or ions.

The colloidal state refers to *a two-phase system in which one material(s) in a very finely divided state is dispersed through second phase*.The examples are:(i) *Solid in liquid* i.e., clay in water (dispersion of clay in water), (ii)*Liquid in gas* i.e., Fog or clouds in atmosphere.

Hydrated aluminosilicate secondary minerals with particle size less than 0.002 mm in diameter are clay minerals. The clay fractions in soils are of less than 0.002 mm in size. By definition, ***particles less than 0.001 mm size possess colloidal properties and are known as soil colloids, and hence most clay fractions exhibits colloidal properties***. The individual particle of a colloid is called ***micelle*** or ***micro cell***.

10.1.1 Nature and general properties of soil colloidal particles

- **Size of colloidal particle**
  The most important common property of most colloids is their extremely small size. They are too small to be seen only with an electron microscope. Most are smaller than 2 μm (0.002 mm) in diameter.

- **Surface area of colloidal particle**
  Because of their smaller size, all soil colloids expose a large external surface per unit mass. The external surface area of 1 g of colloidal clay is at least 1000-times than that of 1 g of coarse sand. Some colloids, especially certain silicate clays have extensive internal surfaces as well. These internal surfaces occur between plate like crystal units that make up each particle and often greatly exceed the external surface area.

- **Brownian movement**
  When a suspension of colloidal particles is examined under a microscope, the particles seem to oscillate. The oscillation (*zig-zag motion*) is due to the collision of colloidal particles or molecules with those of the liquid in which they are suspended. Soil colloidal particles in water are always in a constant state of motion. The smaller the size of colloidal particle, the more is the rapid brownian movement.

- **Surface charges**
  Soil colloidal surfaces (both external and internal surfaces) characteristically carry negative and/or positive charges and for most soil colloids, electro negative charges predominate.The negative electrical charge on clays originates through either ***ionizable hydrogen ions/exposed crystal edges*** or ***isomorphism substitution***.

- **Adsorption of cations**
  Surface adsorption is very large when large amount of colloidal materials are present in a substance, because of having large surface area contributed by its presence. Since, soil colloids possess negative charge; they attract the positive charged ions to the colloidal surfaces. Adsorption of ions is governed by the type and nature of ion and type of colloidal particles. The higher the valence of cations, the more strongly adsorbed it is. A hydrogen (H^+) ion behaves as a polyvalent and hence it is adsorbed on the surfaces of colloids more

strongly than other divalent cations like Ca^{2+}. Among the clay minerals, kaolinitic clay has a greater anion e.g., phosphate adsorbing capacity than montmorillonitic or illitic clay.

- **Adsorption of water**
  In addition to the adsorbed cations, a large number of water molecules are associated with soil colloidal particles. Some are attracted to the adsorbed cations, each of which is hydrated; others are held in the internal surfaces of the colloidal particles. These water molecules play a critical role in determining both the physical and chemical properties of soil.

- **Cohesion and adhesion**
  Cohesion is the phenomenon of sticking together of colloidal particles that are of similar nature. Cohesion indicates the tendency of clay particles to stick together. This tendency is primarily due to the attraction of the clay particles for the water molecules held between them. When colloidal substances are wetted, water first adheres to the particles and then brings about cohesion between two or more adjacent colloidal particles. Adhesion refers to the phenomenon of colloidal particles sticking to other substances. It is the sticking of colloida1 materials to the surface of any other body or substance with which it comes in contact.

- **Swelling and shrinkage**
  Some clay (soil colloids) such as *smectites* swell when wet and shrink when dry. After a prolonged dry spell, soils high in smectites (*Vertisols*) often are characterized by wide, deep cracks, which at first allow rain to penetrate rapidly. Later, because of swelling, such soil is likely to close up and become much more impervious than soil that dominated by other clay minerals such as kaolinite, chlorite, or fine grained micas.

- **Dispersion and flocculation**
  As long as the colloidal particles remain charged, they repel each other and the suspension remains stable. If on any account, they lose their charge, or if the magnitude of the charge is reduced, the particles coagulated, form flocs or loose aggregates, and settle down. This phenomenon of formation of flocs is known as *flocculation*. The reverse process of the breaking up of flocs into individual particles is known as *deflocculation or dispersion*. E.g., clay suspension is coagulated by the use of aluminium (Al^{3+}). This condition is generally beneficial in relation to agriculture since it is the first in the formation of stable aggregates or granules. The ability of common cations to flocculate soil colloids is in the order of: Al >Ca = H >Mg >K >Na. In soils of humid and sub-humid regions, the colloidal complexes are dominated by Al, H, and Ca and these ions encourage flocculation and consequently they help to form aggregates. Whereas, in soils of arid regions, Na ions have become dominate on the exchange complex and thereby poor physical condition of the soil resulting from the dispersion of the soil colloids which is not desirable.

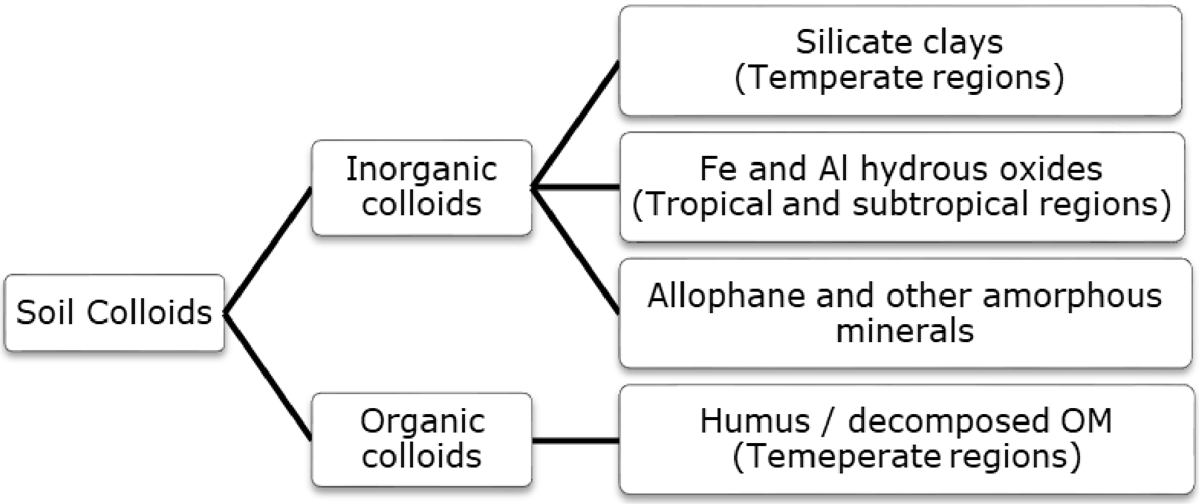
- **Tyndall effect/scattering**
  Scattering of light by particles in a colloid or suspension is known as ***Tyndall effect or Tyndall scattering***. When a strong beam of light is passed through a colloidal solution, the path of the light becomes visible. It is observed when the particles are larger than the wavelength of visible light. The intensity of ***Tyndall scattering*** increases with increase in the size of colloidal particles as well as the concentration.

- **Non permeability**
  Colloids, as opposed to crystalloid, are unable to pass through a semi-permeable membrane. Even though the colloidal particles are extremely small, they are bigger than molecules of

crystalloid dissolved in water. The membrane allows the passage of water and of the dissolved substance through its pores, but retains the colloidal particles.

10.2 Types of soil colloids

Except sand fraction, all soils contain particles of colloidal size. Soil colloids are chemically active portion of soil. They are classified as:

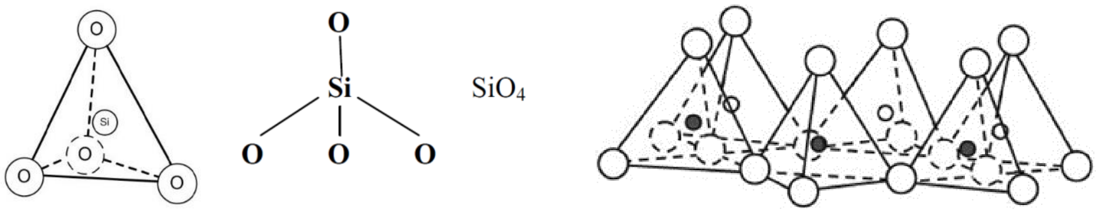


10.2.1 Inorganic colloids – Silicate clay minerals

The most important silicate clays are known as ***phyllosilicates*** (Gr. phullon, leaf), meaning a leaf-like or platelet structure. They are characterized by alternating sheets comprised of planes of mineral cations surrounded and linked together by planes of oxygen and hydroxyl anions **(Figure 10.1 and 10.2)**. One type of sheet is dominated by silicon, and the other by aluminum and/or magnesium. Comparative properties of silicate clay minerals are given in **Table 10.1**.
On the basis of number and arrangement of silica sheet (tetrahedral) and alumina-magnesia sheet (octahedral), silicate clays may be classified into several groups as under:

- **A.** 1:1 type minerals
- **B.** 2:1 expanding and non-expanding type minerals
- **C.** 2:1:1 or 2:2 type minerals

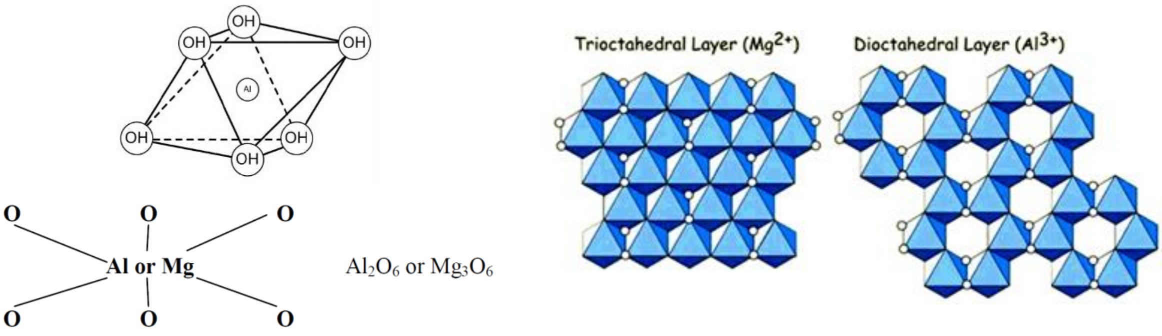
- ***Silica Tetrahedral sheet:*** is the basic building block for the silica-dominated sheet, is a unit composed of one silicon atom surrounded by four oxygen atoms, which gives four-sided configuration. An interlocking array or a series of these silica tetrahedrons tied together horizontally by shared oxygen anions gives a ***silica tetrahedral sheet*****(Figure 10.1)**.



(a) **(b)**

Figure 10.1:(a) Si-tetrahedron unit and **(b)**Si-tetrahedral sheet

- **Alumina Octahedral sheet:** is a unit composed of an aluminum (or magnesium) ion surrounded by six oxygen or hydroxyl atoms, gives an eight sided building block structure. Numerous octahedrons linked together horizontally make the octahedral sheet. An aluminium dominated sheet is known as a ***dioctahedral*** sheet, whereas one dominated by magnesium is called a ***trioctahedral*** sheet. The distinction is due to the fact that two aluminium ions in a dioctahedral sheet satisfy the same negative charge from surrounding oxygen and hydroxyls as three magnesium ions in a trioctahedral sheet **(Figure 10.2)**.



(a) **(b)**

Figure 10.2:(a) Al- or Mg-octahedron unit and **(b)**di- or trioctahedral sheet

(A) 1:1 type minerals

The layers of the 1:1-type minerals are made up of one tetrahedral (silica) sheet combined with one octahedral (alumina) sheet, hence the termed as 1:1-type crystal **(Figure 10.3)**. In soils, ***kaolinite*** is the most prominent member of this group, which includes halloysite, nacrite, and dickite.

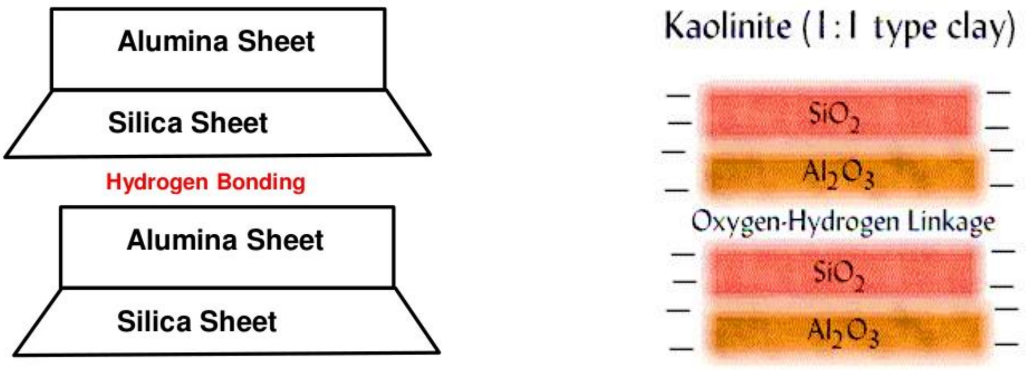


Figure 10.3 Structure of kaolinite (1:1 layer silicate) mineral

The tetrahedral and octahedral sheets in a given layer of ***kaolinite*** are ***held together by oxygen anions***, which are mutually shared by the silicon and aluminum cations in their respective sheets. These layers, in turn, are held together by ***hydrogen bonding***.

Consequently,

- The lattice (framework of Si- and Al-sheets) is *fixed*
- No expansion ordinarily occurs between layers when the clay is wetted
- Cations and water do not enter between the structural layers of the particle
- The effective surface of kaolinite is thus restricted to its external surface area
- Also, there is little isomorphic substitution in this mineral

(B) 2:1 type minerals

The crystal units (layers) of these minerals are characterized by an octahedral sheet sandwiched between two tetrahedral sheets**(Figure 10.4)**. Three general groups have this basic crystal structure. Two of them, ***smectite***and ***vermiculite***are expanding-type minerals. While the third,***fine-grained micas (illite)***is nonexpanding.

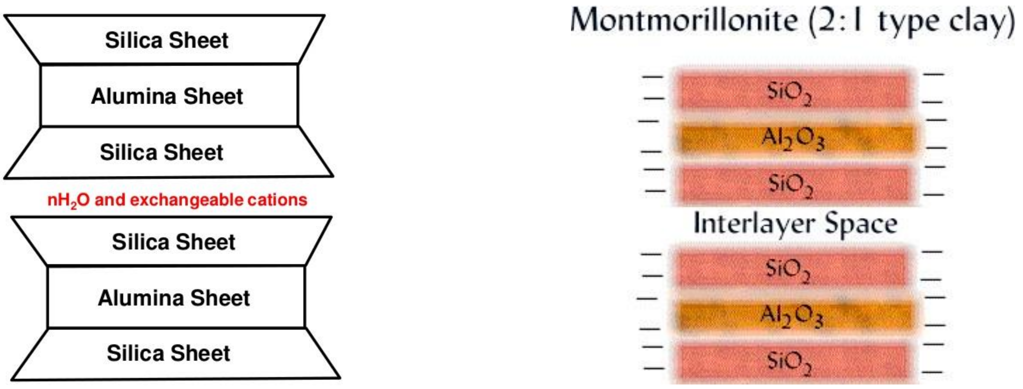
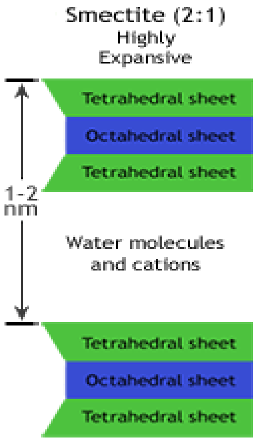


Figure 10.4: Structure of 2:1 type mineral

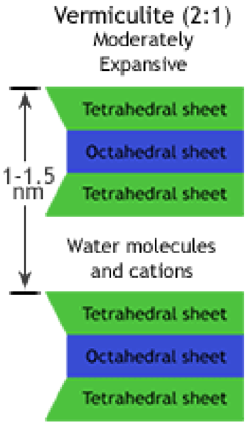


- **(i)** ***Expanding 2:1 type mineral***

  The smectite groupincludes montmorillonite, beidellite, nontronite, and saponite. It is noted for interlayer expansion, occurs by swelling when the minerals are wetted, the water entering the interlayer space and forcing the layers apart. ***Montmorillonite*** is the most prominentmember of this group in soils.

  The flake-like crystals of this mineral are composed of 2:1-type layers, as shown in **Figure 10.4.**These layers are loosely held together by ***very weak oxygen-oxygen*** and ***cation-oxygen*** linkages. Exchangeable cations and associated water molecules are attracted between layers (interlayer space), causing ***expansion***of crystal lattice. Consequently,

✓ Smectite crystals much smaller than the average kaolinite.
✓ They are unstable under high pH and high soil moisture.
✓ Very large internal surface, exceeds the external surface area of these minerals.
✓ Specific surface area (i.e., external and internal) of montmorillonite is700-800 m^{2}g^{-1}.
✓ Smectites shows a ***high cation exchange capacity***, ~10-15 times than that of kaolinite.
✓ Smectites also are noted for their ***high plasticity and cohesion*** and their ***high shrinkage*** on drying. Wide cracks commonly form as soils dominated by smectites are dried.



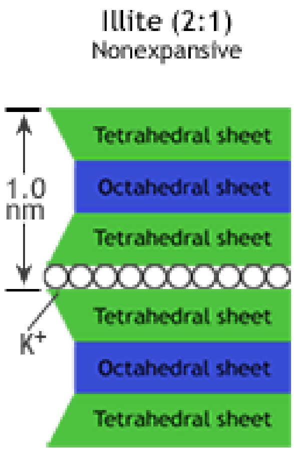
Vermiculites have structural characteristics similar to those of the smectite group. Vermiculites are moderately expanding 2:1 type mineral and have following properties.

✓ More structured, limited shrinking-swelling.
✓ Larger cation adsorption → Isomorphic substitution in both layers, even more than montmorillonite.
✓ Very high negative charges in the tetrahedral sheet.

- ✓ Vermiculite crystal are larger in size than montmorillonite, but smaller than those of kaolinite.
- ✓ Stable under moderate to low soil pH, High in Mg and Fe content.

- **(ii) *Non-expanding 2:1 type mineral***

***Micas*are the type minerals in this group. *Muscovite* and *biotite* are examples of micas often found in sand and silt separates. Minerals similar in structure to these micas found in the clay fraction of soils, are called ***fine-grained micas*or *illite*.**

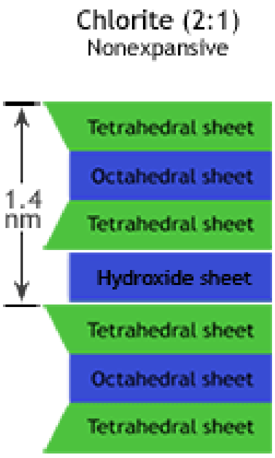


Like smectites, ***fine-grained mica*** or ***illite*** has a 2:1-type crystal. The particles are much larger than smectites, and the major source of charge is in tetrahedral rather than octahedral sheet. About 20% of the tetrahedral silicon sites are occupied by aluminum atoms. This results in a high net negative charge in the tetrahedral sheet, even higher than that found in vermiculite. To satisfy this charge, potassium ions in the interlayer space are strongly attracted and are just the right size to fit comfortably into certain spaces in the adjoining tetrahedral sheets. The potassium thereby acts as a binding agent, preventing expansion of the crystal. Hence, ***fine-grained mica*** or ***illite*** is ***non-expansive type mineral***.

Consequently, the properties as hydration, cation adsorption, swelling, shrinkage, and plasticity are much less in fine-grained micas than smectites. In size,also, fine-grained mica crystals are intermediate between the smectitesand kaolinites.

(C) 2:1:1 or 2:1 or 2:2 type minerals

This silicate group is represented by ***chlorite minerals***. Chlorites are basically ferro-magnesium silicates with presence of aluminum. In chlorite clay crystal, 2:1 layersare alternate with a magnesium-dominated trioctahedral sheet, giving a 2:1:1 ratio.Thus, the crystal unit contains two silica tetrahedral sheets and two magnesium-dominated trioctahedral sheets, giving rise to the term 2:1:1- or 2:2-type structure.



- ✓ The cation exchange capacity of chlorites is similar to illite, and less than smectites orvermiculites.

- ✓ Particle size and surface area of chlorite crystal also same as of illite. There is no water adsorptionbetween the chlorite crystal units, which accounts for the non-expansive nature of this mineral.

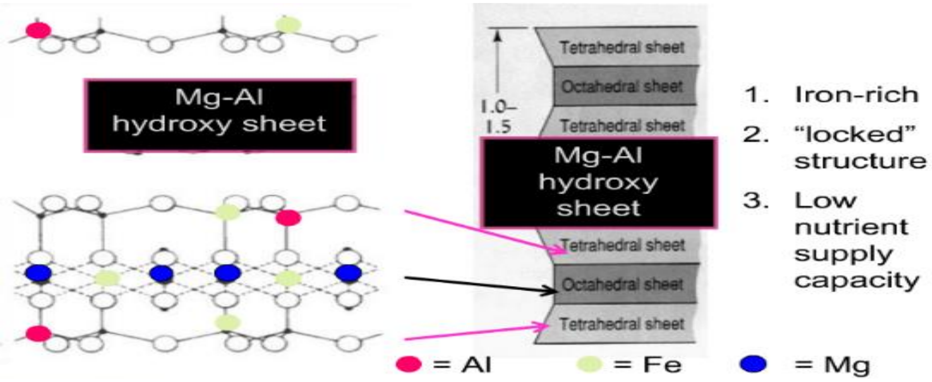


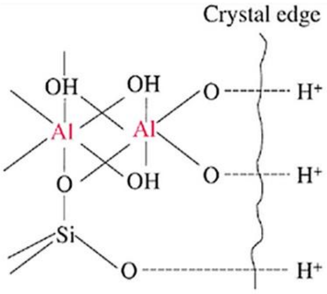
Table 10.1 Comparison between different inorganic silicate clay minerals

Property	Kaolinite	Montmorillonite	Illite
Structure	1:1 (Tetra-Octa) No substitution	2:1 (Tetra-Octa-Tetra) Substitution in Octahedral sheet by Mg of Fe	2:1 (Tetra-Octa-Tetra) Substitution in Tetrahedral sheet by Al
Shape and Size (μ)	Hexagonal Crystal 0.1-5.0μ	Irregular Flakes 0.01-1.0μ	Irregular Flakes 0.1-2.0μ
Layer Bonding	Hydrogen bonding (Strong)	O – O or O – Cation Van Der Waals (Weak)	Potassium ion (Strong)
–ve Charges; CEC (meq 100 g^{-1})	Low –ve charge CEC, 3-15	Highest –ve charge CEC, 80-100	Moderate –ve charge CEC, 15-40
Swelling	Very little	High/Moderate	Low
Surface Area (Total; m^2 g^{-1})	No internal surface area. Only External surface 5-20m^2 g^{-1}	Very high (Internal and External) 700-800m^2 g^{-1}	Medium (External) 100-120m^2 g^{-1}

10.2.2 Sources of negative charges on silicate clays

The negative electrical charge on silicate clays comes through the process called: (i) Ionizable hydrogen ions/exposed crystal edges, and (ii) Isomorphism substitution

- ***pH dependent charges***
  This involves the unsatisfied negative charges associated with oxygen and hydroxyl groups exposed at the broken edge and flat external surfaces of minerals such as kaolinite. The O and OH are attached to silicon and aluminum ions within their respective sheets. *Ionizable hydrogen ions* are hydrogen from hydroxyl ions on clay surfaces. At pH 7 or higher, the −Al−OH or −Si−OH portion of the clay ionizes the H-ion and leaves an unneutralized negative charge on oxygen (−Al−O−, −Si−O).



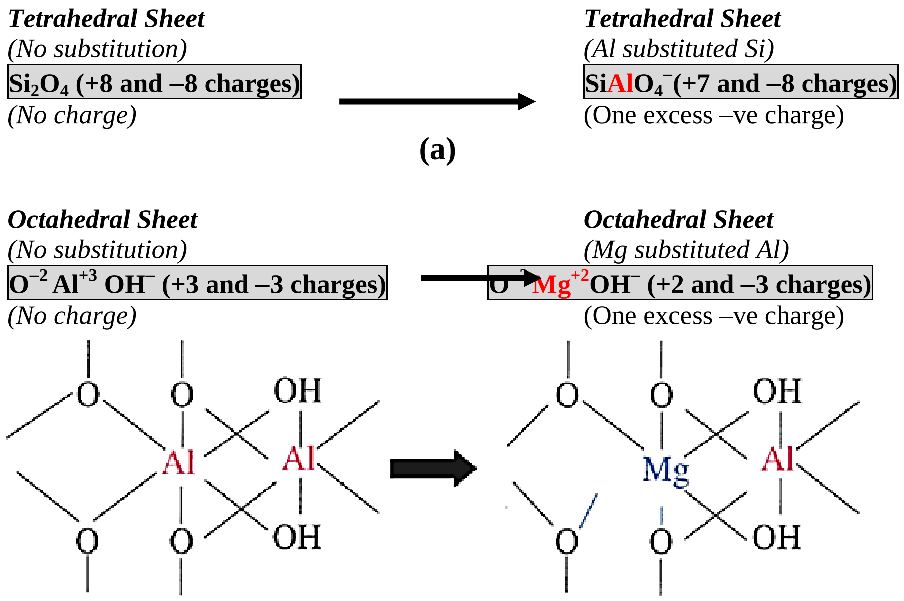
$$–SiOH + OH^{-} \Leftrightarrow –SiO^{-} + H_2O$$
$$–AlOH + OH^{-} \Leftrightarrow –AlO^{-} + H_2O$$

The extent of ionized hydrogen depends on solution pH; more ionization occurs in more alkaline (basic; pH 7 or higher) solutions, hence also called ***pH-dependent charges***. The magnitude of this pH dependent negative charges varies with the types of colloid. This type of charge is predominant in the organic colloids, due to larger functional groups like carboxyl, phenolic, and hydroxyl.

Low pH value (Acidic) →+ve charge forms → Anion adsorption
High pH value (Alkaline) → −ve charge forms → Cation adsorption

- ***Isomorphous substitution***
  The second source of charge on clay particles is due to the substitution of one ion for another of ***similar size*** and often with ***lower positive valence***. In clay structures, certain ions fit into certain mineral lattice sites because of their convenient size and charge.

Dominantly, clays have Si^{4+} in tetrahedral sites and Al^{3+} in octahedral sites, can be replaced by other ions present in large amounts during clay crystallization (**Figure 10.5**). Substitutions that are common are the Si^{4+} replaced by Al^{3+}, and even more extensive replacement of Al^{3+}by one or more of these: Fe^{2+}, Mg^{2+} or Zn^{2+}. Since, the total negative charge from the anions (the oxygen) remains unchanged, the lower positive charge because of substitution results in an excess negative charge at that location in the structure. These charges are pH independent.



(b)

Figure 10.5 Isomorphous substitution in **(a)**tetrahedral and **(b)** octahedral sheet

10.2.3 Inorganic colloids – Sesquioxides clays

Hydrous oxides of Iron and Aluminium (sesquioxides clays)

The Latin word '*sesqui*' means one and one-half times; meaning one and one-half times more oxygen than Al and Fe.

These type of clay minerals are present in red and yellow soil of tropical and sub-tropical regions. The sesquioxides (metal-oxides) are mixtures of aluminium hydroxide, $Al(OH)_3$, and iron oxide, Fe_2O_3, or iron hydroxide, $Fe\cdot(OH)_3$.Examples of iron and aluminium oxides common in soils are ***gibbsite*** **($Al_2O_3 \cdot 3H_2O$)** and ***goethite*** **($Fe_2O_3 \cdot H_2O$)**.These clays may be amorphous or crystalline and do not swell.They are not sticky and have high phosphorus adsorption capacity.

Inorganic colloids – Allophane and other amorphous minerals

These silicate clays are mixtures of silica and alumina. They are amorphous (non-crystalline) in nature. Typically, these clays occur where large amount of weathered products existed.

- ✓ These clays are common in soils forming from volcanic ash (e.g., ***Allophane***).
- ✓ These clays have high anion exchange capacity or even high cation exchange capacity.
- ✓ Almost all of their charge is from accessible hydroxyl ions (OH^-). These clays have a variable charge that depends on H^+ in solution (soil acidity; pH dependent charge).

10.2.4 Organic soil colloids – Humus

Humus is a product of decomposition of plant and animal residues which is fairly stable, amorphous, dark brown to black, nearly insoluble in water, but mostly soluble in dilute alkali solutions.So, humus are referred as organic soil colloids, and they have following properties.

- ✓ Humus arenon-crystalline minerals and found in nearly all soils.
- ✓ Humus are non-crystalline colloids dominated by long carbon-chain molecules bonded with hydrogen, oxygen and nitrogen.
- ✓ Very high capacity to adsorb water.
- ✓ High amounts of both −ve and +ve charges (pH dependent), but net charge is always −ve.
- ✓ The –ve charges on humus are associated with partially dissociated alcoholic (−OH), carboxyl (−COOH), and phenolic groups **(Figure 10.6)**.
- ✓ Organic colloid exhibits 5-7 folds higher adsorption of water and cations than inorganic colloids.

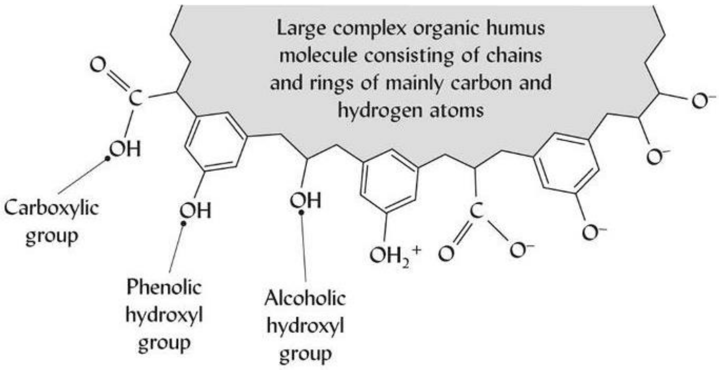


Figure 10.6: Organic humus molecule

10.3 Ion exchange

Each colloid (both inorganic and organic) possess a net negative charge and this means it can attract and hold positively charged ions such a potassium, sodium, hydrogen, calcium and magnesium. ***Ion exchange*** *is defined as a reversible process by which cations and anions are exchange between solid and liquid phases, and between solid phases, if they are in close contact with other*(**Figure 10.7**). The exchange of cations and anions, the term is used as ***cation exchange*** and ***anion exchange***, respectively.

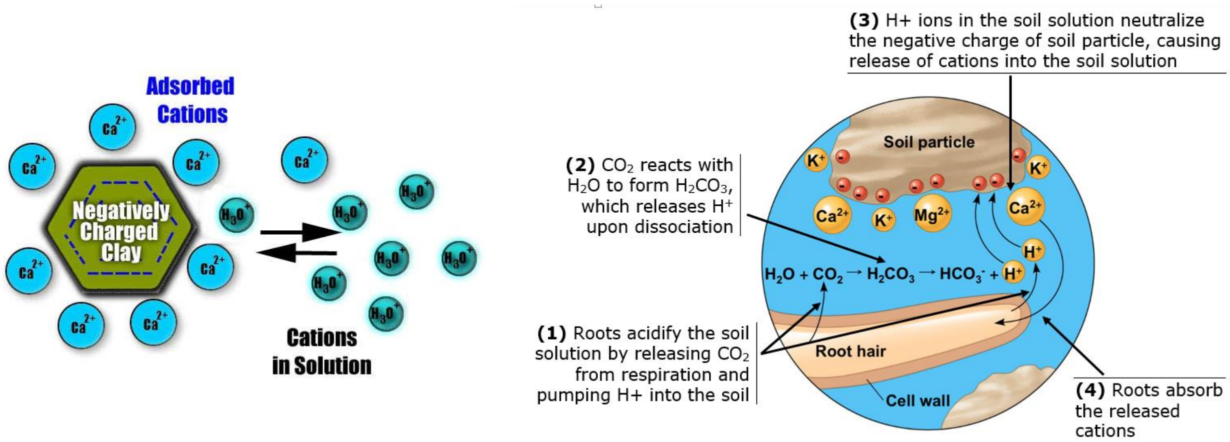


Figure 10.7: Ion exchange between solid phases (roots, clay particles) and liquid phase (soil solution), and between solid phases.

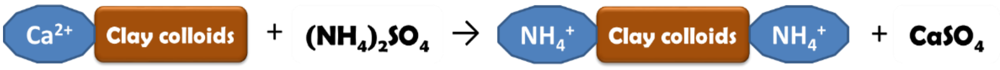
- ✓ Most cations are → **Ca^{2+}, Mg^{2+}, H^+, Na^+, NH_4^+**
- ✓ In strong acid soil → **$Al(OH)_2^+$**
- ✓ In Alkali soil → **Na^+**
- ✓ Dominant Anions → **SO_4^{2-} , Cl^- , HCO_3^-**

The ion exchange properties of a soils is entirely due to the clay and silt fractions, and the organic matter. Negatively charged colloids attract cation and hold them like a magnet holds small pieces of metal. This characteristic explains:why does nitrate-N (NO_3^-) more easily leach from the soil than ammonium-N (NH_4^+)? Nitrate has a negative charge like soil colloids, so nitrate is not held by the soils, but remains as a free ion in soil water to be leached through the soil profile especially under rainfall conditions.

10.3.1 Cation exchange or base exchange

In a near neutral soil, Ca^{+2} is remaining adsorbed on colloidal particle. H^+ ion generated as organic and mineral acid formed due to decomposition of organic matter. In colloid, H^+ ion is adsorbed more strongly than is the Ca^{+2}. The reaction is as follow:

This phenomenon of the exchange of cations between soil and salt solution is known as ***cation exchange*** or ***base exchange*** and the cations that take part in this reaction are called ***exchangeable cations***. **Thompson and Way (1892)** first recognized cation exchange phenomenon. They passed a solution of $(NH_4)_2\ SO_4$ through a soil column and found that effluent contained no NH_4^- salt but $CaSO_4$. This phenomenon is always in equivalent quantities of ions.



The exchange of cations in the soil take place between…

- ✓ Cations in the soil solution and those on the exchanges complexes of soil
- ✓ Cations released by plant roots and those on the exchange complexes of soil
- ✓ Cation on the surface of either two clay crystals, two organic colloids, or a clay particle and a humus particle

Cation exchange reaction is *reversible* and considered as *ion redistribution*. This reaction is chemically equivalent. The most important cations in soils arecalcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), hydrogen (H^+) andaluminium (Al^{3+}).All cations are not adsorbed with equal tenacity for a clay saturated with a particular cation.Again, all exchange sites do not possess the same strength of negative charge at particle surface.Hydrogen is most tenaciously bound by soil colloids.

In general the cations adsorbed on the surface of silicate clays are in the order of:

$$H^+ \geq Al^{3+} > Ca^{+2} \geq Mg^{2+} > K^+ = NH_4^+ > Na^+$$

Certain cations are especially prominent under natural conditions.

Humid region soils	$Al^{3+} \geq H^+ > Ca^{+2} = Mg^{2+} > K^+ > Na^+$
Well drained and semi arid soils	$Ca^{+2} > Mg^{2+} > Na^+ > K^+ > H^+$
Sodic or Alkali soils	$Na^+ > Ca^{+2} > Mg^{2+} > K^+ > H^+$

Cation exchange capacity

The sum of total of exchangeable cations that can be adsorbed on the exchange complex of the soil is called as ***cation exchange capacity*** of the soil. The higher the CEC of soil, the morecation it can retain. Soils differ in their capacities to hold exchangeable cations.

It is expressed in ***milliequivalent per 100g*** of soil or adsorbing material. The milliequivalent weight of ion or substance is one thousandth of its equivalent weight, since the equivalent weight of H ion is 1 g. ***Milliequivalent*** is defined as 1 milligram of hydrogen or the amount of any other ion that will combine with or displace it. (*milliequivalent is one-thousandth of equivalent weight*).

It implies that, 1meq H^+ = 1 meq Ca^{+2} = 1 meq Mg^{+2} = 1 meq K^+ =1 me Na^+
That means, 1 mg H^+ = 20 mg Ca^{+2} = 12 mg Mg^{+2} = 23 mg Na^+ = 39 mg K^+

This CEC unit is now represented by new unit **moles (+)**, which indicates a monovalent ion portion. One meq per 100 g soil is equal to one cmol (p+) kg soil. It can be abbreviated as **cmol-**$_c$, centimoles of charges or as **cmol (p+)**, centimoles of protons.

1 meq per 100 g = 1 cmol(p+) per kgof soil = 100 mmol (p+) kgof soil (millimoles of protons)

Following are some formula for calculation:

$$\mathrm{mg/100\ g = meq/100\ g\ \times equivalent\ weight}$$

$$\mathrm{ppm\ (mg/kg) = meq/100\ g\ \times 10}$$

$$\mathrm{kg/ha = ppm\ \times 2.24*}$$

$$\mathrm{lbs/acre\ (pounds\ per\ acre) = ppm \times 2}$$

*The weight of hectare furrow slice (at 15 cm soil depth) is taken as 2.24×10^6 kg, considering average bulk density of most cultivated soil as 1.49 g cm^{-3}.

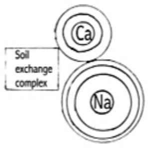
The proportion of the CEC occupied by various bases/cations is called ***percent base saturation***.

Factors affecting the cation exchange

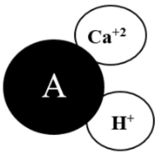
- **Valiancy of cations**
  Cations having *higher valency* are *strongly held* or adsorbed on the colloids than the cations having lower valiancy.For example, Al^{+3} strongly bounds than Ca^{+2} and Na^+. Hydrogen ion (H^+) is an exception, because it acts like a polyvalent ion even though it is monovalent. H^+ion bounds more strongly bound even than Al^{+3} because it has higher affinity for oxygen which is present on the edges of silicate clay minerals.

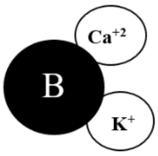
- **Zeta potential**
  Zeta potential is the magnitude of negative charge on the colloidal particles. Cations which have lower valiancy are *hydrated* and have *higher zeta potential*. So, the Na^+ion has higher zeta potential as compared to Ca^{+2}ion. Those cations, which have higher zeta potential, are loosely held and easily replaced. Thus., Na^+ ion can be easily replaced compared to Ca^{+2} ion.

- **Water hull**
  Every cation carries some water with it, and water remains around the cation as a very thin film, which is called ***water hull***. As the valency of the cation decreases, it has higher water hull and it remains away from the clay particles. Hence, it is loosely held and can be easily replaced. This is because of decrease in the force of attraction between the two particles.



- **Presence of complementary ion**
  For**particles A**, H^+ ion is the complementary ion of Ca^{+2}. H^+ is strongly bound compared to Ca^{+2}. So, Ca^{+2} replaced first through exhange process. While in case of **B particle**, K^+ is the complementary ion of Ca^{+2}. Here, Ca^{+2}ion is quite strongly bound compared to K^+ ion.So, the K^+ion replaced first.





- **Types of silicate clay mineral**
  Monovalent cations are more strongly held to the kaolinite clay minerals. While divalent cation are strongly held to the montmorillonite clay minerals, due to higher CEC of such clay minerals.

Significance of cation exchange

Cation exchange is an important reaction in soil fertility, in causing and correcting soil acidity and basicity, in changes altering soil physical properties, and as a mechanism in purifying or altering percolating waters. The plant nutrients like calcium, magnesium and potassium are supplied to plants in large measure from exchangeable forms.

Cation exchange is very important in soils because of the following relationships:

- ✓ The exchangeable K is a major source of plant K.
- ✓ The exchangeable Mg is often a major source of plant Mg.
- ✓ The more amount of lime is required to raise the pH of an acidic soil having high CEC.
- ✓ Cation exchange sites hold Ca^{+2}, Mg^{+2}, K^+, Na^+, NH_4^+ ions and reducestheir leaching losses.
- ✓ Cation exchange sites hold fertilizer K^+ and NH_4^+ and greatly reduce their mobility in soils.
- ✓ Cation exchange sites adsorb many metals (Cd^{+2}, Zn^{+2}, Ni^{+2} and Pb^{+2}) that might be present in wastewater, hence minimize or stabilize their movement within the soil.

10.3.1Anion exchange

The process of anion exchange is similar to that of cation exchange. Under certain conditions hydrous oxides of Fe and Al shows evidence of having positive charges on their crystal surfaces. These positive charges of colloids are due to addition of hydrogen (H^+) in hydroxyl group (OH^-) resulted in net positive charge, will attract anions.

- ✓ he capacity for holding anions increases with increase in acidity.
- ✓ The lower the pH, greater is the anion adsorption.
- ✓ All anions are not adsorbed equally readily.
- ✓ Some anions (e.g., $H_2PO_4^-$)are adsorbed quickly at acid as well as alkaline pH range.
- ✓ $Cl^-$and SO_4^{-2} ions are adsorbed slightly at low pH but none at neutral soil, while NO_3^- ions are not adsorbed at all. Hence, at pH commonly prevailing in cultivated soils, NO_3^-,Cl^-, and SO_4^{-2}ions can be readily lost through leaching.
- ✓ In general, the relative order of anion exchange is: $OH^- > H_2PO_4^- > SO_4^{-2} > NO_3^-$

Importance of anion exchange

The phenomenon of anion exchange assumes in relation to phosphate ions and their fixation. The exchange is brought mainly by the replacement of OH^- ions of the clay minerals.

$$\underset{}{\text{OH-Clay}^-} + \underset{\textit{(Available form)}}{H_2PO_4^-} \rightarrow \underset{\textit{(Unavailable form)}}{H_2PO_4\text{-Clay}^-} + OH^-$$

The adsorption of phosphate ions by clay particles from soil solution reduces its availability to plants. This is also known as ***colloid bound phosphate*** fixation. The phosphate ion again becomes available when lime is applied to increase the pH of acidic soil.

The OH ion originated not only from silicate clay minerals but also from hydrous oxides of iron and aluminum present in the soil. The phosphate ions reacts with the hydrous oxides also get fixed forming insoluble hydroxyl phosphate of iron and aluminum, which is called ***saloid bound phosphate.***

$$Al(OH)_3 + \underset{\textit{(Available form)}}{H_2PO_4^-} \rightarrow \underset{\textit{(Unavailable form)}}{Al(OH)_2 \cdot H_2PO_4} + OH^-$$

If this reaction takes place at a low pH under strongly acid conditions, the phosphate ions are irreversibly fixed, and are become unavailable for the plant use.

Numerical:

Soil having CEC of 20 meq per100 gsoil and different exchangeable cations present in soil are:

Ca^{+2} = 10meq per 100 g soil	Mg^{+2} = 5meq per 100 g soil
K^+ = 1meq per 100 gsoil	Na^+ =1me/100 g soil

Using above given values calculate

(i) % base saturation

(ii) % base unsaturation or H-saturation

(iii) %saturation of individual exchangeable cation

(iv) Amount of individual cation in mg per 100 g, ppm, lb per acre, kg per hectare, and

(v) Amount of lime-$CaCO_3$require to neutralize exchangeable H^+.

(i) Percent base saturation

Total exchangeable bases = Sum of the given cations

= 10 + 5 + 1 + 1 = 17 meq per 100 g soil

$$\text{Percent base saturation} = \frac{\text{Total exchangeable cations}}{\text{CEC}} \times 100$$

$$\text{Percent base saturation} = \frac{17}{20} \times 100 = 85\%$$

(ii) Percent base unsaturation or H-saturation

$$\text{Exchangeable H} = \text{CEC} - \text{Total exchangeable cations}$$

$$\text{Exchangeable H} = 20 - 17 = 3 \text{ meq per 100 g soil}$$

$$\text{Percent base saturation} = \frac{\text{Total exchangeable H}^{+}}{\text{CEC}} \times 100$$

$$\text{Percent base unsaturation or H saturation} = \frac{3}{20} \times 100 = 15\%$$

(iii) Percent saturation of individual cations

$$\text{Percent Ca}^{+2}\text{ saturation} = \frac{\text{Total exchangeable Ca}^{+2}}{\text{CEC}} \times 100 = \frac{10}{20} \times 100 = 50\%$$

$$\text{Percent Mg}^{+2}\text{ saturation} = \frac{\text{Total exchangeable Mg}^{+2}}{\text{CEC}} \times 100 = \frac{5}{20} \times 100 = 25\%$$

$$\text{Percent K}^{+}\text{ saturation} = \frac{\text{Total exchangeable K}^{+}}{\text{CEC}} \times 100 = \frac{1}{20} \times 100 = 5\%$$

$$\text{Percent Na}^{+}\text{ saturation} = \frac{\text{Total exchangeable Na}^{+}}{\text{CEC}} \times 100 = \frac{1}{20} \times 100 = 5\%$$

(iv) Amount of individual cation in mg per 100 g, ppm, lb per acre, kg per hectare

For Ca^{+2}

1 meq Ca^{2+} per 100 g soil = 20 mg Ca^{2+} per 100 g soil

$\therefore$ 10meq Ca^{2+} per 100 g soil = 200 mg Ca^{2+} per 100 g soil

ppm Ca^{2+} = mg Ca^{2+} per 100 g soil × 10

= 2000 × 100

= 2000 ppm Ca^{2+}

lbs per acre Ca^{2+} = ppm Ca^{2+} × 2

= 2000 × 2

= 4000 lbs per acre

kg per hectare Ca^{2+} = ppm Ca^{2+} × 2.24

= 2000 × 2.24

= 4480 kg per hectare

For Mg^{+2}

1 meq Mg^{+2} per 100 g soil = 12 mg Mg^{+2} per 100 g soil

$\therefore$ 5meq Mg^{+2} per 100 g soil = 60 mg Mg^{+2} per 100 g soil

Similar to above calculation:

ppm = 600 ppm Mg^{+2}

lbs per acre = 1200 lbs Mg^{+2} per acre

kg per hectare = 1344 kg Mg^{+2}per hectare

For Na^+

1 meq Na^+ per 100 g soil = 23 mg Na^+ per 100 g soil

Similar to above calculation:

ppm Na^+ = 230 ppm Na^+

lbs per acre = 460 lbs Na^+ per acre

kg per hectare = 515.2 kg Na^+per hectare

For K^+

1 meq K^+ per 100 g soil = 39 mg K^+ per 100 g soil

Similar to above calculation:

ppm = 390 ppm K^+

lbs per acre = 780 lbs K^+ per acre

kg per hectare = 873.6 kg K^+per hectare

(v) Amount of lime-$CaCO_3$require to neutralize exchangeable H^+

1 meq H+ per 100 g soil = 1 meq $CaCO_3$ per 100 g soil

= 50 mg $CaCO_3$ per 100 g soil

$\therefore$3 meq H+ per 100 g soil = 150 mg $CaCO_3$ per 100 g soil

ppm $CaCO_3$= 150 mg $CaCO_3$ per 100 g soil × 10 = 1500 ppm $CaCO_3$

kg $CaCO_3$ per hectare = ppm CaCO3 × 2.24

= 1500 × 2.24

= 3360 kg per hectare = 3.36 tonnes per hectare

CHAPTER 11: SOIL REACTION

11.1 Soil reaction

One of the outstanding physiological characteristics of the soil solution is its reaction, i.e., whether it is acid, alkaline, or neutral. Since microorganisms and plants respond so significantly to their chemical environment, the importance of soil reaction and the factors associated with it have long been recognized.

The reaction of a solution represents the degree of acidity or basicity caused by the relative concentration of H^+ ions (acidity) or OH^- ions (alkalinity) present in it. Acidity is due to the excess of H^+ ions over OH^- ions, and alkalinity is due to the excess of OH^- ions over H^+ ions. A neutral reaction is produced by an equal activity of H^+ and OH^- ions.

11.2 Soil pH scale – Expressing soil reaction

The soil reaction can be measured in terms of soil pH values. Soil pH is the negative logarithm of the H^+ or H_3O^+ (hydronium) ion activity in soil solution, expressed in moles per litre.Danish biochemist **Sørenson** proposed the term pH, where suffix "*p*" refers to the "*Puissance de hydrogen*i.e., potential of hydrogen ion". He defined *pH as the negative logarithm of hydrogen ion activity*. *Soil pH generally refers to the degree of soil acidity or alkalinity*. pH is expressed as:

$$\mathbf{pH = -\log [H^+ \text{ or } H_3O^+]}$$

The pH scale ranges from 0 to 14; a pH of 7 is considered neutral. If pH values are >7, the solution is considered basic or alkaline; if they <7, the solution is acidic. A solution with an H+ ion activity of 0.001 Moles (M) will have a pH value 3, and one with H+ activity 0.0001 M, pH 4, and so on.

It is important to recognize that because the pH scale is in logarithmic units, a change of just a few pH units can induce significant changes in the chemical environment and sensitive biological processes. For example, a soil with pH 5.0 is 10-times more acidic than a soil with pH 6. Similarly, a soil with pH 5 is 100-times more acidic than pH 7.

Why pH scale ranges from 0 – 14?

The answer is due to *self-ionization or self-dissociation constant*($\boldsymbol{K_w}$) of water molecule. Due to its *amphoteric* nature (i.e., acts as both, an acid or a base), water does not always remain as H_2O molecules. In fact, two water molecules react to form hydronium (H_3O^+) and hydroxide (OH^-) ions:

$$2H_2O_{(liquid)} \leftrightarrows H_3O^+_{(aqueous)} + OH^-_{(aqueous)}$$

The concentration of H_3O^+ and OH^- are equal in pure water because of the 1:1 stoichiometric ratio of above equation. The molarity of H_3O^+ and OH^- in water are also both 1×10^{-7}M at 25 °C temperature. Thus, a constant of water ($\boldsymbol{K_w}$) is created to show the equilibrium condition for the self-ionization of water. The product of the molarity of H_3O^+ and OH^- ion is always 1×10^{-14}.

$$\text{At room temperatue, } \boldsymbol{K_w} = [H_3O^+]\,[OH^-] = 1 \times 10^{-14}$$

$$pK_w = -\log [1 \times 10^{-14}], \quad \therefore 10^{-pKw} = 10^{-14} \;\therefore pK_w = 14$$

$$pK_w = pH + pOH = 14$$

11.3 Acidic and alkaline soils

- **Acidic soil:** It is common in region where precipitation is high. The high precipitation leaches appreciable amounts of exchangeable bases from the surface layers of the soils, so that the exchange complex is dominated by H^+ ions. Acid soils, therefore, occur widely in humid regions, and affect the growth of plants significantly.

  There are three kind of soil acidity (**Figure 11.1**):
  - ✓ ***Active acidity*** is due to the H^+ ion in the soil solution.
  - ✓ ***Salt replaceable (exchangeable)*** *acidity* represented by the hydrogen and aluminium that are easily exchangeable by other cations in a simple unbuffered salt solution such as KCl.
  - ✓ ***Residual acidity*** is that acidity which can be neutralized by limestone or other alkaline materials but cannot be detected by the salt-replaceable technique. Obviously, these types of acidity all add up to the total acidity of a soil.

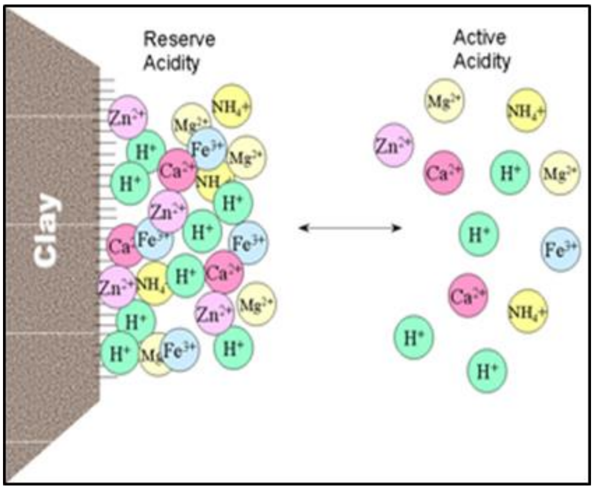


Figure 11.1: Soil reserve and active acidity

- **Alkaline soil:** Alkalinity occurs when there is comparatively high degree of base saturation. Salts like carbonates of calcium, magnesium and sodium also give a dominance of OH^- ions over H^+ ions in the soil solution. When salts of strong base such as sodium carbonate go into soil solution and hydrolyse, consequently they give rise to alkalinity. The reaction is follows:

  $Na_2CO_3 \rightarrow 2Na^+ + CO_3^-$

  $2Na^+ + CO_3^- + 2HOH \rightarrow 2Na^+ + \mathbf{2OH^-} + H_2CO_3$

  Since, sodium hydroxide dissociates to a greater degree than the carbonic acid, OH^- ions dominate, and give rise to alkalinity. This may be as high as pH 9 or 10. These soils most commonly occur in arid and semi-arid regions.

11.4 Factors controlling soil reactions

The soil reaction varies due to following factors:

- **Nature of soil colloids:** Hydrogen (H^+) ion predominantantly adsorbed cations on clay colloids, makes soil reaction acid.

- **Soil solution:** The concentration of cations in bulk of the solution is more or less (or nearly) the same as that near the particle surfaces. For an unsaturated soil (clay), the more compact layer, greater is the number of hydrogen ions dissociating into the solution. This increases the acidity of soil solution. The more dilute the solution, the higher the pH value. Hence the pH tends to drop as the soil gets progressively dry. Soil reaction is also influenced by the presence of CO_2 in soil air. As the CO_2 concentration increases, the soil pH falls.

- **Climate:** In general, soils formed in regions of high rainfall are acidic (low pH value), while those formed in regions of low rainfall are alkaline (high pH value).

- **Soil management:** Cultural operations in general tend to increase soil acidity. They make an acid soil more acidic, and an alkaline soil less alkaline. As a result of constant cultivation, basic elements are lost from the soil through leaching and crop removal. This leads to change the soil reaction to the acid side.

- **Parent materials:** Soils developed from parent material of basic rocks generally have higher pH than those formed from acid rocks (e.g., granite).

- **Decomposition of organic matter:** Soil organic matter is continuously being decomposed by micro-organisms into organic acids, carbon dioxide (CO_2) and water, forming carbonic acid. Carbonic acid, in turn, reacts with the Ca and Mg and carbonates in the soil to form more soluble bicarbonates, which are leached away, leaving the soil more acid.

- **Native vegetation:** Soils often become more acid when crops are harvested because of removal of bases. Type of crop determines the relative amounts of removal of bases. For example, legumes generally contain higher levels of bases than do grasses. Many legumes release H-ions into their rhizosphere when actively fixing atmospheric N_2. The acidity generated can vary from 0.2 to 0.7 pH units per mole of fixed N.

- **Soil depth:** Except in low rainfall areas, acidity generally increases with depth, so the loss of topsoil by erosion can lead to a more acid pH in the plough layer.

- **Nitrogen fertilization:** Nitrogen from fertilizer, organic matter, manures and legume N fixation produces acidity. Acidic fertilizers like ammonium fertilizers make the soil acidic, while basic fertilizer like sodium nitrate make the soil more alkaline in reaction.

- **Flooding:** The overall effect of submergence is an increase of pH in acid soils and a decrease in basic soils.

11.5 Buffering of soil reaction

Buffer action

Buffering refers to resistance to a change in pH. If 1 mL0.01 N HCl is added to 1 L of pure distilled water of pH 7.0, the resulting solution would have a pH of about 5. On the other hand, if this same amount of acid is added to a soil suspension, the resulting change in pH would be very small. There is, a distinct resistance to a change in pH. The soil suspension is buffered against a change in pH. The power to resist a change in pH is called ***buffer action***. Buffer solution contains ***reserve acidity*** and ***alkalinity*** and does not change pH with small additions of acid or alkali.

Buffer capacity of soil

Soils also exhibit buffering action. A capacity of soil to resist an abrupt/sudeen changes in the soil pH. The colloidal complex of soil acts as a powerful buffer in the soil and does not allow rapid and sudden changes in soil reaction. Buffering capacity largely depends upon the amount of colloidal material present in soil. Clay soils and soils rich in organic matter are more buffered than sandy soils.

Importance of buffering in agriculture

The changes in soil reaction i.e. pH have a direct influence on the plants and it also affects the availability of plant nutrients.Buffering prevents sudden fluctuations in soil pH, so it regulates the availability of nutrients and also checks direct toxic effect to plants and microorganism. Buffer also influences the amount of chemicals such as lime and gypsum application in problematic soils.

Hence, The importance of buffering soil is: (i) the stabilization of soil pH, so the regulates plant nutrient availability, and (ii) the amounts of amendments required to change in soil reaction.

11.5 Influence of soil reaction on availability of nutrients

The unproductiveness of acid and alkali soils is very often due to the lack of available plant nutrients. In highly acid soils (low pH), the availability of some of the nutrients such as aluminium, iron, manganese etc., is increased to a point to become toxic to the plant. At the same time the supplies of available calcium, nitrogen, phosphorus etc., are reduced to starvation level (become unavailable; **Figure 11.2**).

The same is the case at high pH (alkaline conditions), plant growth suffers due to the unavailability of nutrients like nitrogen, phosphorus and some minor elements (e.g., iron, manganese, boron etc.; **Figure 11.2**).

Another indirect effect occurs through the activity of microorganisms. Most microorganisms function at their best within a pH range 6.0 to 7.5. If soil reaction is changed beyond this range, the microorganisms become functionless. Consequently the supply of some of the essential plant nutrients like nitrogen is considerably reduced.

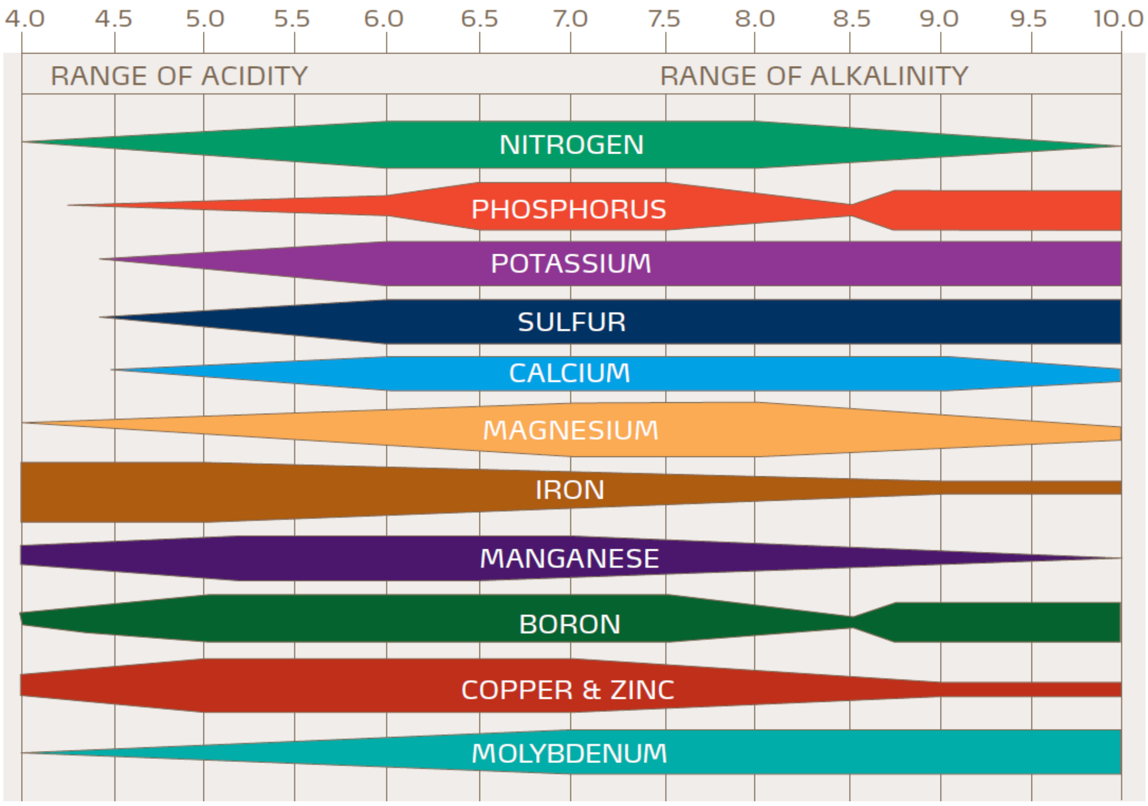


Figure 11.2: Influence of soil pH on plant nutrient availability

- **Nitrogen (N):** Plant absorbs most nitrogen in the form of nitrate (NO_3^-) of which availability depends on activity of nitrifying bacteria. These microorganisms responsible for nitrification are most active when the pH is between 6.5 and 7.5. They are adversely affected if the pH falls below 5.5 and rises above 9.0. The decomposition of organic matter which is the primary source of nitrogen is also slowed down under acidic condition.

- **Phosphorus (P):** Its availability is at its highest when the reaction is between 6.5 and 7.5.In strongly acidic soil (pH 5.0 or less), iron, aluminium, manganese and other bases are present in a soluble state, which binds phosphate ionand makes it unavailable.

- **Potassium (K):** The availability of K does not influence by soil reaction to any great extent. In acid soil,K is lost through leaching. The unavailability of K is due to the conversion of exchangeable to non-exchangeable K in alkaline soil.

- **Calcium (Ca) and magnesium (Mg):** Acid soils are poor in available Ca and Mg. In alkaline soil (pH not exceeding 8.5) the availability of Ca and Mg nutrients are always high. When the pH is above 8.5, the availability of these nutrients again decreases.

- **Iron (Fe), aluminium (Al) and manganese (Mn):**When the pH is low the solubility of Fe, Al, and Mn compounds are increased and hence, they are readily available in acid soils. At the pH range 5.5 to 7.0, Fe and Mn are present in the soluble ferrous (Fe^{2+}) and manganous (Mn^{2+}) forms. Under neutral and alkaline conditions, Fe and Mn are usually present in ferric (Fe^{3+}) and manganese (Mn^{4+}) states.

- **Sulphur (S):** Sulphur compounds are soluble in low pH range. It is more soluble in acid soil and lost in leaching.

- **Micronutrients:** In general, the availability of boron (B), copper (Cu) and zinc (Zn) is reduced in alkaline soils and that of molybdenum (Mo) in acid soils. The availability of these nutrients progressively decreases as the soil pH increases.

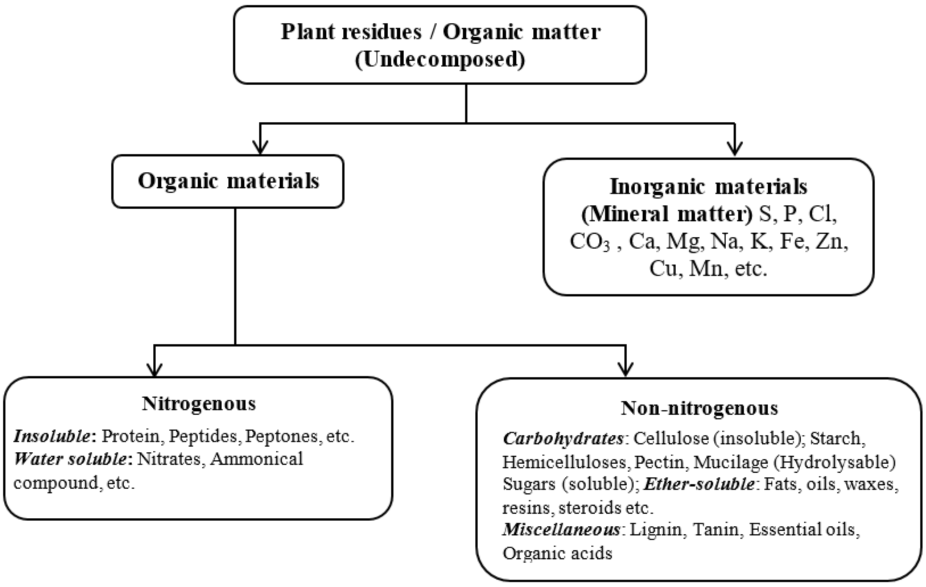
CHAPTER 12: SOIL ORGANIC MATTER

Soil organic matter (SOM) is the fraction of the soil consisting of plant and animal residues in various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by soil organisms. Most of our productive agricultural soils have between 3 and 6% organic matter. Soil organic matter contributes to soil productivity in many different ways.

Organic matter contains organic carbon and nitrogen. Carbon is a source of energy and nitrogen is a source of protein for microorganisms in the soil. Some of the microorganisms are pathogens which cause plant disease but in a healthy soil the vast majorities of these organisms are beneficial and help prevent any one type of organism such as a plant pathogen from being dominant.

12.1 Composition of plant residues

The moisture content of plant residues varies from 60-90% and 25% dry matter. Plant tissues (organic residues) may be divided into (i) organic and (ii) inorganic composition as given below. Relative percentage of compound in plant material is showin in **Figure 12.1**.



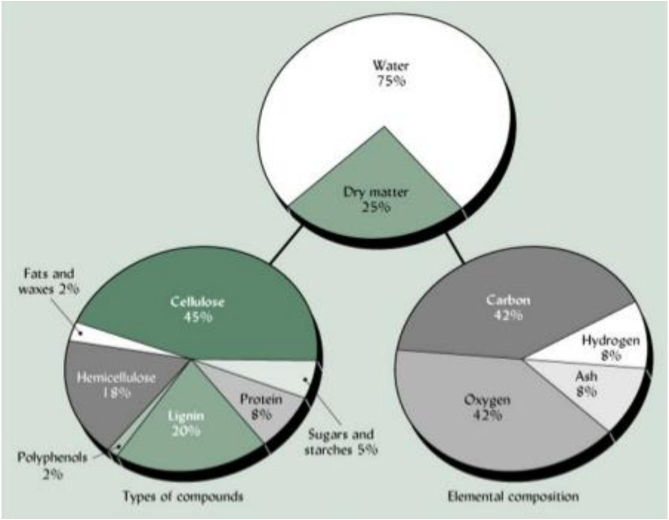


Figure 12.1: An approximate composition of a green plant material

12.2 Decomposition of organic matter

The microorganism for obtaining their food, break up the various constituents of organic residues, and convert them into new substances, some of which are simple in composition and others are complex. So, different groups of compounds have their different ease of decompostion.

12.2.1 Decomposition of soluble substances

Decomposition of sugar

First, sugar and water-soluble nitrogenous compounds are decomposed as they offer a very readily available source of carbon, nitrogen and energy to the microorganisms. When glucose is decomposed under aerobic conditions the reaction is as under:

Sugar + Oxygen → **(in aerobic condition)***→ Carbon dioxide + Water*

Decomposition of nitrogenous compounds

The transformation of organic nitrogenous compounds into ammonia is called ***ammonification***, followed by mineralization process termed as ***nitrification***. Thes reactionsare largely carried out heterotrophic microorganisms wherein oxygen is taken up and carbon dioxide is released. *Ammonification* process involves a gradual simplification of complex compounds, as follows:

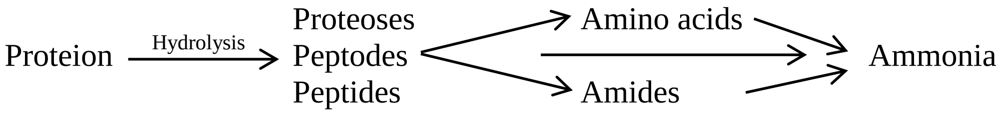
Organic N → NH3 or Protein → Polypeptides → Amino acids → Ammonia or salts

Nitrification: NH_4^+ *ions* → $NO_{2(\text{by Nitrosomas bacteria})}$ → $NO_{3(\text{by Nitrobacter bacteria})}$

12.2.2 Decomposition of insoluble substances

Breakdown of protein

Proteins are complex organic substances containing nitrogen, sulphur, and sometimes phosphorus, in addition to carbon, hydrogen and oxygen. The proteins are first hydrolyzed to a number of intermediate products, e.g., proteoses, peptones, peptides, etc., collectively known as ***polypeptides***.



The process of conversion of proteins into amino acids is called ***aminization***.

Breakdown of cellulose

Cellulose is the most abundant carbohydrate present in plant residues. The microorganisms break downn the cellulose into ***cellobiose*** and ***glucose***. Glucose is further attacked by organisms and converted into organic acids.

$$\text{Cellulose} \xrightarrow[\text{Cellulase}]{\text{Hydrolysis}} \text{Cellobiose} \xrightarrow[\text{Cellobiase}]{\text{Hydrolysis}} \text{Glucose}$$

$$\text{Glucose} \xrightarrow[\text{Aerobic}]{\text{Oxidation}} CO_2 + H_2O \qquad \text{Glucose} \xrightarrow{\text{Anerobic}} \text{Organic acids, alcohols}$$

The decomposition of cellulose in acid soils proceeds more slowly than in neutral and alkaline soils. It is quite rapid in well-aerated soils and comparatively slow in those poorly-aerated.

Breakdown of hemicellulose

Hemicelluloses are first hydrolyzed into their component *sugars* and *uronic acids*. The sugars are further converted to organic acids, alcohols, carbon dioxide and water. The *uronic acids* are broken down to *pentose* and *carbon dioxide*. Hemicelluloses decompose faster than cellulose.

Breakdown of starch

Chemically, starch is a glucose polymer, is first hydrolyzed to *maltose* by the action of enzymes (*amylases*). Maltose is then converted to *glucose* by enzyme *maltase*.

$$\text{Starch}_{\text{(glucose)}n} \xrightarrow{\text{amylase}} \text{Maltose}_{\text{(glucose)2}} \xrightarrow{\text{glucosidase}} \text{Glucose}$$

Decomposition of ether-soluble substances

Fats are broken down by microorganisms through enzyme *lipase* into ***glycerol*** and ***fatty acids***. Glycerol is further oxidized to organic acids, are finally oxidized to carbon dioxide and water.

Decomposition of lignin

Lignin decomposes slowly, much slower than cellulose. Complete oxidation of lignin gives rise to carbon dioxide and water.

12.3 Humus

Humus is a complex and rather resistant mixture of brown or dark brown coloured amorphous and colloidal substances that modified from the original tissues or synthesized by the various soil microorganisms.It possesses various chemical and physical properties of great significance to soils and plants. The ***humic*** and ***non-humic compounds*** collectively make up the humus.

The ***humic substances*** comprise about 60-80% of soil organic matter. *Humic* substances are dark in colour, amorphous and have high molecular weight. *Humic* substances can be classified into following three chemical groups.

- **Humin:** The highest in molecular weight, dark in colour, insoluble in both acid and alkali and more resistant to microorganism attack

- **Humic acid:** medium in molecular weight, medium in colour, soluble in alkali but insoluble in acid, intermediate resistant to microbial degradation

- **Fulvic acid:** lowest in molecular weight, light in colour, soluble in both acid and alkali and most susceptible to microorganism attack

The ***non-humic group*** make up of about 20-30% of soil organic matter, consists *polymers, polysaccharides*, and*polyuronides*. Polysaccharides are especially effective in enhancing soil aggregate stability. *Non-humic* substances are relatively simple and susceptible to microbial attack than *humic* sunstances.

Humus is more resistant to decay and may present in soils for even hundreds of years. This resistant property of humus is important in maintaining organic matter level in soils and protect nitrogen and other essential nutrients that are founds in humus complex.

The classical method of ***fractionation of humic substances*** is based on difference in the solubility of constituents in aqueous *acidic* and *alkaline* solutions and *ethanol*.

12.4 Benefits of organic matter

- **Improve soil structure**
  As organic matter decays to humus, the humus molecules 'cement' particles of sand, silt, clay and organic matter into aggregates which will not break down in water. This cementing effect, together with the weaving and binding effect of roots and fungal strands in the decomposing organic matter, makes the soil aggregates stable in water.

- **Improves drainage**
  These larger, stable aggregates have larger spaces between them, allowing air and water to pass through the soil more easily.

- **Holds moisture**
  The aggregates are also very effective in holding moisture for use by plants. Humus molecules can absorb and hold large quantities of water for use by plant roots.

- **Provides nutrients**
  Organic matter is an important source of nitrogen, phosphorus and sulfur. These nutrients become available as the organic matter is decomposed by microorganisms. Because it takes time for this breakdown to occur, organic matter provides a slow release form of nutrients. If crops are continually removed from the soil, there is no organic matter for microbes to feed on and break down into nutrients, so fewer nutrients are available to plants.

- **Improves cation exchange capacity**
  Humus molecules are ***colloids***, which are negatively charged structures with an enormous surface area. This means they can attract and hold huge quantities of positively charged nutrients such as calcium, magnesium and potassium until the plant needs them. Clays also have this capacity, but humus colloids have a much greater CEC than clays.

12.5 Carbon to Nitrogen ratio (C:N Ratio)

The ratio of the weight of organic carbon (C) to the weight of total nitrogen (N) in a soil (or organic material), is known as C:N ratio. For example, a C:N of 10:1 means there is ten units of carbon for each unit of nitrogen in the substance.The C:N ratio influences the rate of decomposition of OM. This results in the release (Mineralisation) or binding (Immobilization) of soil nitrogen.

The C:N in the arable (cultivated) soils commonly ranges from 8:1 to 15:1. The C:N in plant material is variable, ranging from 20:1 to 30:1. Low ratios of carbon to nitrogen (10:1) in soil organic matter generally indicate an average stage of decomposition and resistance to further microbiological decomposition. A wide ratio of C: N (35:1) indicates little or no decomposition, susceptibility to further and rapid decomposition and slow nitrification.

Graphs below (**Figure 12.2**) show what happens when organic material with high C:N ratio like rice straw is added to soil. The graph is divided into 3 time periods.

Initial phase – net immobilization

- Microorganisms consume N (NH_4^+) causing NH_4^+ to decrease (bottom graph)
- Microorganisms consume C products and release CO_2 (bottom graph)
- C:N ratio is decreasing (top graph)

Intermediate phase

- Microorganisms have immobilized the available N (NH_4^+) in soil (bottom graph)
- Maximum consumption of C products and production of CO_2 (bottom graph)

Final phase – net mineralization

- NH4$^+$ level is increasing – N in organic compounds is released and NH_4^+ is now available in soil (bottom graph)
- C compounds are decomposed – CO_2 production is low (bottom graph)C:N ratio is low (top graph)

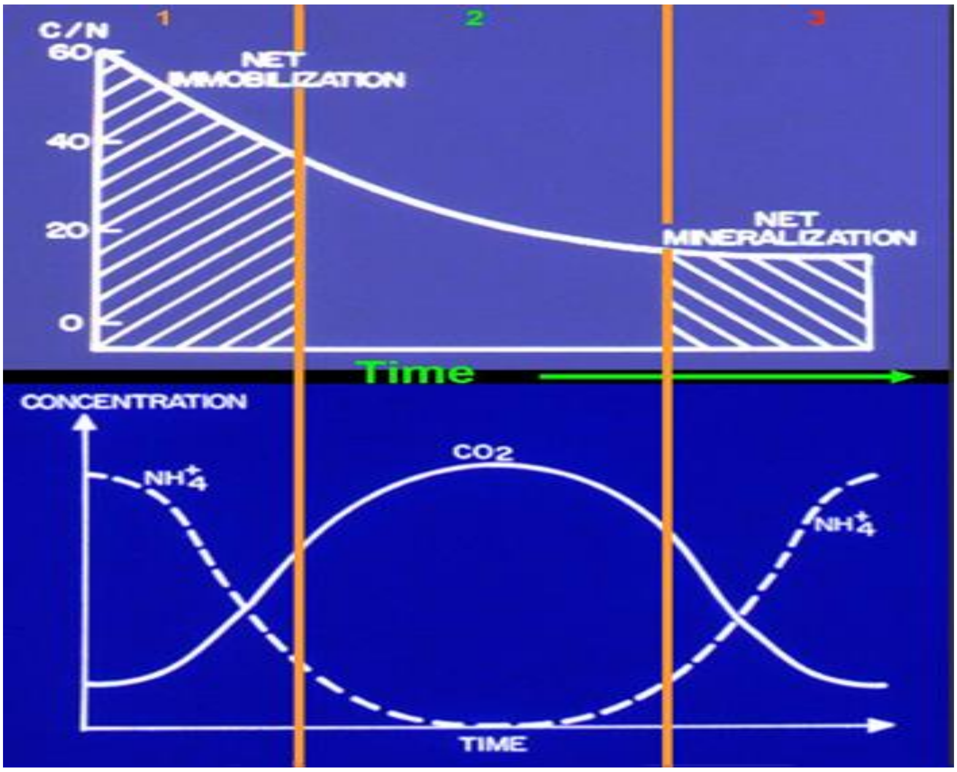


Figure 12.2: Relationship between rate of decompostion, C:N ratio and N availabity

A low C:N ratio (less than about 30 parts C to 1 part N) means sufficient nitrogen is supplied through the decomposition of the organic materials to meet the nitrogen needs of the decomposing organisms. As a result, there will be a net release and build up of inorganic nitrogen in soil (mineralization).

In contrast, when the C:N ratio of added organic materials is high (30 or more parts C to 1 part N), microorganisms will require more nitrogen from soil (in the form of nitrate or ammonium) to decompose the carbon in the organic materials. This nitrogen will be immobilized (unavailable to plants) until these microorganisms die and the nitrogen is released **(Figure 12.2)**.

CHAPTER 13: SOIL ORGANISMS

The physico-chemical properties of soil determine the nature of environment in which vase number of soil organisms are found. ***Soil biology*** is the scientific study of life in and on the soil. Living organisms in soils include both macro (i.e., earthworms, rodents, etc.) and microorganisms (i.e., bacteria, fungi, actinomycetes, algae and protozoa). Microorganism churn the soil, mixing organic residues, modify the physical condition of soils.Further, soil microorganisms take part in the decomposition of organic residues, transformation of different nutrient elements, and other soil biological processes. Hence, soil organisms are involved in nearly every aspect of soils.

Soil is alive! How many microbes ?

10^7 to 10^9 bacteria per cm^3
10^3 to 10^6 fungi per cm^3
10 to 1,000 protozoa per cm^3

Following microorganisms are prominently found in soil.

(A) Soil flora

Soil flora classified into two groups as under:

- **Microflora**
  - i. Bacteria
  - ii. Fungi, molds, yeast, mushroom
  - iii. Actinomycetes, stretomyces
  - iv. Algae eg. BGA, yellow green algae, golden brown algae

  Bacteria is again classified as:

  Heterotrophic –e.g., symbiotic and non-symbiotic N_2 fixers, ammonifier, cellulose decomposers, denitrifiers
  Autrotrophic –e.g.,*Nitrosomonas, Nitrobacter,* sulphur oxidizers, etc.

- **Macroflora**
  Includes roots of most higher plants

(B) Soil Fauna

- **Microfauna:** Protozoa, Nematodes
- **Macrofauna:** Earthworms. moles, ants & others.

As soil inhabit several diverse groups of microorganisms, but the most important amongst them are: ***bacteria, actinomycetes, fungi, algae and protozoa***. The characteristics and their functions in the soil are described below.

13.1 Bacteria

Amongst the different microorganisms inhabiting in the soil, bacteria are the most abundant and predominant organisms. These are primitive, prokaryotic, microscopic and unicellular microorganisms without chlorophyll. Morphologically, soil bacteria are divided into three groups *Cocci, Spirilla and Bacilli. Bacilli* are most numerous followed by *Cocci and Spirilla in* soil.

Bacteria are also classified on the basis of mode of nutrition, especially the manner in which they obtain their carbon, nitrogen, energy and other nutrient requirements. They are divided into two groups: (a) ***Autotrophs*** and (b) ***Heterotrophs***.

- ***Autotrophic bacteria*** are capable synthesizing their food from simple inorganic nutrients. All autotrophic bacteria utilize CO_2 (from atmosphere) as carbon source and derive energy either from sunlight (photoautotrophs)

- ***Heterotrophic bacteria*** depend on pre-formed food for nutrition.Majority of soil bacteriaare*heterotrophic* and derive their carbon and energy from complex organic substances/organic matter, decaying roots and plant residues. They obtain their nitrogen from nitrates and ammonia compounds (proteins).

Functions of bacteria

Bacteria bring about a number of changes and biochemical transformations in the soil. They directly or indirectly help in the plant nutrition. The important transformations and processes of plant nutrition in which soil bacteria play vital role are:

- ✓ Decomposition of cellulose and other carbohydrates
- ✓ Ammonification (proteins ammonia)
- ✓ Nitrification (ammonia-nitrites-nitrates)
- ✓ Denitrification (release of free elemental nitrogen)
- ✓ Biological fixation of atmospheric nitrogen (symbiotic and non-symbiotic)
- ✓ Oxidation and reduction of sulphur and iron compounds.

13.2 Fungi

Fungi in soil are present as mycelial bits, rhizomorph or as different spores. Their number varies from a few thousand to a few million per gram of soil.Most commonly encountered genera of fungi in soil are; *Alternaria, Aspergillus, Cladosporium, Cephalosporium Botrytis, Chaetomium, Fusarium, Mucor, Penicillium, Verticillium, Trichoderma, Rhizopus, Gliocladium, Monilia, Pythium,* etc.

As these soil fungi are aerobic and heterotrophic, they require abundant supply of oxygen and organic matter in soil. Fungi are dominant in acid soils. The optimum pH range for fungi lies between **4.5 to 6.5.** They are also present in neutral and alkaline soils.

Functions of fungi

- ✓ They plays important role in the degradation / decomposition of cellulose, hemi cellulose, starch, pectin, lignin in the organic matter added to the soil.
- ✓ Lignin which is resistant to decomposition by bacteria is mainly decomposed by fungi.
- ✓ They also serve as food for bacteria.
- ✓ They also plays important role in soil aggregation and in the formation of humus.
- ✓ Some soil fungi are parasitic and causes number of plant diseases such as wilts, root rots, damping-off and seedling blights.
- ✓ May soil fungi forms *mycorrhizal association* with the roots of higher plants (*symbiotic association of a fungus with the roots of a higher plant*) and helps in mobilization of soil phosphorus and nitrogen.

13.3 Actinomycetes

These are the organisms with characteristics common to both bacteria and fungi but yet possessing distinctive features to delimit them into a distinct category. They are unicellular like bacteria, but produce a mycelium which is non-septate. Actinomycetes are numerous and widely distributed in soil and are ***next to bacteria in abundance.*** They are widely distributed in the soil, compost, etc.

- They are sensitive to acidity (optimum pH range 6.5 to 8.0) and waterlogged soil conditions.
- The population of actinomycetes increases with depth of soil up to horizon ‘C’ of soil profile.
- They are heterotrophic, aerobic and mesophilic (25-30 °C temperaure) organisms.
- Some species are commonly present in compost and manures are thermophilic growing at 55-65 °C temperature (e.g., *Thermoatinomycetes*, *Streptomyces*).

Functions of actinomycetes

- ✓ Degrade most organic materials like cellulose, polysaccharides, protein fats, organic acids.
- ✓ Organic residues added soil are first attacked by bacteria and fungi and later by actinomycetes, because they are slower in activity and growth than bacteria and fungi.
- ✓ They decompose the more resistant and indecomposable organic matter and produce a number of dark black to brown pigments which contribute to the dark colour of soil humus.
- ✓ They are also responsible for further decomposition of humus (resistant material) in soil.
- ✓ They are responsible for *earthy* / *musty odor* / *smell of freshly ploughed* soils.
- ✓ Many genera species and strains produce or synthesize antibiotics like Streptomycin, Terramycin, Aureomycin, etc.
- ✓ Actinomycetes *Streptomyces scabies* causes disease “Potato scab” in potato.

13.4 Algae

Algae are present in most of the soils where moisture and sunlight are available. Their number in soil usually ranges from 100 to 10000 per gram of soil. They are photoautotrophic, aerobic organisms and obtain CO_2 from atmosphere and energy from sunlight and synthesize their own food. They are unicellular, filamentous or colonial. Soil algae are divided in to four main classes or phyla as follows:

i. Cyanophyta (Blue-green algae; BGA)
ii. Chlorophyta (Grass-green algae)
iii. Xanthophyta (Yellow-green algae)
iv. Bacillariophyta (diatoms or golden-brown algae)

- Out of these 4 classes, blue-green and grass-green algae are more abundant in soil.
- The green-grass algae and diatoms are dominant in the soils of temperate region.
- Blue-green algae predominant in the tropical soils.
- Green-algae prefer acid soils, while blue-green algae found in neutral and alkaline soils.
- Most common genera of green algae found in soil are: *Chlorella, Chlamydomonas, Chlorococcum*, *Protosiphon* etc., and diatoms are *Navicula, Pinnularia.*
- Some blue-green algae posses specialized cells know as “***Heterocyst***” which is the sites of nitrogen fixation. They fixes nitrogen (non-symbiotically) in puddle paddy/waterlogged paddy fields (20-30 kg/ha/season).
- There are certain BGA which possess the character of symbiotic nitrogen fixation in association with other organisms like fungi, mosses, liverworts and aquatic ferns *Azolla, eg Anabaena-Azolla* association fix nitrogen symbiotically in paddy fields.

Functions of algae or BGA

- ✓ Plays important role in the maintenance of soil fertility especially in tropical soils.
- ✓ Add organic matter to soil when die, thus increases amount of organic carbon in soil.
- ✓ Most of soil algae (especially BGA) act as cementing agent in binding soil particles and thereby reduce/prevent soil erosion.

- ✓ Mucilage secreted by BGA is hygroscopic in nature and thus helps in increasing water holding capacity of soil for longer period.
- ✓ Soil algae liberate large quantity of oxygen in the soil via photosynthesis and thus facilitate the aeration in submerged soils or oxygenate the soil environment.
- ✓ They helps in reducing the loss of nitrates through leaching and drainage especially in un-cropped soils.
- ✓ They help in the weathering of rocks and building up of soil structure.

13.5 Protozoa

These are unicellular, eukaryotic, colourless, and animal like organisms (animal kingdom). They are larger than bacteria and size varying from few microns to a few centimeters. Their population in arable soil ranges from $l0^4$ to 10^5 per gram of soil and are abundant in surface soil. Most of the soil protozoa are mobile by *flagella* or *cilia* or *pseudopodia* as locomotive organs.

Functions of protozoa

- ✓ Most of protozoans derive their nutrition by feeding or ingesting soil bacteria.
- ✓ Some protozoa are used as biological control agents against phytopathogens.

13.6 Role of soil microorganisms in nutrient cycling

The microbes through the process of biochemical reactions convert / breakdown complex organic compounds into simple inorganic compounds and finally into their constituent elements. This process is known as "***Mineralization***".

Mineralization of organic carbon, nitrogen, phosphorus, sulphur and iron by soil microorganisms makes these elements available for reuse by plants. The cycling or transformations of nitrogen, phosphorus and sulphur are discussed below:

13.6.1 Nitrogen transformations

Several biochemical steps involved in the nitrogen cycle are:

- **Ammonification:** Amino acids released during proteolysis (*break down of protein into amino acids*) undergo *deamination* in which nitrogen containing amino ($-NH_2$) group is removed, and leads to the production of *ammonia* is called "***ammonification***". The process is commonly carried out by *Clostridium* sp., *Micrococcus* sp., *Proteus* sp, etc.

- **Nitrification:** Ammonical nitrogen/ammonia released during ammonification are oxidized to *nitrates* and the process is called "***nitrification***". It is a two stage process and each stage is performed by a different group of bacteria as follows:

  Oxidation of ammonia to***nitrite*** is brought about by ammonia oxidizing bacteria viz. ***Nitrosomnonas europaea***, and the process is known as "***nitrosification***".

  $$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ \textbf{ or } NH_3 + O_2 \rightarrow 2NO_2^- + 3H^+ + 2e^-$$

  In the second step *nitrite* is oxidized to ***nitrate*** by nitrite oxidizing bacteria such as ***Nitrobacter winogradsky*** and several fungi (e.g., *Penicillium, Aspergillus*) *and* actinomycetes (e.g., *Streptomyces, Nocardia*).

  $$2NO_2^- + O_2 \rightarrow 2NO_3^- \quad \textbf{or} \quad NO_2^- + H_2O \rightarrow NO_3^- + 2H^+ + 2e^-$$

- **Denitrification:**This is the reverse process of nitrification. During denitrification nitrates are reduced to nitrites and then to nitrogen gas and ammonia. Thus, reduction of nitrates to gaseous nitrogen by microorganisms in a series of biochemical reactions is called "***denitrification***". The process is harmful as available nitrogen in soil is lost to atmosphere.

  Most denitrifying bacteria are: *Thiobacillus denitrificans, Micrococcus denitrificans,* and species of *Pseudomonas, Bacillus, Achromobacter, Serrtatia paracoccus* etc.

  $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_{2\,(gas)}$
  $2NO_3^- + 10e^- + 12H^+ \rightarrow N_2 + 6H_2O$

- **Biological N-fixation in soils:**
  Atmospheric nitrogen (N_2) is converted into ammonia and then to amino acids (by soil microorganisms and plant-microbe associations) which are used for the biosynthesis of complex nitrogen-containing organic compound such as proteins, nucleic acids, amino sugars etc. is called biological N-fixation. The nitrogen fixed by microorganisms in the soil is known as '***bio-fertilizers***'. The N_2-fixing microorganisms are: (i) bacteria (ii) algae (iii) mycorrhizae (fungus root).

  There are two main groups of bacteria which fix atmospheric nitrogen: ***symbiotic and non-symbiotic*** nitrogen fixing bacteria.

  Symbiotic nitrogen-fixing bacteria (Rhizobium) fixes N_2 in association with leguminous plants, living in their roots. They takes their food from roots of the leguminous plants and inturns fixes atmospheric N_2 into the soil, and produce nitrogenous compound useful to the leguminous host plants. Both the legume crop and bacteria are benefited by this association, known as '***symbiosis***'.

Rhizobium sp. Name	Leguminous group name	Leguminous crops
R. leguminosarum	Pea group	All types of pea, lentil, bean
R. japonicum	Soybean group	Soybean
R. phaseoli	Phaseolus group	Kidney and garden beans
R. trifoli	Clover group	White clover
R. meliloti	Alfalfa group	Lucerne

  Non-symbiotic nitrogen fixing bacteria (*Azotobacter* and *Clostridium*) do not require a host plant. ***Azotobacter***is an ***aerobic nitrogen-fixing*** bacteria and thrives well in neutral soil. ***Clostridium***is ***anaerobic*** and fixes *less amount of nitrogen* than *Azotobacter* because of anaerobic fermentation releases only a small amount of energy. Whereas, aerobic changes produce large amount of energy which helps to fix more nitrogen.
  The main genus of **algae** which fix nitrogen are *Anabaena, Nostoc* and *Cylindrospermum.*

  Mycorrhizae (*Myco=fungus; rhiza=root***)** is mutual beneficial association between certain fungi and roots of higher plants is called ***mycorrhizae*** (fungus roots). By this symbiotic association, fungi get sugars and organic exudates from the roots of higher plant. In return, the fungi provide several essential nutrients to the plant. Mycorrhizae are divided into two types: ***ectomycorrhiza*** and ***endomycorrhiza***. The endomycorrhiza group are called ***vesicular-arbuscular mycorrhizae*** (VAM) increase the uptake of phosphorus, enhance resistance against drought and certain root-infecting fungus.

13.6.2 Phosphorus and sulphur mineralization

Organic phosphorus and sulphur compounds are mineralized by the action of microorganism into inorganic phosphorus and sulphur, respectively.

$$\text{Organically-bound phosphorus} \xrightarrow{\text{Microorganism}} H_2PO_4^{-} \text{ or } HPO_4^{-2}{}_{\textit{(Available P)}}$$

Autotrophic bacteria (sulphur bacteria) oxidised sulphur into sulphate form.

$$S + O_2 \xrightarrow[\text{Oxidation}]{\text{Enzymatic}} SO_4^{-}{}_{\textit{(sulphate; Available S)}}$$

13.7 Functions of microorgnisms

Beneficial function	Harmful function
• Organic matter decomposition • Inorganic transformations of essential plant nutrients	• Denitrification process carried out by a particular microorganisms and causes loss of gaseous N into atmosphere • Development of various plant diseases..
• *Symbiotic and Non-symbitic* fixation of atmospheric nitrogen	• Production of antibiotic and other toxi substances..
• Helps in Formation and development of soil : (a) decomposition of rocks and minerals; (b) Improves and stabilizes the soil structure and stability of soil aggregates; (c) facilitate the movement of soil materials within soil profile	• Competition for plant nutrients..
• Production of soil enzymes	

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CHAPTER - 1
SOIL FERTILITY AND PLANT NUTRITION

The word 'fertile' means bearing abundantly and a fertile soil is considered to be one that produces abundant crops under suitable environmental condition. Soil fertility is vital to a productive soil. But a fertile soil is not necessarily a productive soil. All fertile soils may or may not be productive. Poor drainage, insects, drought and other factors can limit production, even when fertility is adequate. To fully understand soil fertility, one must know other factors which support or limit productivity.

SOIL FERTILITY:

It refers to the inherent capacity of soil to supply all the essential nutrients to plant in suitable quantity and in the right proportion.

SOIL PRODUCTIVITY:

Soil productivity is the ability of a soil for producing a specified plant or sequence of plants under a specified system of management. It is usually expressed in terms of crop yield.

The soil is said to be productive when good yields are obtained. Productive soils are those, which contain adequate amounts of all essential nutrients in readily forms to plants are in good physical condition to support plants and contain just the right amount of water and air for desirable root growth. Thus, soil fertility, good management practices, availability of water supply and a suitable climate contribute towards soil productivity. Therefore, a soil can be highly fertile, yet it may be unproductive, even a soil has ready supply of nutrients but has an in sufficient water supply, presence of toxic substances or physical properties. For a soil to be productive, it must of necessity be fertile. Soil fertility denotes the status of plant nutrients in the soil while soil productivity denotes the resultant of various factors influencing crop production both within and beyond the soil. Thus, soil productivity is a function of environmental factors combined with soil fertility or more correctly, in combination with environmental factors and management practices constituents soil productivity.

"All the productive soils are fertile but all the fertile soils may not be productive"

History of development of soil fertility

Francis Bacon (1591- 1624) suggested that the principle nourishment of plants was water and the main purpose of the soil was to keep plants erect and to protect from heat and cold.

Jan Baptiste Van Helmont (1577 – 1644) was reported that water was sole nutrient of plants.

Robert Boyle (1627 – 1691) an England scientist confirmed the findings of Van Helmont and proved that plant synthesis salts, spirits and oil etc from H_2O.

Anthur Young (1741 – 1820) an English agriculturist conducted pot experiment using Barley as a test crop under sand culture condition. He added charcoal, train oil, poultry dung, spirits of wine, oster shells and numerous other materials and he conduced that some of the materials were produced higher plant growth.

Priestly (1800) established the essentiality of Oxygen for the plant growth.

J.B. Boussingault (1802-1882) French chemist conducted field experiment and maintained balance sheet. He was first scientist to conduct field experiment. He is considered as **father of field experiments.**

Justus Von Liebig (1835) suggested that

a. Most of the carbon in plants comes from the CO_2 of the atmosphere.

b. Hydrogen and O_2 comes from H_2O.

c. Alkaline metals are needed for neutralization of acids formed by plants as a result of their metabolic activities.

d. Phosphorus is necessary for seed formation.

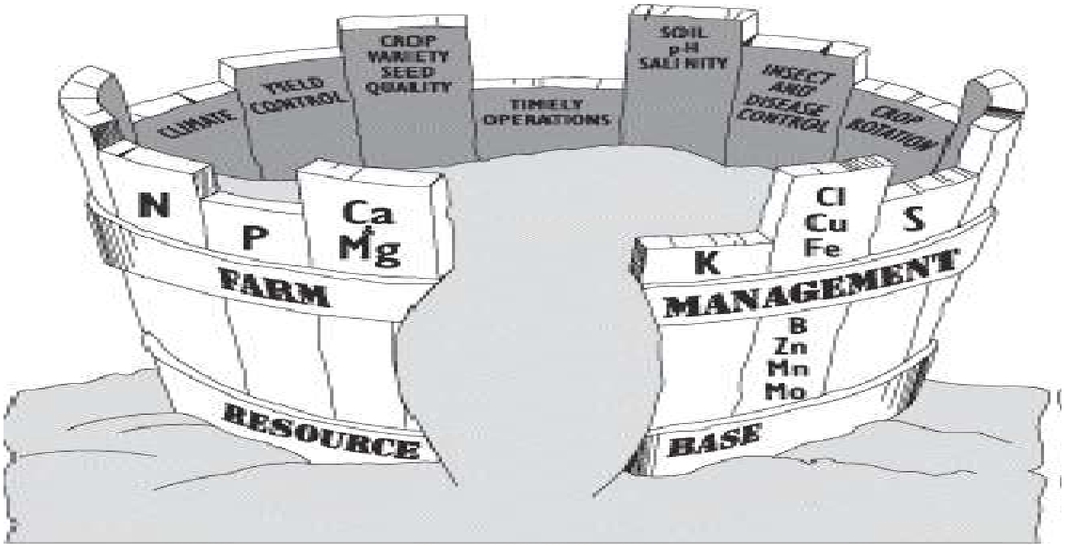
e. Plant absorb every thing from the soil but excrete from their roots those materials that are not essential.

The field may contain some nutrient in excess, some in optimum and some in least, but the limiting factor for growth is the least available nutrient. **The Law of Minimum**, stated by **Liebig in 1862**, is a simple but logical guide for predicting crop response to fertilization. This law states that, "the level of plant production cannot be greater than that allowed by the most limiting of the essential plant growth factors". The contributions made by Liebig to the advancement of agriculture were monumental and he is recognized as the **father of agricultural chemistry.**

Crops depend on extrinsic and intrinsic factors for their growth and environment to provide them with basic necessities for photosynthesis. These essential plant growth factors include:

- light, heat, air, water, nutrients & physical support

If any one factor, or combination of factors, is in limited supply, plant growth will be adversely affected. The importance of each of the plant growth factors and the proper combination of these factors for normal plant growth is best described by the principle of limiting factors. This principle states: "The level of crop production can be no greater than that allowed by the most limiting of the essential plant growth factors." The principle of limiting factors can be compared to that of a barrel having staves of different lengths with each stave representing a plant growth factor.



J.B. Lawes and J. H. Gilbert (1843) established permanent manurial experiment at Rothemsted Agricultural experiment station at England. They conducted field experiments for twelve years and their findings were

a. Crop requires both P and K, but the composition of the plant ash is no measure of the amounts of these constituents required by the plant.

b. No legume crop require N. without this element, no growth will be obtained regardless of the quantities of P and K present. The amount of ammonium contributed by the atmosphere is insufficient for the needs of the crop.

c. Soil fertility can be maintained for some years by chemical fertilizers.

d. The beneficial effect of fallow lies in the increases in available N compounds in the soil.

S. N. Winogradsky discovered the autotrophic mode of life among bacteria and established the microbiological transformation of nitrogen and sulphur. Isolated for the first time nitrifying bacteria and demonstrated role of these bacteria in nitrification (l890), further he demonstrated that free-living *Clostridium pasteuriamum* could fix atmospheric nitrogen (1893). Therefore, he is considered as **"Father of soil microbiology".**

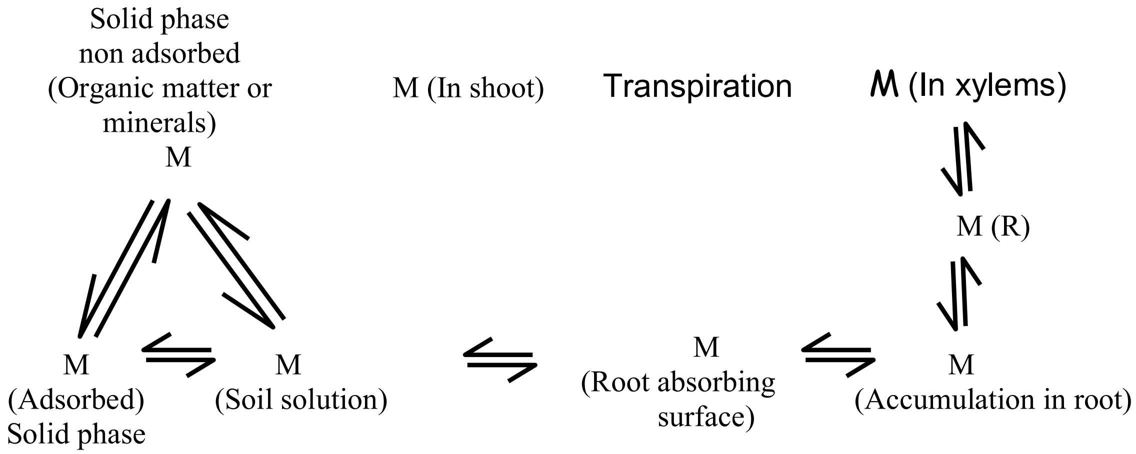
Robert Warrington England showed that the nitrification could be supported by carbon disulphide and chloroform and that it would be stopped by adding a small amount of unsterilized soil. He demonstrated that the reaction was two step phenomenon. First NH_3 being converted to nitrites and the nitrites to nitrates.

1.1 The soil as a Nutrient Source for Plants

Mineral Nutrients in the Soil: Mineral nutrients occur in the soil in both dissolved and bound form. Only a small fraction (less than 0.2%) of the mineral nutrient supply is dissolved in soil water. Most of the remainder, i.e., almost 98% is either bound in organic detritus, humus and relatively insoluble inorganic compounds or incorporated in minerals. These constitute a nutrient reserve, which becomes available very slowly as a result of weathering and mineralization of humus. The remaining 2% is adsorbed on soil colloids. The soil solution, the soil colloids and the reserves of mineral substances in the soil are in a state of dynamic equilibrium, which ensures continued replenishment of supplies of nutrient elements.

Adsorption and Exchange of ions in the soil: Both clay minerals and humic colloids have a negative net charge so that they attract and adsorb primarily cations. There are also some positively charged sites where anions can accumulate. How tightly a cation is held depends on its charge and degree of hydration. In general, ions with high valences are attracted more strongly for example, Ca^{2+} is more strongly attracted than K^+. Among ions with the same valence those with little hydration are retained more firmly than those that are strongly hydrated. The tendency for cations adsorption decreases in the order Al^{3+}, Ca^{2+}, Mg^{2+}, NH_4^+, K^+ and Na^+

The swarm of ions around particles of clay and humus as an intermediary between the solid soil phase and the soil solution. If ions are added to or withdrawn from the soil solution, exchange takes place between solid and liquid phases. Adsorptive binding of nutrient ions offers a number of advantages nutrients liberated by weathering and the decomposition of humus are captured and protected from leaching the concentration of the soil solution is kept low and relatively constant; so that the plant roots and soil organisms are not exposed to extreme osmotic conditions; when required by the plant, however, the adsorbed nutrients are readily available.



Nutrient release and path for absorption

1.2 ESSENTIAL AND BENEFICIAL ELEMENTS

Plant nutrition is the study of the chemical elements and compounds necessary for **plant** growth, **plant**metabolism and their external supply.

Essential Element: Elements (nutrients) required by the plants for normal growth and developmenand not replacable in their function by another are referred essential (Mengel, 1982).

► ***The criteria of essentiality***: In order to distinguish elements, which are essential from those which may be taken up by the plant but are not essential, Arnon (1954) has laid down the following criteria:

(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 can not be replaced by another; and

(3) The element plays a direct role in metabolism.

► ***Essential nutrients so far recognized***:

Plants require 17 essential elements for plant growth & development are: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn). There is convincing evidence that these mineral elements are essential requirements for diverse groups of plants algae, bacteria, fungi and the green plants.

Table 1: Essentiality of nutrients discovered by scientists

Nutrient	**Essentiality discovered authors (Discoverer)**	**Year of discovery**
Discovered as element		
H	Henry Cavendish	1766
C	A.L. Lavoisier	1789
Discovered as essential nutrient for plant		
O	Joseph Priestley	1800
N	Theodore de Saussure	1804
K, Ca, Mg & P	C. Sprengel	1839
S	Sachs and Knop	1860
CI	T.C. Broyer, A.B. Carlton, CM. Johnson and P.R. Stout	1954
Fe	E Gris	1843
B	K. Warington	1923
Mn	J.S. McHargue	1922
Zn	A.L. Sommer and C. P. Lipman	1926
Cu	A.L. Sommer, C. P. Lipman and G. McKinney	1931
Mo	D.I. Arnon and P.R. Stout	1939
Ni	P.H. Brown, R.M. Welch and E.E. Cary	1987

1.2.1 CLASSIFICATION OF ESSENTIAL PLANT NUTRIENTS:

(i) On the basis of amount of nutrients present in plants:

Nutrients	Average concentration in plant tissue	Function in plant	Nutrient category
N	1.5%	Proteins, amino acids	**Primary Macronutrients**
P	0.2%	Nucleic acids, ATP	
K	1.0%	Catalyst, ion transport	
Ca	0.5%	Cell wall component	**Secondary**
Mg	0.2%	Part of chlorophyll	
S	0.1%	Amino acids	
Fe	100 mg/kg	Chlorophyll synthesis	**Micronutrients**
Cu	6 mg/kg	Component of enzymes	
Mn	20 mg/kg	Activates enzymes	
Zn	20 mg/kg	Activates enzymes	
B	20 mg/kg	Cell wall component	
Mo	0.1 mg/kg	Involve in N fixation	
Cl	100 mg/kg	Photosynthesis reactions	
Ni	--	Activates enzymes	

Plant takes H, O and C from air and water it's Average concentration in plant tissue and Relative numbers of atoms compared to Mo are 6% and 60,000,000, 45% and 30,000,000 and C 45% and 30,000,000, respectively.

(ii) According to mobility:

(a) In soil:

1. **Mobile:** NO_3^-, SO_4^{2-}, BO_3^{3-}, Cl^- and Mn^{2+}
2. **Less mobile:** NH_4^{2-}, K^+, Ca^{2+}, Mg^{2+} and Cu^{2+}
3. **Immobile:** $H_2PO_4^-$, HPO_4^{2-} , Zn^{2+} and Ni^{2+}

(b) In plant:

1. **Highly mobile:** N, P and K
2. **Moderately mobile:** Zn
3. **Less mobile:** S, Fe, Mn, Cu, Ni, Mo and Cl
4. **Immobile:** Ca and B

(iii) According to metal and non metal

1. **Metal:** K, Ca, Mg, Fe, Mn, Zn, Ni and Cu
2. **Non metal:** N, P, S, B, Mo and Cl

(iv) According to cation and anion

1. **Cation:** K, Ca, Mg, Fe, Mn, Zn, Ni and Cu
2. **Anion:** NO_3, H_3PO_4 and SO_4

1.3 Beneficial elements: Apart from vanadium, silicon, aluminum, iodine, selenium and gallium, which have been shown to be essential for particular species of plants, there are several other elements, like rubidium, strontium, nickel, chromium and arsenic, which at very low concentrations and often under specific conditions have been shown to stimulate the growth of certain plants or to have other beneficial effects. These elements, the essentiality of which for growth and metabolism has not been unequivocally established but which are shown to exert beneficial effects at very low concentrations are often referred to as 'beneficial elements',

1.4 Forms of nutrients in soil

In soil, Nutrient present in different forms are as under

Sr. No.	**Nutrient**	**Forms**
1.	Nitrogen	Organic N (97%) and Mineral N NH_4^+, NO_3^-
2.	Phosphorus	Solution P, Calcium, Iron, Aluminium and Occluded P, Organic P (25%-90%) and Mineral P
3.	Potassium	Water soluble K, Exchangeable K, Fixed K and Mineral K (90-98%),
4.	Sulphur	Sulphate S, Non sulphate S, Adsorbed S, Organic S(95%) and Total S,
5.	Micronutrients	Water soluble ion, Exchangeable, Adsorbed, chelated or complexed ion, Cation held in secondary clay mineral and insoluble metal oxides and cation held in primary mineral

1.5 Mechanisms of nutrient transport to plants

Two important theories, namely, soil solution theory and contact exchange theory explain nutrient availability to plants.

(i) Soil solution theory:

- ***(a) Mass flow:*** Movement of nutrient ions and salts along with moving water.
- ***(b) Diffusion:*** Occurs when there is concentration gradient of nutrients between root surface and surrounding soil solution. Ions move from the region of high concentration to the region of low concentration.

(ii) Contact exchange theory: The important of contact exchange in nutrient transport is less than with soil solution movement. A close contact between root surface and soil colloids allows a direct exchange of ions.

1.6 Factors Influencing Nutrient Availability

Several factors influence nutrient availability:

(1) Natural supply of nutrients in the soil which is closely tied up to parent material of that soil and vegetation under which it is developed.
(2) Soil pH as it affects nutrient release,
(3) Relative activity of microorganisms which play a vital role in nutrient release and may as in the case of mycorrhizae directly function in nutrient uptake
(4) Fertility addition in the form of commercial fertilizer, animal manure and green manure, and
(5) Soil temperature, moisture and aeration.

1.7 Nutrient deficiency

Nutrient deficiency occurs when an *essential nutrient* is not available in sufficient quantity to meet the requirements of a growing *plant*.

Nutrient deficiency may not be apparent as striking symptoms such as chlorosis on the plant, especially when mild deficiency is occurring. However, significant reduction in crop yields can occur with such deficiencies. This situation is termed **hidden hunger** and can only be detected with plant tissue analysis or yield decline

Generalized symptoms of plant nutrient deficiency

Nutrients		Visual deficiency symptoms
N	:	Light green to yellow appearance of leaves, especially older leaves, stunted growth, poor fruit development
P	:	Leaves may develop purple colouration, stunted plant growth and delay in plant development
K	:	Marginal burning of leaves, irregular fruit development
Ca	:	Reduced growth or death of growing tips, poor fruit development and appearance
Mg	:	Initial yellowing of older leaves between leaf veins spreading to younger leaves, poor fruit development and production
S	:	Initial yellowing of young leaves spreading to whole plant, similar symptoms to N deficiency but occurs on new growth
Fe	:	Initial distinct yellow or white areas between veins of young leaves leading to spots of dead leaf tissue
Mn	:	Interveinal yellowing or mottling of young leaves

Zn : Interveinal yellowing on young leaves, reduce leaf size, brown leaf spot on paddy

Cu : Stunted growth, terminal leaf buds die, leaf tips become white and leaves are narrowed and twisted.

B : Terminal buds die, breakdown of internal tissues in root crops, internal cork of apple, impairment of flowering and fruit development

Mo : Resemble N deficiency symptoms, whiptail diseases of qualiflower, leaves show scorching and whithering

Cl : Chlorotic leaves, some leaf necrosis

1.8 Management:

1. Addition of nutrient through fertilizer in soil as well as foliar application
2. Addition of organic manure
3. Correction of soil problems *i.e.* salinity, sodicity, acidity *etc.*

1.9 Nutrient toxicity and management

Nutrient Toxicity: The presence of a *plant nutrient* in the soil in such high concentrations that it is harmful to the *plant*, whether directly or by creating imbalance among other *nutrients*.

Nutrient toxicities in crops are more frequent for manganese (Mn) and boron (B) than for other nutrients. Manganese toxicity is found on acid soils in many parts of the world. Boron toxicities occur in irrigated regions where the well or irrigation waters are exceptionally high in B. Most other nutrient toxicities occur when large amounts of nutrients in question have been added in waste, e.g., sewage sludge. Crops grown near mines and smelters are prone to nutrient toxicities. Generally, the symptoms of toxicity in crops occur as burning, Chlorosis and yellowing of leaves. Toxicities can result in decreased yield and/or impaired crop quality.

Prevention of toxicity

(1) With the exception of Mo, toxicity of other nutrients can be reduced by liming.
(2) Following recommended rates of fertilizers and the safe and controlled use of waste materials, such as sewage sludge and coal fly ash, should reduce metal loading and nutrient toxicity in crops.
(3) Use of crop species and genotypes less susceptible to toxicity are recommended where toxicity is suspected.
(4) Provided sufficient drainage because availability of nutrients like Fe and Mn is increases up to toxicity level under water logged condition.
(5) Ground water must be monitored regularly, if content of B and Cl is too high stop to applied water or applied with dilution.
(6) Addition of sufficient amount of organic matter, that bind the some of the toxic elements.
(7) Ploughing in dry soil so increase the infiltration rate and leach the toxic element with rain water.

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CHAPTER-2
CHEMISTRY OF NUTRIENT IN SOILS

The changes undergone by common fertilizers after these are taken out of the bag and added to soils are discussed. By understanding the fate of fertilizers, measures for increasing their efficiency can be suggested and adopted. When fertilizers react with soils, the compounds produced are by and large similar to the ones which are present in soils and which are produced by the breakdown of minerals and organic matter. That is why soils accept fertilizers without any fuss.

2.1 Nitrogen:

Nitrogen occurs in soil in both cationic (NH_4^+) and anionic (NO_3^-, NO_2^-) forms, the greater parts occurs in organic forms. NH_4^+ fixed on the cation exchange sites, are tightly bound by clay and is slowly available to plants. The available nitrates and ammonium form is only 1-2% of the total soil nitrogen. Nitrate is highly mobile. Nitrogen availability depends upon the rate at which organic nitrogen is converted to inorganic nitrogen (mineralization). Most soil nitrogen is unavailable to plants. The amount in available forms is small and crops withdraw a large amount of nitrogen. Two forms of nitrogen available to plants are nitrate (NO_3^-) and ammonium (NH_4^+). Roots can absorb both of these forms, although many species preferentially absorb nitrate-nitrogen over ammonium-nitrogen.

Nitrogen transformation in Soils

The cycling of N in the soil-plant-atmosphere system involves many transformations of N between inorganic and organic forms. Nitrogen is subjected to amino compounds ($R\text{-}NH_2$, R represents the part of the organic molecules with which amino group (NH_2) is associated), then to ammonium (NH_4^+) ion and nitrate (NO_3^-). Ammonium nitrogen is often converted to nitrate-nitrogen by micro-organisms before absorption through a process called **nitrification**.

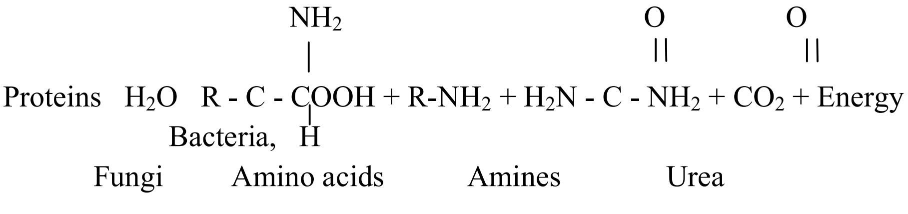
Nitrogen Minerlization

The conversion of organic N to NH_4^+ and NO_3^- is known as **nitrogen mineralization**. Mineralization of organic N involves two reactions, aminisation and ammonification, which occur through the activity of heterotrophic micro-organisms. The enzymatic process may be indicated as follows:

$$RNH_2 \underset{\substack{-H_2O \\ \text{Immobilization}}}{\overset{+H_2O \quad \text{Mineralization}}{\rightleftarrows}} ROH + NH_4 \underset{-O_2}{\overset{+O_2}{\rightleftarrows}} NO_2^- + 4H \underset{O}{\overset{+O}{\rightleftarrows}} NO_3^-$$

Aminisation:

The decomposition of protein into amines, amino acids and urea is known as **aminisation**.



$$\text{Proteins} \xrightarrow[\text{Bacteria, Fungi}]{H_2O} \underbrace{R-\overset{NH_2}{\underset{H}{\overset{|}{\underset{|}{C}}}}-COOH}_{\text{Amino acids}} + \underbrace{R\text{-}NH_2}_{\text{Amines}} + \underbrace{H_2N-\overset{O}{\overset{\|}{C}}-NH_2}_{\text{Urea}} + CO_2 + \text{Energy}$$

Ammonification

The step, in which, the amines and amino acids produced by aminisation of organic N are decomposed by other heterotrophs, with the release of NH_4^+, is termed as **ammonification**.

$$R\text{ -}NH_2 + H_2O \rightarrow NH_3^+ \qquad R\text{ - }OH + \text{Energy}$$

$$\downarrow$$

$$H_2O$$

$$NH_4^+ + OH^-$$

Nitrogen immobilization

Immobilisation is the process in which available forms of inorganic nitrogen (NO_3^- NH_4^+) are converted to unavailable organic nitrogen. Immobilisation includes assimilation and protein production so those inorganic ions are made into building block of large organic molecules.

Nitrification

Nitrification is a process in which NH_4^+ released during mineralization of organic N is conveted to NO_3^-. it is a two step process in which NH_4^+ is converted first to NO_2^- and then to NO_3^-. Biological oxidation of $NH_4^+$to NO_2^- is represented by:

$$2NH_4+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 2H_2O + 4H+$$

NO_2^- is further oxidized to NO_3- be bacteria

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobactor}} 2\,NO_3^-$$

2.2 Phosphorus

Organic and inorganic forms of phosphorus occur in soils and both the forms are important to plants as source of phosphorus. The relative amounts of phosphorus in organic and inorganic forms vary greatly from soil to soil.

Organic phosphorus compounds

Organic phosphorus represents about 50% of the total P in soils (Varies between 15 and 80% in most soil. Most organic P compounds are esters of orthophosphoric acid and have been identifies primarily as (a) inositol phosphates, (b) phospholipids and (c) nucleic acids.

Inorganic phosphorus compounds

Most inorganic phosphorus compounds in soil fall into one of the two group: (a) those in which calcium is the dominant controlling cation (calcium phosphate) and (b) those in which iron and aluminum are the controlling cations (iron and aluminum phosphates).

Phosphate Retention and Fixation

Phosphate anions can be attracted to soil constituents with such a bond that they become insoluble and not easily available to plants. This process is called phosphate fixation or retention.

Phosphate retention

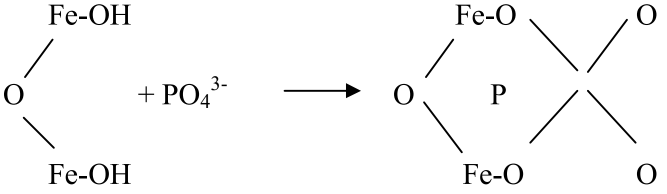
Acid soils usually contain significant amounts of soluble and exchangeable Al_3^+, Fe_3^+ and Mn_2^+ ions. Phosphate, when present, may be adsorbed to the colloid surface with these ions serving as a bridge. This phenomenon is called co-adsorption. The phosphate retained in this way is still available to plants. Such a reaction can also take place with Ca-saturated clays.

Ca clay adsorbs large amounts of phosphate. The $Ca2^+$ ions forms the linkage between he clay and phosphate ions as : Clay-Ca-H_2PO_4.

The phosphate ions can also enter into a chemical reaction with the foregoing free metal ions as: $Al3^+ + 3H_2PO_4^- \rightarrow Al(H_2PO_4)_3.\downarrow$ The product formed is not soluble in water and precipitates from solution. With the passage of time the Al phosphate precipitates, become less soluble and less available to plants. The lower the soil pH, the greater the concentration of soluble Fe, Al, and Mn: consequently, larger the amount of phosphorus retention in this way.

Phosphate fixation in acidic soils:

Many acidic soils contain high amounts of free Fe and Al and Fe and Al hydrous oxide clays. The free Fe, Al and the sesquioxide clays react rapidly with phosphate, forming a series of not easily soluble hydroxyl phosphates.



The amount of phosphate fixed by this reaction usually exceeds that fixed by phosphate retention. Generally, clays with low sesquioxide ratios (SiO_2/R_2O_3) have a higher P-fixing capacity.

Phosphate fixation in alkaline soils:

Many alkaline soils contain high amounts of soluble and exchangeable Ca2+ and, frequently, CaCO3. Phosphate react with both the ionic and carbonate form of Ca.

$$3Ca^{2+} + 2PO_4^{3} \longrightarrow Ca_3(PO_4)_2 \text{ (Insoluble)}$$

$$3CaCO_3 + 2PO_4^{3-} \longrightarrow Ca_3(PO_4)_2 + 3CO_2 \text{ (Insoluble)}$$

Phosphate fixation cannot be avoided entirely, but it may be reduced by addition of competing ions for fixing sites. Organic anions from stable manure and silicates are reported to be very useful in reducing P fixation.

2.3 Potassium

Forms and availability of potassium in soils

Potassium in soil occurs in four phases namely soil solution phase, exchangeable phase, non-exchangeable phase and mineral phase. The different forms are in dynamic equilibrium with one another.

The forms of potassium in soils were positively and significantly correlated with K content in silt and clay.(Venkatesh and Satyanarayan, 1994).

Water soluble K:

The water soluble K is the fraction of soil potassium that can be readily adsorbed by the growing plants. However this is a very small fraction of total K. The dilution of the soil incrases the concentration of water-soluble K and drying decreases it further. It is about 1 to 10 mg kg^{-1} of total K.

Exchangeable K:

Exchangeable K is held around negatively charged soil colloids by electrostatic attraction. Thus, exchangeable potassium represents that fraction of K, which is adsorbed on external and accessible internal surfaces. It is about 40 to 60 mg kg^{-1} of total K.

Non-exchangeable (fixed) K:

Potassium held at inter lattice position is generally non-exchangeable. Non-exchangeable K is distinct from mineral K in that it is not bonded covalently within the crystal structures of soils mineral particles. Instead, it is held between adjacent tetrahedral layers of dioctahedral and trioctahedral micas, vermiculites and intergrade clay minerals. It is about 50 to 750 mg kg-1 of total K.

Mineral (lattice) K:

Lattice K is a part of the mineral structure and is available to the plants very slowly. (As compared to the non-exchangeable K). Both the rate and amount of lattice K released to plants depend on the quantity of clay, especially the smaller clay particles, and its mineralogy. It is about 5,000 to 25,000mg kg^{-1}.

For convenience, the various forms of potassium in soils can be classified on the basis of availability in three general groups: (a) unavailable (b) readily available and (c) slowly available.

A dynamic equilibrium of various forms of K in the soil may be shown as :

$$K(\text{lattice}) \leftrightarrow K(\text{exchangeable}) \leftrightarrow K\ (\text{solution})$$

Relatively Unavailable Forms

The greatest part (90-98%) of all soil potassium in a mineral soil is in relatively unavailable forms. The compounds containing most of this form of potassium are the feldspars and micas. These minerals are quite resistant to weathering and probably supply relatively insignificant quantities of potassium during a given growing season.

Readily Available Forms

The readily available potassium constitutes only about 1-2% of the total amount of this element in an average mineral soil. It exists in soils in two forms; (i) potassium in soil solution and (ii) exchangeable potassium adsorbed on soil colloidal surfaces. Most of this available potassium is in the exchangeable form (approximately 90%). Soil solution potassium is most readily adsorbed by higher plant and is, of course, subject to considerable leaching loss.

Slowly Available Forms

In the presence of vermiculite, smectite, and other 2:1- type minerals the potassium of such fertilizers as muriate of potash not only becomes adsorbed but may become definitely 'fixed' by the soil colloids. The potassium as well as ammonium ions fit in between layers in the crystals of these normally expanding clays and become an integral part of the crystal. Potassium in this form cannot be replaced by ordinary exchange methods and consequently is referred to as non-exchangeable potassium. As such this element is not readily available to higher plants. This form is in equilibrium, however, with the available forms and consequently acts as an extremely important reservoir of slowly available potassium.

2.4 Sulphur Transformation in Soil

Sergei Nikolaievich Winogradsky (1856 – 1953) was microbiologist, ecologist and soil scientist who pioneer for his notable work on bacterial sulfate reduction. The transformation of sulphur are important indicators of its availability to plants. Availability of sulphur from organic sulphur reserves in soils depends on its mineralization through microbial activity.

Sulphur Oxidation:

Sulphur oxidation ocuuring in soils is mostly biochemical in nature. Sulphur oxidation is accomplished by number of autotrophic bacteria including those of genus *Thiobacillus*, five species of which have been characterized:

(a) *Thiobacillus thioxidans* (b) *T. thiparus* (c) *T. nonellus* (d) *T. denitrificans* (e) *T. ferooxidans*

In soils, sulfides, elemental sulphur, thiosulphates and polythionates are oxidized.

Oxidation reactions:

$H_2S + 2O_2 \longrightarrow H_2SO_4 \longrightarrow 2H^+ + SO_4^{2-}$

$2S + 3O_2 + 2H_2O \longrightarrow 2H_2SO_4 \quad 4H^+ + 2SO_4^{2-}$

Thus S-oxidation is an acidifying process.

Sulphur reduction:

Sulphate tend to be unstable in anaerobic environments so they are reduced sulfides by a number of bacteria of two genera, *Desulfovibro* (five species) and *Desulfotomaculum* (three species).

The organisms use the combined oxygen in sulfate to oxidize organic materials.

Reduction reactions:

$2R\text{-}CH_2OH + SO_4^{2-} \longrightarrow 2R\text{-}COOH + 2H_2O + S^{2-}$

(Organic alcohol) (Sulfate) (Organic acid) (Sulfide)

Also, sulfites (SO_3^{2-}), thiosulfates ($S_2O_3^{2-}$) and elemental sulphur (S) are rather easily reduced to the sulfides form by bacteria and other organisms.

The oxidation and reduction of inorganic sulphur compounds are of great importance to growing plants. These reactions determine the quantity of sulfate present in soils at any one time. Also, the state of sulphur oxidation determines to a marked degree the soil acidity as S-oxidation is an acidifying process.

2.5 Calcium and Magnesium Transformations in Soil

Calcium is an important amendment element in saline and alkali soils. Calcium application helps in correcting the toxicity and deficiency of several other nutrients. The main transformations of Ca and Mg in soils are (i) solubilization and leaching and (ii) conversion into less soluble fractions by adsorption.

Solubilization and leaching of calcium and magnesium: It is affected by following:

Soil texture: Losses are more in light textured soils because of high permeability and percolation of rain and irrigation water.

Rainfall: As the rainfall increases the loss of Mg and Ca also increases.

Organic matter: Application of organic matter leads to net loss of Ca and Mg from the soil.

Ferrolysis: High amounts of bases such as Ca2+ and Mg2+ may be lost from the exchange complex and laeached by high amounts of cations such as Fe2+ and Mn2+ which are released following reduction of soil. This is called **ferrolysis**.

Conversion of calcium and magnesium into less soluble form by adsorption:

Clacium and magnesium in soil solution and in exchange complex are in a state of dynamic equilibrium. When their concentration in solution decreases, Ca and Mg coming from the exchange complex replenish this. On the other hand if their concentration in soil solution is high, there is tendency towards their being adsorbed on the exchange complex.

(***Source***: Textbook of Soil Science: R. K. Mehra)

2.6 Fe and Zn Transformations in Soil:

Iron

The most important chemical change that takes place when a soil is submerged is the reduction of iron and the accompanying increase in its solubility. The intensity of reduction depends upon time of submergence, amount of organic matter, active iron, active manganese, nitrate etc.

Due to reduction of Fe^{3+} to Fe^{2+} on submergence, the colour of soil changes from brown to grey and large amounts of Fe^{2-} enter into the soil solution. It is evident that the concentration of ferrous iron (Fe^{2+}) increases initially to some peak value the thereafter decreases slowly with the period of soil submergence. Organic matter also enhances the rate of reduction of iron in submerged soils. The initial increase in the concentration of ferrous iron (Fe2+) on soil submergence is caused by the reduction that are shown below:

$$\underset{\text{(Insoluble)}}{Fe(OH)_3} + e^- \overset{\text{Reduction}}{\rightleftharpoons} \underset{\text{(Soluble)}}{Fe^{2+}} + 3OH^-$$

The decrease in the concentration of Fe^{2+} following the peak rise is caused by the precipitation of Fe^{2+} as $FeC0_3$ in the early stages where high partial pressure of $C0_2$ prevails and *as* $Fe_3(OH)_8$ due to decrease in the partial pressure of $C0_2$($pC0_2$)

$$\underset{\text{(Soluble)}}{2Fe^{2+}} + 3CO_2 \longrightarrow \underset{\text{(Insoluble)}}{2FeCO_3}$$

Rice benefits from the increase in availability of iron but may suffer in acid soils, from an excess. The reduction of iron has some important consequences: (i) the concentration of water soluble iron increases, (ii) pH increases, (iii) cations are displaced from exchange sites, *(iv)* the solubility of P and Si increases and *(v)* new minerals are formed.

A schematic representation for the transformation of iron in submerged soils is shown below:

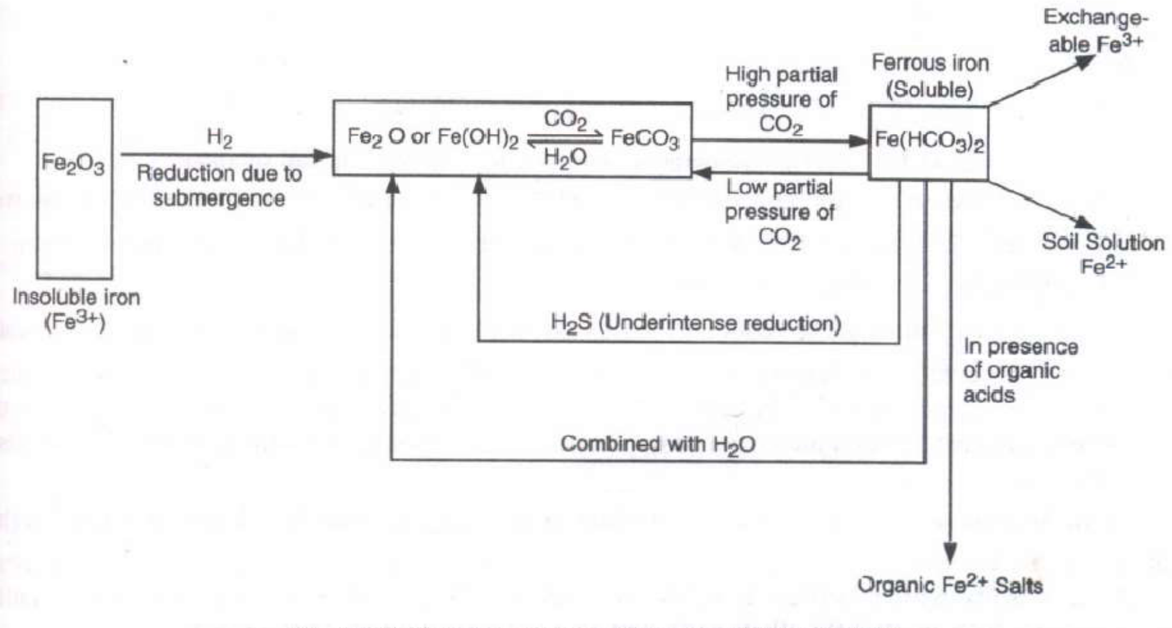


Fig. 21.12. Transformation of iron in submerged soils.

Zinc

The transformation of zinc in submerged soils is not involved in the oxidation-reduction process like that of iron and manganese. However, the reduction of hydrous oxides of iron and manganese, changes in soil pH, partial pressure of C02, formation insoluble sulphide compound etc. In soil on submergence is likely to influence the solubility of Zn in soil either favourably or adversely and consequently the Zn nutrition of low and rice. The reduction of hydrous oxides of iron and manganese, formation of organic complexing agents, and the decrease in pH of alkaline and calcareous soils on submergence are found to favour the solubility of Zn, whereas the formation of hydroxides, carbonates, sulphides may lower the solubility ofZn in submerged soils. Zinc deficiency in submerged rice soils is very common owing to the combined effect of increased pH, $HC0_3^-$ and S^{2-} formation.

The solubility of native forms of Zn in soils is highly pH dependent and decreases by a factor of 10^2 for each unit increase in soil pH. The activity of Zn-pH relationship has been defined as follow:

$$\text{Soil} + Zn^{2+} \rightleftarrows \text{Soil} - Zn + 2H^+$$

The pK value for the above reaction with the solid phase of soils is 6.0. This equation holds good for submerged soils. Some equations relating to solubility of Zn in submerged soils governed by various metastable compounds are given below :

$$\begin{array}{rcll}
3Zn^{2+} + 2PO_4^{3-} & \rightleftarrows & Zn_3(PO_4)_2 & pK_2 = 32.0 \\
Zn^{2+} + NH_4^+ + PO_4^{3-} & \rightleftarrows & ZnNH_4PO_4 & pK_s = 16.0 \\
Si(OH)_4 + Zn^{2+} & \rightleftarrows & Zn(OH)_2 + SiO_2 + 2H^+ & pK_2 \geq 17.5 \\
Zn^{2+} + S^{2-} & \rightleftarrows & Zn\ S & pK_2 = 22.8 \\
Zn^{2+} + 2OH^- & \rightleftarrows & Zn(OH)_2 & pK_s = 17.5 \\
Zn^{2+} + CO_3^{2-} & \rightleftarrows & ZnCO_3 & pK_s = 16.5
\end{array}$$

Many of these compounds are metastable intermediate reaction products and varying mean residence time in submerged soils. Applied Zn tends to approach the solubility of the native forms instead of having residual effect in the former Zn forms.

When an aerobic soil is submerged, the availability of native as well as applied Zn decreases and the magnitude of such decrease vary with the soil properties. The transformation of Zn in soils was found to be greatly influenced by the depth of submerged and application of organic matter. If an acid soil is submerged, the pH of the soil will increase and thereby the availability of Zn will decrease. On the other hand, if an alkali soil is submerged, the pH of the soil will decrease and as a result the solubility of Zn will generally increase.

The availability of Zn decreases due to submergence may be attributed to the following reasons:

(i) formation of insoluble franklinite ($ZnFe20_4$) compound in submerged soils.

$$Zn^{2+} + 2Fe^{2+} + 4H_2O \underset{\text{reduction}}{\rightleftarrows} ZnFe_2O_4\ \text{(Franklinite)}$$

(ii) Formation of very insoluble compounds of Zn as ZnS under intense reducing conditions.

$$Zn^{2+} + S^{2-} \rightleftarrows \underset{\text{(Very insoluble in water}}{ZnS\ \text{(Sphalerite)}}$$

(iii) Formation of insoluble compounds of Zn as $ZnC0_3$ at the later period of soil submergence owing to high partial pressure of $C0_2(PC0_2)$ arising from the decomposition of organic matter.

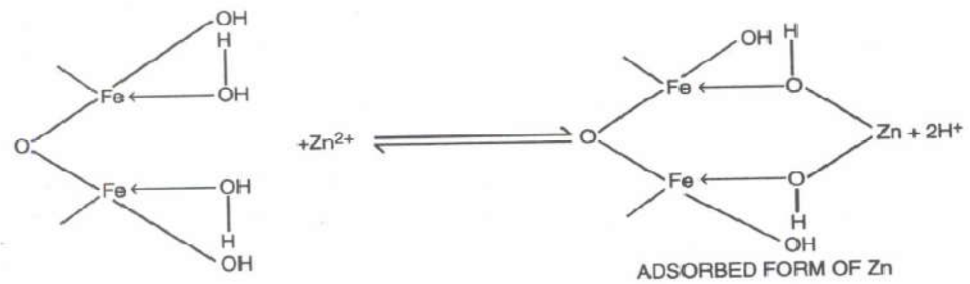
$$Zn^{2+} + CO_2 \rightleftharpoons \underset{\text{(Insoluble)}}{ZnCO_3} \text{ (Smithsonite)}$$

(iv) Formation of Zn(OH)2 at a relatively higher pH which decreases the availability of Zn.

$$Zn^{2+} + 2HO^- \rightleftharpoons \underset{\text{(Insoluble)}}{Zn(OH)_2}$$

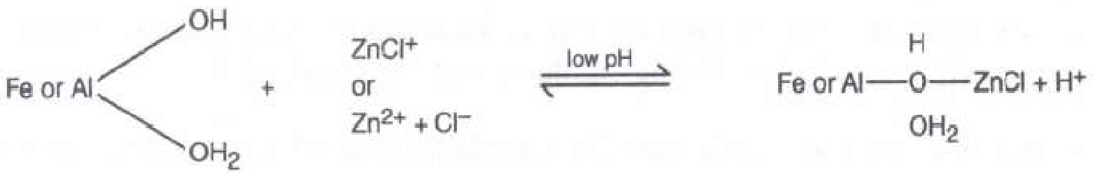
(v) Adsorption of soluble Zn^{2+} by oxide minerals *e.g.* sesquioxides, carbonates, soil organic matter and clay minerals etc. decreases the availability of Zn, the possible mechanism of Zn adsorption by oxide minerals is shown below :

Mechanism I:



In mechanism I, Zn^{2+} adsorption occurs as bridging between two neutral sites, but in addition to this mechanism, Zn^{2+} could also be adsorbed to two positive sites or to a positive and neutral site.

Mechanism II:



This mechanism occurs at low pH and results non-specific adsorption of Zn^{2+}. In this way Zn^{2+} is retained and rendered unavailable to plants.

(vi) Formation of various other insoluble zinc compounds which decreases the availability of Zn in submerged soils, *e.g.* high phosphatic fertilizer induces the decreased availability of Zn^{2+}.

$$Zn^{2+} + PO_4^{3-} \longrightarrow \underset{\text{(Insoluble)}}{Zn_3(PO_4)_2}$$

A simplified diagram illustrating dynamic equilibria of Zn in submerged soils is shown in figure.

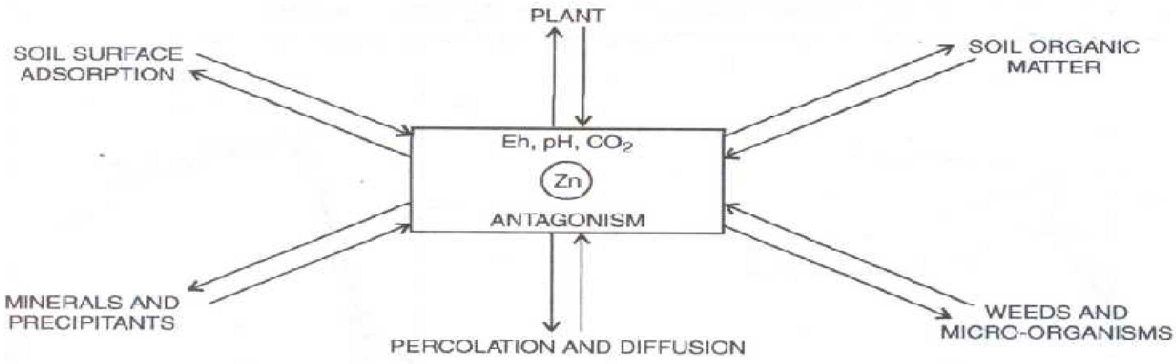


Fig. 21.14. Dynamic equilibria of Zn in submerged soils.

It shows that rice receives Zn from the soil solution and the exchangeable and adsorbed solid phase including the soil organic fractions.

Zinc sulphide (ZnS, Sphalerite) in the presence of traces of hydrogen sulphide (H_2S) in submerged soils may control the solubility of Zn. Zinc is stable in submerged soils. So it can be concluded that higher the pH and poorer the aeration, the greater is the likelihood of Zn deficiency if the soil solution Zn activity is controlled by sphalerite (ZnS).

Therefore, a variety of chemical reactions in soils influence the availability of Zn to rice. For example, high manganese concentration antagonizes Zn absorption and translocation.

Q/I relationship

In addition to these, the availability of Zn in submerged soils is governed by the mutual interaction of quantity *(q)* intensity *(c),* and kinetic parameters as regulated by the adsorption, desorption, chelation and diffusion of Zn from soils to the plant roots. The quantity-intensity relationship of Zn in submerged soils may be described by the linear form of the Langmuir type equation. The supply parameter assumes the form,

$$\text{Supply parameter} = qc^{1/2} \,.\, K_1K_2^{-1/4} \text{ or } \sqrt{cq/\sqrt{K_1K_2}}$$

where *q* is the quantity c is the intensity, K_1 and K_2 are constants.

The optimum Zn supply to rice is ensured when the value of the supply parameter is unity (1.0).

Different crop management factors combined influence the availability of Zn to rice like, native Zn content of the soil, soil pH, organic matter, submergence, partial pressure of CO_2, HCO_3, organic acids, various natural interactions, environmental effects and water quality etc.

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CHAPTER-3
SOIL FERTILITY EVALUATION

The proper rate of plant nutrient is determined by knowing the nutrient requirement of the crop and the nutrient supplying power of soil. Hence, the evaluation of soil fertility becomes important. Soil fertility evaluation is essential for balanced nutrition of the crops. Balance nutrients use refers to the application of essential plant nutrients in right amounts and proportions using correct methods and time of application suited for specific soil-crop-climatic situations. It helps in maintenance and improving soil productivity. Thus soil fertility evaluation is the key for adequate and balanced fertilization in crop production. Several techniques are commonly employed to asses the fertility status of the soils. A proper evaluation of the fertility of a soil before planting of a crop helps in adopting appropriate measures to make up for the shortcoming and ensuring a good crop production. The diagnostic techniques are

1. Soil testing
2. Analysis of tissues from plant growing on the soil
3. Biological tests in which the growth of higher plants or certain micro-organisms is used as a measure of soil fertility
4. Nutrient deficiency symptoms of plant

3.1 Soil testing:

Soil testing is the chemical analysis that provides a guideline for amendments and fertilizer needs of soils. The primary advantage of soil testing when it is compared to the plant analysis is its ability to determine the nutrients status of the soil before the crop is planted

The soil testing is done with following objectives:

1. Soil fertility evaluation for making fertilizer recommendation
2. Prediction of likely crop response to applied nutrient
3. Classification of soil into different fertility groups for preparing soil fertility maps of a given area
4. Assessment of the type and degree of soil related problems like salinity, sodicity, acidity etc., and suggesting appropriate reclamation / amelioration measures

The following steps are involved in soil analysis

1. Sampling
2. preparation of samples
3. Analytical procedure
4. Calibration and interpretation of the results
5. Fertilizer recommendation

1. Sampling: Soil sampling is perhaps the most vital step for any analysis. Since, a very small fraction of the huge soil mass of a field is used for analysis; it becomes extremely important to get a truly representative soil sample from it.

2. Preparation of sample: Drying, grinding and sieving according to the need of analytical procedure

3. Analytical procedure: A suitable method is one which satisfies the following three criteria.

i. It should be fairly rapid so that the test results can be obtained in a reasonably short period.

ii. It should give accurate and reproducible results of a given samples with least interferences during estimation.

iii. It should have high predictability *i.e.,* a significant relationship of test values with the crop performance.

Following chemical methods are widely used for determination of different nutrients

Nutrients	**Methods**	**Merits and demerits**
Total N	Kjeldahl method	• This method is time consuming, lengthy and costly • Rate of mineralization of N varies with the soil
Organic C	Walkley and Black method	• This method is simple and rapid • Based on C:N ratio which is varied (7.7 to 11.7)
Available N	Alkaline-$KMnO_4$	• Extract part of organic and mineral N
Available P_2O_5	Olsen's method for alkaline soils	• High efficiency of HCO_3 ion to remove P from Ca, Al and Fe • Reduce the activity of Ca • Used in slightly acidic, neutral and alkaline soil
	Bray's method for acid soils	• High efficiency of F ion in dissolving P • Useful in acidic or slightly calcareous soils
Available K_2O	NH_4OAc extratable	• Higher efficiency of extraction as compared to salt solution • Inefficiency to remove part of non exchangeable K, which isconsidered to be available to some extent
Available S	0.15% $CaCl_2$ extractable	• Extract water soluble S and adsorbed S
	Heat soluble S	• Heat soluble- extract WS + organic S • Time consuming and lengthy procedure
Available Micronutrients	DTPA extractable	• Extract complexed, chelated and adsorbed form of Fe, Mn, Zn, Cu

4. **Calibration and interpretation of the results:** For the calibration of the soil test data, a group of soils ranging in soil fertility from low to high in respect of the particular nutrient are selected and the test crop is grown on these soils with varying doses of particular nutrient with basal dose of other nutrients.

The most common method is to plot soil test values against the percentage yield and to calculate the relation ship between soil test values and per cent yield response

$$\text{Percent yield} = \frac{\text{Crop yield with adequate nutrient} - \text{Yield of control without addition of particular nutrient under study}}{\text{Crop yield with adequate nutrient}} \times 100$$

► Critical level of nutrients in soil:

SN	Nutrients	Category		
		Low	**Medium**	**High**
1.	Alkaline $KMnO_4$-N (kg/ha)	<250	250-500	>500
2.	Olsens-P_2O_5 (kg/ha),	<28	28-56	>56
3.	Neutral N NH_4OAc-K_2O	<140	140-280	>280
4.	0.15% $CaCl_2$ –S (mg/kg)	<10	10-20	>20
5.	DTPA extractable Fe (mg/kg)	<5	5-10	>10
6.	DTPA extractable Mn (mg/kg)	<5	5-10	>10
7.	DTPA extractable Zn (mg/kg)	<0.5	0.5-1.0	>1.0
8.	DTPA extractable Cu (mg/kg)	<0.2	0.2-0.4	>0.4
9.	Hot water soluble B (mg/kg)	<0.1	0.1-0.5	>0.5
10.	Hot water soluble Mo (mg/kg)			

This classification indicated that low class of soil would respond to added fertilizer means add 25% more fertilizer than recommended dose. Medium class soil may or may not respond to added fertilizer, add recommended dose of fertilizer. High status soils do not respond to added fertilizer, add 25% less recommended dose.

3.2 Plant Testing:

1. Analysis of tissues from plant growing on the soil

Plant analysis in a narrow sense is the determination of the concentration of an element or extractable fraction of an element in a sample taken from a particular part or portion of a crop at a certain time or stage of morphological development

Plant analysis is complementary to soil testing. In many situations, the total or even the available content of an element in soil fails to correlate with the plant tissue concentration or the growth and yield of crop. This can be ascribed to many reasons including the physico chemical properties of the soils and the root growth patterns. On the other hand, the concentration of an element in the plant tissue is, generally, positively correlated with the plant health. Therefore, the plant analysis has been used as a diagnostic tool to determine the nutritional cause of plant disorders/diseases. The plant analysis constitutes (1) the collection of the representative plant parts at the specific growth stage, (2) washing, drying and grinding of plant tissue, (3) oxidation of the powdered plant samples to solubilize the elements, (4) estimation of different elements, and (5) interpretation of the status of nutrients with respect to deficiency / sufficiency /toxicity on the basis of known critical concentrations.

► Plant analysis has many applications such as:

1. Diagnosis of nutrient deficiencies, toxicities or imbalances
2. Measurement of the quantity of nutrients removed by a crops to replace them in order to maintain soil fertility
3. Estimating overall nutritional status of the region or soil types
4. Monitoring the effectiveness of the fertilizer practices adopted
5. Estimation of nutrient levels in the diets available to the live stock

2. Collection and Preparation of plant samples

Plant scientists have been able to standardize the procedures for collection of samples of plant tissue with respect to the plant part and growth stage, which reflect the nutrient concentrations corresponding to the health of the growth because the concentrations of different nutrients vary significantly over the life cycle of a plant. Generally, the recently matured fully expanded leaves just before the onset of the reproductive stage are collected and put in perforated paper bags. The plant samples are often contaminated with dust, dirt and residues of the sprays, *etc.* and need to be washed first under a running tap water followed by rinsing with dilute HCl (0.001N), distilled water and finally in deionized water. The washed samples are dried in a hot air oven at 60±5°C for a period of 48 hours and ground in a stainless steel mill to pass through a sieve of 40/60 mesh.

3. Oxidation of plant material

The main objective of oxidation is to destroy the organic components in the plant material to release the elements from their combinations. The plant materials can be oxidized by either dry ashing at a controlled high temperature in a muffle furnace or wet digestion in an acid or a mixture of two or more acids.

(a) Dry-ashing : The powdered plant materials in tall form silica crucibles are ashed at 500ºC in a muffles furnace for 3-4 hours. High temperatures are likely to result in the loss of some volatile elements but with adjusting the time of muffling between 2-72 hours, any significant effect on the analytical results can be avoided. Nitrogen and sulphur, being highly volatile, are lost more or less completely during dry ashing even at 500ºC but at higher temperatures, elements like K are also reported to be lost. Thus, temperature is an important consideration in dry ashing. The ash is dissolved in 2ml of 6N HCl, heated on a hot plate to near dryness and taken in 10 ml dilute HCl (0.01N) or 20% aqua regia before making up the final volume with distilled water. These extracts contain different amounts of insoluble materials, mainly silica, depending upon the plant species. These insoluble materials settle down on keeping for sometime or can be separated by filtration before estimation of different elements. All elements, except N and S, can be estimated in these extracts by any technique. In general, the results obtained by this method, are quite satisfactory and comparable to those obtained by this method, are quite satisfactory and comparable to those obtained by wet digestion procedures. Moreover, B can only be determined by dry ashing since it is volatilized during wet digestion with di-or triacid mixtures.

(b) Wet Digestion :

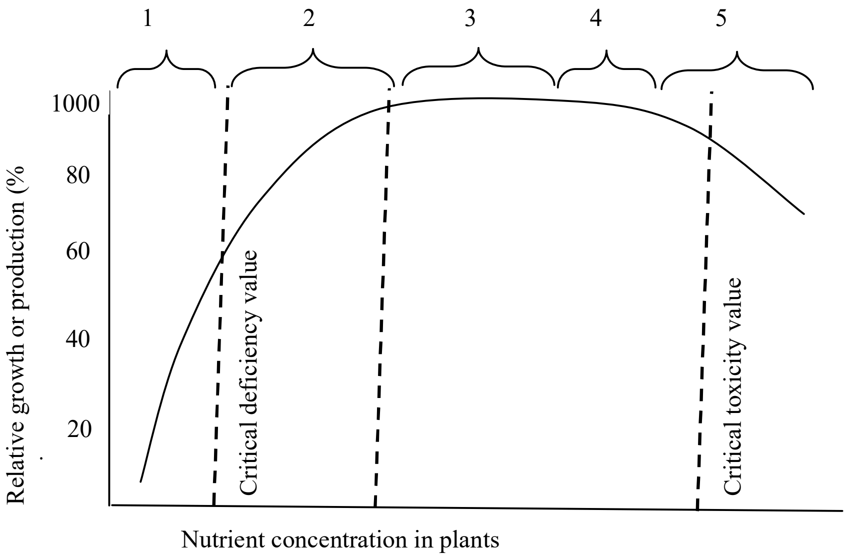
Wet oxidation digestion reagents and their applicability

Sr. No.	Reagents	Applicability to organic manure	Remarks
1	H_2SO_4/HNO_3	Vegetable origin	Most commonly used
2	H_2SO_4/H_2O_2	Vegetable origin	Not very common
3	HNO_3	Biological origin	Easily purified reagent, short digestion time, temperature 350 ^{0}C
4	$H_2SO_4/HClO_4$	Biological origin	Suitable only for small samples, danger of explosion
5	$HNO_3/HClO_4$	Protein, carbohydrate (no fat)	Less explosive
6	HNO_3/ $HClO_4/H_2SO_4$	Universal (also fat and carbon black	No danger with exact temperature control

The powdered plant samples can also be dissolved by digesting in acids, usually HNO_3, $HClO_4$ and H_2SO_4. These acids are used either singly or in combinations of two or three acids, e.g. a di-acid combination is HNO_3 and $HClO_4$ (in 4:1 ration) or a triple acid is a mixture of HNO_3, $HClO_4$ and H_2SO_4 (in 10:4:1 ration). A triple acid combination destroys the organic matter in a shorter time without any hazard. But the method is unsatisfactory for plant materials with high Ca and in cases where S is one of the test elements. The insoluble sulphate renders the method unsuitable because of adsorption of different element ions on the precipitate and exclusion of Ca from the analysis. The use of perchloric acid in the di- or triple acid digestion mixtures results in the formation of sparingly soluble potassium perchlorate, resulting in lower estimates of K, especially when the plant material contains K, more than 1%. As such for multi element analysis, the plant materials should be digested in nitric acid alone.

4. Interpretation of results: The basis for plant analysis as a diagnostic technique is the relationship between nutrient concentration in the plant and growth and production response. This relation should be significant to have complete interpretation in teem of deficient, adequate and excess nutrient concentration in the plant. Curves representing the relationship between nutrient concentration and growth response vary in shape and character depending on both the nutrient concentration in the growth medium and the plant species.

When nutrients are in deficiency range, plant growth and yield are significantly reduced and foliar deficiency symptoms appear. In this range, application of nutrient results in sharp increase in growth. In marginal range, growth or yield is reduced, but plant does not show deficiency symptoms. Sometimes the marginal range is also called transition zone. Within the marginal or transition zone lies the critical level or concentration. The critical level can be defined as that concentration at which the growth or yield begins to decline significantly.



1. Deficient	2. Marginal	3. Adequate	4. Excess	5. Toxic

Rapid tissue tests:

These tests are rapid and are essentially qualitative. The nutrients are absorbed by roots and transported to those parts of plants where they are needed. The concentration of cell sap is usually good indication of how well the plant is supplied at the time of testing.The plant parts, usually leaves are removed and plant sap is extracted. The plant sap is usually tested for nitrate, phosphorus and potassium. The use of specific reagent for each nutrient to be tested develops the colour. The intensity of colour is a qualitative measure of the content of the nutrient.

DRIS approach

Recently Diagnosis Recommendation Integration System (DRIS) is suggested for fertilizer recommendation. In this approach, plant samples are analyzed for nutrient content and they are expressed as rations of nutrients with others. Suitable ratios of nutrients are established for higher yields from experiments and plant samples collected from farmer's fields. The nutrients whose ratios are not optimum for high yields are supplemented by top dressing. This approach is generally suitable for long duration crops, but it is being tested for short duration crops like soybean, wheat *etc.*

3.3 Biological tests

The biological methods consist of raising a crop or a microbial culture in a field or in a sample of the soil and estimating its fertility from the volume of crop or microbial count. Although these methods are direct estimates of soil fertility, they are time consuming and therefore, not well adapted to the practice of soil testing.

(i) **Field tests:** The field plot technique essentially measures the crop response to nutrients. In this, specific treatments are selected, randomly assigned to an area of land, which is representative of the conditions. Several replications are used to obtain more reliable results and to account for variation in soil. Field experiments are essential in establishing the equation used to provide fertilizer recommendation that will optimize crop yield. Maximum profitability, and minimize environment impact of nutrient use

(ii) Pot culture tests: The pot culture test utilize small quantities of soil to quantify the nutrient supplying power of a soil. Selected treatments are applied to the soils and a crop is planted and evaluated. Crop response to the treatments can be than determined by measuring total plant yield and nutrient content

(iii) Laboratory tests

(a) Neubauer seedling Method: the neubaur technique is based on the uptake of nutrient by growing a large number of plants on a small amount of soil. The seedlings (plants) exhaust the available nutrient supply within short time. The total nutrients removed are quantified and tables are established to give the minimum values of nutrients available for satisfactory yield of various crops.

(b) Microbial methods: In the absence of nutrients, certain microorganisms exhibits behaviour similar to that of higher plants. For example, growth of Azotobacter or Aspergillus niger reflacts nutrient deficiency in the soil. The soil is rated from very deficient to not deficient in the respective elements, depending on the amount of colony growth. In comparison with methods that utilize higher plants, microbiological methods are rapid, simple and require little space. These laboratory tests are not in common use in India.

3.4 Nutrient deficiency symptoms of plant

As already mentioned, the plant requires sixteen essential nutrients for their optimum growth and development. When a plant badly needs a certain nutrient element, it shows deficiency symptoms. These symptoms are nutrient specific and show different patterns in crops for different essential nutrients. It is good tool to detect deficiencies of nutrient in the field but these techniques have several limitations and are:

1. The visual symptoms may be caused by more than one nutrient.
2. Deficiency of one nutrient may be related to an excess quantity of another.
3. It is difficult to distinguish among the deficiency symptoms in the field, as disease or insect damage can be resemble certain micronutrient deficiencies.
4. Nutrient deficiency symptoms are observed only after the crop has already suffered an irreversible loss.There are some indicator plants which shoes the nutrient deficiencies or excesses. Some of them are given as follows:

Plant		Nutrient deficiency/toxicity
Oat	:	Mg, Mn and Cu deficiencies
Wheat and barley	:	Mg, Cu and some times Mn deficiencies
Sugar beets	:	B and Mn deficiencies
Maize	:	N, P, K, Mg, Fe, Mn and Zn deficiencies
Potatoes	:	K, Mg and Mn deficiencies
Brassica species	:	K and Mg deficiencies
Celery and sunflower	:	B deficiency
Cauliflower	:	B and Mo deficiencies
Barley	:	B, Mn and Al toxicities
Cucumber	:	N and P excess

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CHAPTER-4
ORGANIC MANURES

The word manure derived from the French "Manoeuvrer', means to manipulate, to work, to produce crop. In general manure means excreta of animals. The term bulky organic manure generally includes those materials of natural origin, organic in composition having greater volume per unit content of nutrients and being used to increase the nutrient status of the soils as well as organic matter content of soils. They are obtained mainly as natural products.

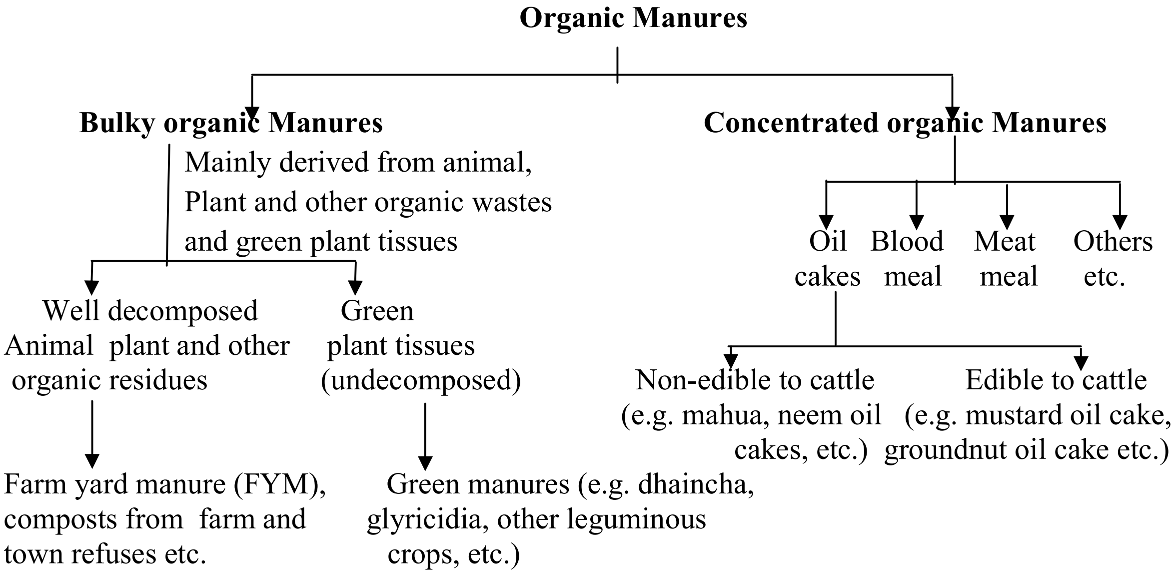
"The manures are organic in nature, plant or animal origin and contain organic matter in large proportion and plant nutrients in small quantities and used to improve soil productivity by correcting soil physical, chemical and biological properties."

The materials included in this group are farmyard manure, compost, sewage sludge and green manure. Of these FYM, compost and green manure are the most important and widely used bulky organic manures.

4.1: Characteristics of manures:

Manure required in large quantity bulky and costly. Nutrients are slowly available upon decomposition. It has long lasting effect on soil and crop. No salt and adverse effect. Manure is organic matter used as organic fertilizer in agriculture. Manures contribute to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, that are trapped by bacteria in the soil. Higher organisms then feed on the fungi and bacteria in a chain of life that comprises the soil food web.

4.2: Classification of organic manures



4.3: Importance of organic manures

1. Organic manure binds soil particles into structural units called aggregates. These aggregates help to maintain a loose, open, granular condition. Water infiltrates and percolates more readily. The granular condition of soil maintains favorable condition of aeration and permeability.

2. Water-holding capacity is increased by organic matter. Organic matter definitely increases the amount of available water in sandy and loamy soils. Further, the granular soil resulting from organic matter additions, supplies more water than sticky and impervious soil.
3. Surface run off and erosion are reduced by organic matter as there is good infiltration.
4. Organic matter or organic manure on the soil surface reduces losses of soil by wind erosion.
5. Surface mulching with coarse organic matter lowers soil temperatures in the summer and keeps soil warmer in winter.
6. The organic matter serves as a source of energy for the growth of soil microorganisms.
7. Organic matter serves as a reservoir of chemical elements that are essential for plant growth. Most of the soil nitrogen occurs in organic combination. Also a considerable quantity of phosphorus and sulphur exist in organic forms upon decomposition, organic matter supplies the nutrients needed by growing plants, as well as many hormones and antibiotics.
8. Fresh organic matter has a special function in making soil phosphorus more readily available in acid soils.
9. Organic acids released from decomposing organic matter help to reduce alkalinity in soils.
10. Fresh organic matter supplies food for such soil life as earthworms, ants and rodents. These macro-organisms improve drainage and aeration. Earthworms can flourish only in soils that are well provided with organic matter.
11. Organic matter on decomposition produces organic acids and carbon dioxide which help to dissolve minerals such as potassium and make them more available to growing plants.
12. Humus (highly decomposed organic matter) provides a storehouse for the exchangeable and available cations – potassium, calcium and magnesium. Ammonium fertilizers are also prevented from leaching because humus holds ammonium in an exchangeable and available form.
13. It acts as a buffering agent. Buffering checks rapid chemical changes in pH and in soil reaction.

4.4 Methods of preparation of Bulky Organic Manures

4.4.1: Farm Yard Manure (FYM)

The FYM refers to the decomposed mixture of dung and urine from farm animals, mainly sheep, cattle and poultry. This is one of the oldest manure known and is highly valued for its many of the beneficial properties that are said to be produced when this manure is added to the soil. It not only adds the constituents to the soil but also adds organic matter to the soil.

On an average well rotted FYM contains 0.5% N_s 0.2% P_2O_5 and 0.5% K_2O.

FYM is one of the most important agricultural by products. Unfortunately, however nearly 50 per cent of the cattle dung production in India today is utilized as fuel and is thus lost to agriculture.

► **Average percentage of N, P_2O_5 and K_2O in the fresh excreta of farm animals:**

Excreta of		N (%)	P_2O_5 (%)	K_2O (%)
Cows and bullocks	Dung	0.40	0.20	0.10
	Urine	1.00	Traces	1.35
Sheep and goat	Dung	0.75	0.50	045
	Urine	1.35	0.05	2.10
Buffalo	Dung	0.26	0.18	0.17
	Urine	0.62	Traces	1.61
Poultry	-	1.46	1.17	0.62

Among bulky organic manures, poultry manure generally contains more amounts of nutrients as compared to others. Moreover, urine portion of all farm animals contains more amounts of N and K as compared to the dung portion.

► Factors Affecting Nutritional Build up of FYM:

The following factors affect the composition of FYM:

1. **Age of animal:** Growing animals and cows producing milk retain in their system nitrogen and phosphorus required for productive purposes like making growth and producing milk and the excreta do not contain all the ingredients of plant food given in the feed. Old animals on the downgrade waste their body tissues and excrete more than what they do ingest.
2. **Feed:** When the feed is rich in plant food ingredients, the excreta produced is correspondingly enriched.
3. **Nature of Litter Used:** Cereal straw and leguminous plant refuse used as litter enriched the manure with nitrogen.
4. **Ageing of Manure:** The manure gets richer and less bulky with ageing.
5. **Manner of Making and Storage:** In making and storage losses are in various ways. (see ‘Losses in FYM).

► Losses during handling and storage of FYM:

(I) Losses during handling:

FYM consists of two original components the solid or dung and liquid or urine. Both the components contain N, P_2O_5 and K_2O the distribution of these nutrients in the dung and urine is shown in figure below:

Approximately half of N and K_2O is in the dung and the other half in urine. By contrast, nearly all of the P_2O_5 (96%) is in the solid portion. To conserve N, P_2O_5 and K_2O, it is most essential that both the parts of cattle manure are properly handled and stored.

i) Loss of liquid portion or urine

Under Indian conditions the floor of the cattle shed is usually un-cemented or Kachha. As such the urine passed by animals during night gets soaked into the Kachha floor. When the animals, particularly bullocks, are kept in the fields during the summer season, urine gets soaked into soil. But during remaining period cattle are kept in a covered shed and therefore the Kachha floor soaks the urine every day. Large quantities of nitrogen are thus lost through the formation of gaseous NH_3. The following reactions take place:

$$\underset{\textbf{Urea in urine}}{NH_2\,CO\,NH_2 + 2H_2O} \longrightarrow \underset{\textbf{Ammonium carbonate}}{(NH_4)_2CO_3}$$

$$(NH_4)_2\,CO_3 + 2H_2O \longrightarrow 2NH_4OH + H_2\,CO_3$$

$$NH_4OH \longrightarrow \underset{\text{Gaseous Ammonia}}{NH_3\uparrow + H_2O}$$

The smell of NH_3 in the cattle shed clearly indicates the loss of N.

No special efforts are made in India to collect the liquid portion of the manure.

ii) Loss of solid portion or dung

It is often said that 2/3 of the manure is either utilized for making cakes or is lost during grazing, the remaining manure is applied to the soil after collecting in heaps. Firstly, the most serious loss of dung is through cakes for burning or for use as fuel-Secondly, when milch animals go out for grazing, no efforts are made to collect the dung dropped by them, nor is this practicable, unless all milch animals are allowed to graze only in enclosed small size pastures.

(II) Loss during storage:

Mostly, cattle dung and waste from fodder are collected daily in the morning by the cultivators and put in manure heaps in an open space outside the village. The manure remains exposed to the sun and rain. During such type of storage, nutrients are lost in the following ways:

i) By leaching:

Losses by leaching will vary with the intensity of rainfall and the slope of land on which manure is heaped. About half of portion of N and P_2O_5 of FYM and nearly 90% of K are water soluble. These water soluble nutrients are liable to get washed off by rain water.

ii) By Volatilization:

During storage considerable amount of NH_3 is produced in the manure heap from

i) the decomposition of urea and other nitrogenous compounds of the urine and
ii) the much slower decomposition of the nitrogenous organic compounds of the dung. As the rotting proceeds, more and more quantity of ammonia is formed. This NH_3 combines with carbonic acid to form ammonium carbonate and bicarbonate. These ammonium compounds are unstable and gaseous NH_3 may be liberated as indicated below :

1. Urea and other nitrogenous compounds in urine and dung $\left.\right\} \xrightarrow[\text{decomposition}]{\text{microbial}} NH_3 \uparrow$
2. $2NH_3 + H_2CO_3 \longrightarrow (NH_4)_2\,CO_3$
3. $(NH_4)_2\,CO_3 + 2H_2O \longrightarrow 2NH_4\,OH + H_2CO_3$
4. $NH_4OH \longrightarrow NH_3 + H_2O \uparrow$

► Loss of NH_3 increases with

i) the increase in the concentration of ammonium carbonate
ii) increase in the temperature and
iii) air movement

► Improved Methods of Handling FYM:

It is practically impossible to check completely the losses of plant nutrients and organic matter during handling and storage of FYM. However, improved methods could be adopted to reduce such losses considerably.

Among these methods are described here under:

i) Trench method of preparing FYM
ii) Use of gobar gas-compost plant
iii) Proper field management of FYM
iv) Use of chemical preservatives

i) Trench method of preparing FYM :

This method has been recommended by Dr. C. N. Acharya. The manure preparation should be carried out in trenches, 20 to 25 ft. long, 5 to 6 ft. broad and 3 to 3.5 ft. deep. Cattle shed and portions of litter mixed with earth if available. When trench is completely filled up, say in about three months time.

ii) Use of gobar gas compost plant:

Methane gas is generated due to anaerobic fermentation of the most common organic materials such as cattle dung, grass, vegetable waste and human excreta. Gobar gas and manure both are useful on farms as well as in homes. A few advantages of this method are giving below:

1) The methane gas generated can be used for heating, lighting and motive power.
2) The methane gas can be used for running oil engines and generators
3) The manure which comes out from the plant after decomposition is quite rich in nutrients. N 1.5%, P_2O_5- 0.5%, K_2O- 2.0%
4) Gobar gas manure is extremely cheap and is made by locally available materials.

► **Superiority of gobar gas compost plant over traditional method:**

1000 Kg fresh dung manure obtained by

Sr. No.	Particulars	Traditional method	Gobar gas plant
1.	Loss of OM	500 Kg	270 Kg
2.	Loss of N	1.25 Kg	Nil
3.	Final manure	500 Kg	730 Kg
4.	% N	0.5%	1.5%
5.	Additional advantage	-	2000 C.ft. gas for cooking

iii) Proper field management of FYM:

Under field conditions, most of the cultivators unload FYM in small piles in the field before spreading. The manure is left in piles for a month or more before it is spread. Plant nutrients are lost through heating and drying. To derive maximum benefit from FYM, it is most essential that it should not be kept in small piles in the field before spreading, but it should be spread evenly and mixed with the soil immediately.

iv) Use of Chemical Preservatives:

Chemical preservatives are added to the FYM to decrease N losses. To be most effective, the preservatives are applied in the cattle yard to permit direct contact with the liquid portion of excreta or urine. This has to be done because the loss of N from urine starts immediately. The commonly used chemical preservatives are I) Gypsum and ii) Super phosphate.

The value of gypsum in preserving the N of manure has been known and it has been used for many years in foreign countries. The reaction of gypsum with ammonium carbonate (intermediate product from decomposition of urea present in urine) is :

$$(NH_4)_2\,CO_3 + CaSO_4 \longrightarrow CaCO_3 + (NH_4)_2\,SO_4$$

As long as the manure is moist, no loss of NH_3 will occur, but if the manure becomes dry, the chemical reaction is reversed and the loss of NH_3 may occur. As such, under Indian conditions, use of gypsum to decrease N losses, does not offer a practical solution.

Superphosphate has been extensively used as a manure preservative:

$$2CaSO_4 + Ca\,(H_2PO_4)_2 + 2\,(NH_4)_2\,CO_3 \longrightarrow Ca_3(PO_4)_2 +$$
$$2\,(NH_4)_2\,SO_4 + 2H_2O + 2CO_2$$

In this reaction, tricalcium phosphate is formed which does not react with ammonium sulphate, when manure becomes dry. As such, there is no loss of NH_3.

Since FYM becomes dry due to high temperature under Indian conditions, the use of superphosphate will be safely recommended as a preservative to decrease N losses.

Use of superphosphate as a chemical preservative will have three advantages

1. It will reduce loss of N as ammonium from FYM.
2. It will increase the percentage of P in manure thus making it a balanced one.
3. Since, tricalcium phosphate produced with the application of superphosphate to the FYM is in inorganic form, which is readily available to the plants, it will increase the efficiency of phosphorus.

It is recommended that one or two pounds of SSP should be applied per day per animal in the cattle shed where animal pass urine.

► **Supply of plant nutrients through FYM:**

On an average, FYM applied to various crops by the cultivators contains the following nutrients:

% N : 0.5 % P_2O_5 : 0.2 % K_2O : 0.5

Based on this analysis, an average dressing of 10 tones of FYM supplies about

50 Kg N
20 Kg P_2O_5
50 Kg K_2O

All of these quantities are not available to crops in the year of application, particularly N which is very slow acting. Only 1/3 of the N is likely to be useful to crops in the first year. About 2/3 of the phosphate may be effective and most of the potash will be available. This effect of FYM application on the yield of first crop is known as the direct effect of application. The remaining amount of plant food becomes available to the second, third and to a small extent to the fourth crop raised on the same piece of land. This phenomenon is known as the residual effect of FYM.

When FYM is applied every year, the crop yield goes on increasing due to direct plus residual effect on every succeeding crop. The beneficial effect is also known as cumulative effect.

4.4.2 Compost

Compost is composed of organic materials derived from plant and animal matter that has been decomposed largely through aerobic decomposition. The process of **composting** is simple and practiced by individuals in their homes, farmers on their land, and industrially by industries and cities. Composting is largely a bio-chemical process in which microorganisms both aerobic and anaerobic decompose organic residue and lower the C:N ratio. The final product of composting is well rotted manure known as compost.

Rural compost: Compost from farm litters, weeds, straw, leaves, husk, crop stubble, bhusa or straw, litter from cattle shed, waste fodder, etc. is called rural compost.

Urban compost: Compost from town refuse, night soil and street dustbin refuse, etc is called urban compost.

► Composition of urban compost:

Nitrogen	Phosphorus	**Potassium**
(%N)	(%P_2O_5)	(%K_2O)
1.4	1.0	1.4

Compared to FYM, urban compost prepared from waste and night soil is richer in fertilizer value.

► Mechanical Composting Plants:

Mechanical composting plants with capacities of 500 – 1000 tonnes per day of city garbage could be installed in big cities in India and 250 tonnes per day plants in the small towns. Refined mechanical compost contains generally about 40% mineral matter and 40% organic materials with organic carbon around 15%. The composition would vary depending on the feed but typically the nutrient content is about 0.7% N, 0.5% P_2O_5 and 0.4% K_2O. There are trace elements like Mn, B, Zn and Cu and the material has C: N ratio of nearly 15-17.

► Decomposition:

The animal excreta and litter are not suitable for direct use as manure, as most of its manurial ingredients are present in an unavailable form. However urine, if collected separately, can be used directly. The dung and litter have to be fermented or decomposed before they become fit for use. Hence, the material is usually stored in heaps or pits, where it is allowed to decompose. Under suitable conditions of water supply, air, temperature, food supply and reaction, the microorganisms decompose the material. The decomposition is partly aerobic and partly anaerobic. During decomposition the usual yellow or green colour of the litter is changed to brown and ultimately to dark brown or black colour; its structural form is converted into a colloidal, slimy more or less homogenous material, commonly known as humus. A well decomposed manure has a typical black colour and a loose friable condition. It does not show the presence of the original litter or dung.

► Factors controlling process of decomposition:

1) Food supply to micro-organisms and C: N ratio:

The suitable ratio of carbonaceous to nitrogenous materials is 40, if it is wider than this, the decomposition takes place very slowly and when narrow it is quick. C:N ratio of the dung of farm animals varies from 20 to 25, urine 1 to 2, poultry manure 5-10, litters-cereals straw 50, and legume refuse 20.

2) Moisture:

About 60-70 per cent moisture is considered to be the optimum requirement to start decomposition and with the advance in decomposition, it diminishes gradually being 30-40 per cent in the final product.

Excess of moisture prevents the temperature form rising high and retards decomposition, resulting in loss of a part of the soluble plant nutrients through leaching and drainage. Hence, in regions receiving heavy rainfall, it is advisable to store the manure or prepare compost in heaps above ground level.

In the absence of sufficient moisture, microbial activity ceases and the decomposition practically comes to an end.

3) Aeration:

Most of the microbial processes are oxidative and hence a free supply of oxygen is necessary.

Reasons for poor aeration in pit/heap

i) Excessive watering
ii) Compaction
iii) Use of large quantities of fine and green material as litters
iv) High and big heaps or deep pits.

4) Temperature:

Under the optimum conditions of air moisture and food supply, there is a rapid increase in the temperature in the manure heap or pit. The temperature usually rises to 50° –60°C and even to 70°C. The high temperature destroys weed seeds, worms, pathogenic bacteria, etc; which prevents fly breeding and makes the manure safe from hygienic point of view.

5) Reaction:

The microorganisms liberate certain organic acids during the course of decomposition, which, if allowed to accumulate, retards fermentation and some time even stop it completely. Hence, it is necessary to control the reaction of the material.

A neutral or slightly alkaline reaction between pH 7.0 and 7.5 is considered the most suitable. The addition of alkaline substances like lime and wood ashes neutralized the excess acidity. Since in the preparation of FYM it is a common practice to add household ashes to the manure pit, it is not necessary to add additional alkaline substances.

Heap V/S Pit decomposition:

	Heap		Pit
1.	Aerobic	1.	Anaerobic
2.	Turning is required	2.	No turning is required
3.	Physical disintegration	3.	Very little physical disintegration
4.	Quick oxidation	4.	Slow rate of decomposition
5.	High temp. 60° – 70°C. Kill weed seeds and pathogenic organisms	5.	High temp. is not developed but weed seeds and MO destroyed due to toxic products of decomposition.
6.	Loss of OM is about 50%	6.	Loss is about 25%
7.	If not properly protected, moisture loss is high. Watering is necessary	7.	Moisture loss is minimized. No watering is necessary
8.	If rainfall is high, leaching takes place	8.	Protected from leaching but anaerobic condition occurs.

4.4.3 Vermicompost

Vermicompost is the product of composting utilizing various species of worms, usually red wigglers, white worms, and earthworms to create a heterogeneous mixture of decomposing vegetable or food waste, bedding materials, and vermicast. Vermicast is also known as worm castings, worm humus or worm manure, is the end-product of the breakdown of organic matter by species of earthworm.[16]

The earthworm species (or **composting worms**) most often used are Red Wigglers (*Eisenia foetida* or *Eisenia andrei*), though European nightcrawlers (*Eisenia hortensis*) could also be used. Users refer to European nightcrawlers by a variety of other names, including *dendrobaenas*, *dendras*, and Belgian nightcrawlers. Containing water-soluble nutrients, vermicompost is a nutrient-rich organic fertilizer and soil conditioner.

Vermiculture means artificial rearing or cultivation of worms (Earthworms) and the technology is the scientific process of using them for the betterment of human beings. Vermicompost is the excreta of earthworm, which is rich in humus. Earthworms eat cow dung or farm yard manure along with other farm wastes and pass it through their body and in the process convert it into vermicompost. The municipal wastes; non-toxic solid and liquid waste of the industries and household garbage's can also be converted into vermicompost in the same manner. Earthworms not only convert garbage into valuable manure but keep the environment healthy. Conversion of garbage by earthworms into compost and the multiplication of earthworms are simple process and can be easily handled by the farmers.

► Method of preparation of Vermicompost Large/community Scale:

A thatched roof shed preferably open from all sides with unpaved (katcha) floor is erected in East-West direction length wise to protect the site from direct sunlight. A shed area of 12' x 12' is sufficient to accommodate three vermibeds of 10' x 3' each having 1' space in between for treatment of 9-12 quintals of waste in a cycle of 40-45 days. The length of shed can be increased/decreased depending upon the quantity of waste to be treated and availability of space. The height of thatched roof is kept at 8 feet from the centre and 6 feet from the sides. The base of the site is raised at least 6 inches above ground to protect it from flooding during the rains. The vermibeds are laid over the raised ground as per the procedure given below.

The site marked for vermibeds on the raised ground is watered and a 4"- 6" layer of any slowly biodegradable agricultural residue such as dried leaves/straw/sugarcane trash etc. is laid over it after soaking with water. This is followed by 1" layer of Vermicompost or farm yard manure.

Earthworms are released on each vermibed at the following rates :

For treatment of cowdung/agriwaste : 1.0 kg. per vermibed

For treatment of household garbage : 1.5 kg. per vermibed

The frequency and limits of loading the waste can vary as below depending upon the convenience of the user

Frequency	Loading
Daily	2" /bed/day
In Bulk	12-15"(3-4q/bed/cycle of 45 days)

The loaded waste is finally covered with a Jute Mat to protect earthworms from birds and insects. Water is sprinkled on the vermibeds daily according to requirement and season to keep them moist. The waste is turned upside down fortnightly without disturbing the basal layer (vermibed).The appearance of black granular crumbly powder on top of vermibeds indicate harvest stage of the compost. Watering is stopped for at least 5 days at this stage. The earthworms go down and the compost is collected from the top without disturbing the lower layers (vermibed). The first lot of vermicompost is ready for harvesting after 2-2 ½ months and the subsequent lots can be harvested after every 6 weeks of loading. The vermibed is loaded for the next treatment cycle.

► **Multiplication of worms in large scale:**

Prepare a mixture of cow dung and dried leaves in 1:1 proportion. Release earthworm @ 50 numbers/10 kg. Of mixture and mix dried grass/leaves or husk and keep it in shade. Sprinkle water over it time to time to maintain moisture level. By this process, earthworms multiply 300 times within one to two months. These earthworms can be used to prepare vermicompost.

► **Advantages of Vermicomposting:**

- Vermicompost is an ecofriendly natural fertilizer prepared from biodegradable organic wastes and is free from chemical inputs.
- It does not have any adverse effect on soil, plant and environment.
- It improves soil aeration, texture and tilth thereby reducing soil compaction.
- It improves water retention capacity of soil because of its high organic matter content.
- It promotes better root growth and nutrient absorption.
- It improves nutrient status of soil-both macro-nutrients and micro-nutrients.

► **Precautions during vermicomposting:**

- Vermicompost pit should be protected from direct sun light.
- To maintain moisture level, spray water on the pit as an when required.
- Protect the worms from ant, rat and bird

4.4.4 Night Soil

Night soil is manure prepared from human excrement *i.e.* solid and liquid.

Night soil is richer in N, P_2O_5 and K_2O as compared to FYM or compost. On oven dry basis, it has an average chemical composition of:

N%	P_2O_5%	K_2O%
5.5	4.0	2.0

In India it is applied to a limited extent directly to the soil. Pits or trenches of 10 to 12 ft. long, 2 to 3 ft. wide and 9 inches to 1 foot deep are made. In these pits, night soil is deposited and covered over on top with layers of earth or Katchara. This is known as the Poudrette **System**. Since the material formed in the above trenches after they become dry, is known as **poudrette.**

► **Improved methods of handling night soil:**

Since night soil is important bulky organic manure, supplying a good deal of organic matter and plant nutrients to the soil, it is important that night soil is used by the following improved methods:

1. Night soil should be protected from flies and fly breeding should be controlled.
2. It should be stored in such a way that it does not pollute the supply of drinking water.
3. Pathogens, protozoa, cysts, worms and eggs should be destroyed before the night soil is applied to the land.
4. Attempts should be made to compost the night soil with other refuse in urban centers by municipal or town authorities and in rural areas by the farmer himself.

4.4.5 Sewage and Sludge

In the modern system of sanitation adopted in cities, water is used for the removal of human excreta and other wastes. This is called the sewage system of sanitation. In this system, there is a considerable dilution of the material in solution and in dispersion in fact, water is the main constituent of sewage, amounting often to 99.0%.

In general sewage has two components, namely

(i) Solid portion, technically known as sludge and
(ii) Liquid portion, commonly known as sewage water.

Both the components are used in increasing crop production as they contain plant nutrients. Both components of sewage as separated and are given a preliminary fermentation and oxidation treatments to reduce the bacterial contamination, the offensive smell and also to narrow down the C:N ratio of the solid portion.

(i) Sludges:

In the modern system of sewage utilization, solid portion or sludge is separated out to a considerable extent and given a preliminary treatment (i.e. fermentation and oxidation) before its use as manure. Such oxidized sludge is also called **activated sludge** which is of inoffensive smell and on dry weight basis contains up to 3 to 6 per cent N, about 2 per cent P_2O_5 and 1 per cent K_2O in a form that can become readily available when applied to soil.

(ii) Sewage irrigation:

When raw sewage is treated to remove the solid portion or sludge the water, technically known as **treated effluent**, is used for irrigation purpose. Such a system of irrigation is known as sewage irrigation.

Thus, both the activated sludge and the effluent can be used with safely for manuring and irrigating all field crops except the vegetables which are eaten raw or uncooked.

4.4.6 Green Manuring

Practice of incorporating undecomposed green plant tissues into the soil for the purpose of improving physical structure as well as fertility of the soil.

In agriculture, a **green manure** is a type of cover crop grown primarily to add nutrients and organic matter to the soil. Typically, a green manure crop is grown for a specific period, and then plowed under and incorporated into the soil. Green manures usually perform multiple functions that include soil improvement and soil protection:

- Leguminous green manures such as clover and vetch contain nitrogen-fixing symbiotic bacteria in root nodules that fix atmospheric nitrogen in a form that plants can use.
- Green manures increase the percentage of organic matter (biomass) in the soil, thereby improving water retention, aeration, and other soil characteristics.
- The root systems of some varieties of green manure grow deep in the soil and bring up nutrient resources unavailable to shallower-rooted crops.
- Common cover crop functions of weed suppression and prevention of soil erosion and compaction are often also taken into account when selecting and using green manures.
- Some green manure crops, when allowed to flower, provide forage for pollinating insects.

Historically, the practice of green manuring can be traced back to the fallow cycle of crop rotation, which was used to allow soils to recover.

►Types of green manuring:

Broadly two types of green manuring can be differentiated.

i) Green manuring *in situ* and
ii) Green leaf manuring

i) Green manuring in situ:

In this system green manure crops are grown and buried in the same field, either as a pure crop or as intercrop with the main crop. The most common green manure crops grown under this system are Sannhemp, dhaincha and guar.

ii) Green leaf manuring:

Green leaf manuring refers to turning into the soil green leaves and tender green twigs collected from shrubs and trees grown on bunds, waste lands and nearby forest areas. The common shrubs and trees used are Glyricidia, Sesbania (wild dhaincha), Karanj, etc.

The former system is followed in northern India, while the latter is common in eastern and central India.

► Advantages of Green Manuring:

1. It adds organic matter to the soil. This stimulates the activity of soil micro-organisms.
2. The green manure crops return to the upper top soil, plant nutrients taken up by the crop from deeper layers.
3. It improves the structure of the soil.
4. It facilitates the penetration of rain water thus decreasing run off and erosion.
5. The green manure crops hold plant nutrients that would otherwise be lost by leaching.
6. When leguminous plants, like sunnhemp and dhaincha are used as green manure crops, they add nitrogen to the soil for the succeeding crop.
7. It increases the availability of certain plant nutrients like phosphorus, calcium, potassium, magnesium and iron.

► Disadvantages of green manuring:

When the proper technique of green manuring is not followed or when weather conditions become unfavourable, the following disadvantages are likely to become evident.

1. Under rainfed conditions, it is feared that proper decomposition of the green manure crop and satisfactory germination of the succeeding crop may not take place, if sufficient rainfall is not received after burying the green manure crop. This particularly applies to the wheat regions of India.
2. Since green manuring for wheat means loss of kharif crop, the practice of green manuring may not be always economical. This applies to regions where irrigation facilities are available for raising kharif crop along with easy availability of fertilizers.
3. In case the main advantage of green manuring is to be derived from addition of nitrogen, the cost of growing green manure crops may be more than the cost of commercial nitrogenous fertilizers.
4. An increase of diseases, insects and nematodes is possible.
5. A risk is involved in obtaining a satisfactory stand and growth of the green manure crops, if sufficient rainfall is not available.

► Green manure crops:

Leguminous	**Non-leguminous**
1. Sannhemp	1. Bhang
2. Dhaincha	2. Jowar

3. Mung
4. Cowpea
5. Guar
6. Berseem

3. Maize
4. Sunflower

► Selection of Green manure crops *in situ*:

Certain green manure crops are suitable for certain parts of the country. Suitability and regional distribution of important green manure crops are given below:

Sannhemp: This is the most outstanding green manure crop. It is well suited to almost all parts of the country, provided that the area receives sufficient rainfall or has an assured irrigation. It is extensively used with sugarcane, potatoes, garden crops, second crop of paddy in South India and irrigated wheat in Northern India.

Dhaincha: It occupies the second place next to sannhemp for green manuring. It has the advantage of growing under adverse conditions of drought, water-logging, salinity and acidity. It is in wide use in Assam, West Bengal, Bihar and Chennai with sugarcane, Potatoes and paddy.

Guar: It is well suited in areas of low rainfall and poor fertility. It is the most common green manure crop in Rajasthan, North Gujarat and Punjab.

► Technique of Green Manuring *in situ*:

The maximum benefit from green manuring cannot be obtained without knowing :

(i) When the green manure crops should be grown,
(ii) When they should be buried in the soil and
(iii) How much times should be given between the burying of a green manure crop and the sowing of the next crop.

(i) Time of sowing:

The normal practice usually adopted is to begin sowing immediately after the first monsoon rains. Green manure crops usually can be sown/broadcast preferably giving some what higher seed rate.

(ii) Stage of burying green manure crop:

From the results of various experiments conducted on different green manure crops, it can be generalized that a green manure crop may be turned in soil at the stage of flowering. The majority of the green manure crops take about six to eight weeks from the time of sowing to attain the flowering stage. The basic principle which governs the proper stage of turning in the green manure crops, should aim at maximum succulent green matter at burying.

(iii) Time interval between burying of green manure crop and sowing of next crop.

Following two factors which affect the time interval between burring of green manure crop and sowing of next crop.

1. Weather conditions
2. Nature of the buried green material

In paddy tracts the weather is humid due to the high rainfall and high temperature. These favour rapid decomposition. If the green material to be buried is succulent there is no harm in transplanting paddy immediately after turning in the green manure crop. When the green manure crop is woody, sufficient time should be allowed for its proper decomposition before planting the paddy.

► Regions not suitable for green manuring:

The use of green manures in dry farming areas in arid and semiarid regions receiving less than 25 inches of annual rainfall is, as a rule, impracticable. In such areas, only one crop is raised, as soil moisture is limited. Such dry farming areas are located in Punjab, Maharashtra, Rajasthan, M.P. and Gujarat (Kutch and Saurashtra).

On very fertile soils in good physical condition, it is not advisable to use green manures as a part of the regular rotation.

In areas where *rabi* crops are raised on conserved soil moisture, due to lack of irrigation facilities, it is not practicable to adopt green manuring. If green manuring is followed in these areas, there is danger of incomplete decomposition of the green matter and as such less moisture for the succeeding crop.

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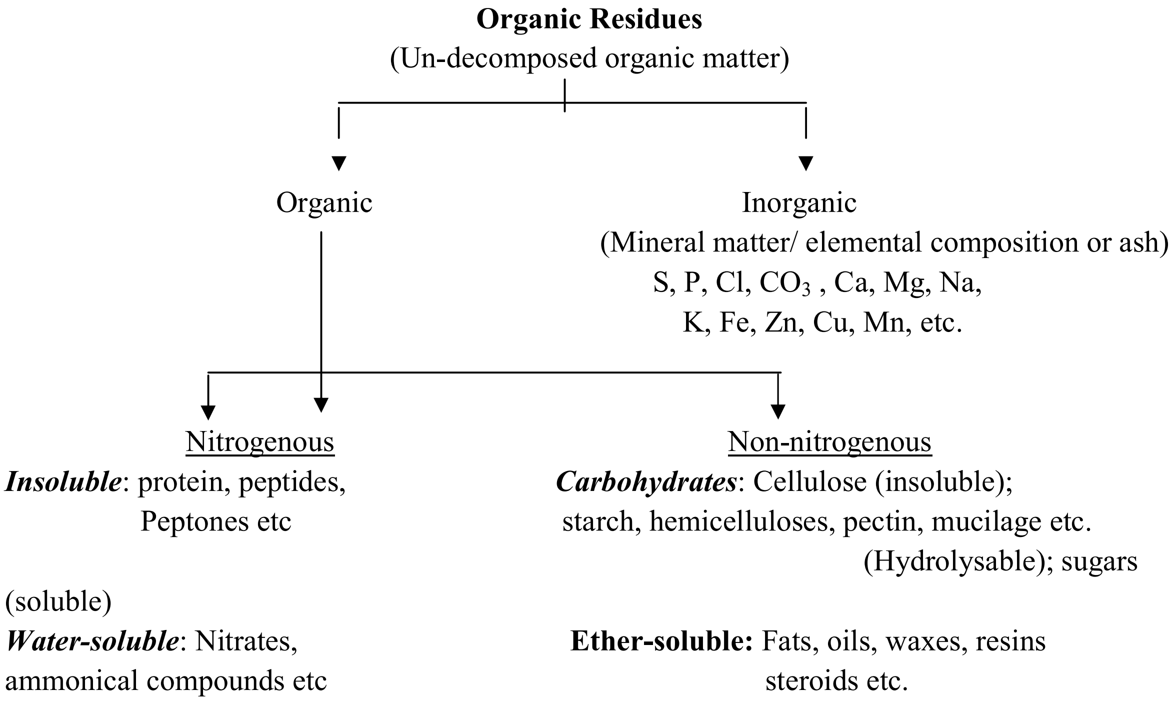
CHAPTER-5
TRANSFORMATION OF ORGANIC MANURES

Organic matter in the soil comes from the remains of plants and animals. As new organic matter is formed in the soil, a part of the old becomes mineralized. The original source of the soil organic matter is plant tissue. Under natural conditions, the tops and roots of trees, grasses and other plants annually supply large quantities of organic residues. Thus, higher plant tissue is the primary source of organic matter. Animals are usually considered secondary sources of organic matter. Various organic manures, that are added to the soil time to time, further add to the store of soil organic matter.

Composition of plant residues

Composition of organic residues have un-decomposed soil organic matter (mainly plant residues together with animal remains, i.e. animal excreta etc.) The moisture content of plant residues varies from 60 to 90% (average 78%) and 25% dry matter (solid). Plant tissues (organic residues) may be divided into 91) organic and (2) inorganic (elemental) composition. The compounds constituting the plant residues or un-decomposed soil organic matter is shown in the following diagram



Organic Residues
(Un-decomposed organic matter)

Organic

Inorganic
(Mineral matter/ elemental composition or ash)
S, P, Cl, CO_3 , Ca, Mg, Na,
K, Fe, Zn, Cu, Mn, etc.

Nitrogenous
Insoluble: protein, peptides,
Peptones etc

(soluble)
Water-soluble: Nitrates,
ammonical compounds etc

Non-nitrogenous
Carbohydrates: Cellulose (insoluble);
starch, hemicelluloses, pectin, mucilage etc.
(Hydrolysable); sugars

Ether-soluble: Fats, oils, waxes, resins
steroids etc.

Miscellaneous: Lignin, tanin, essential oils, organic acids

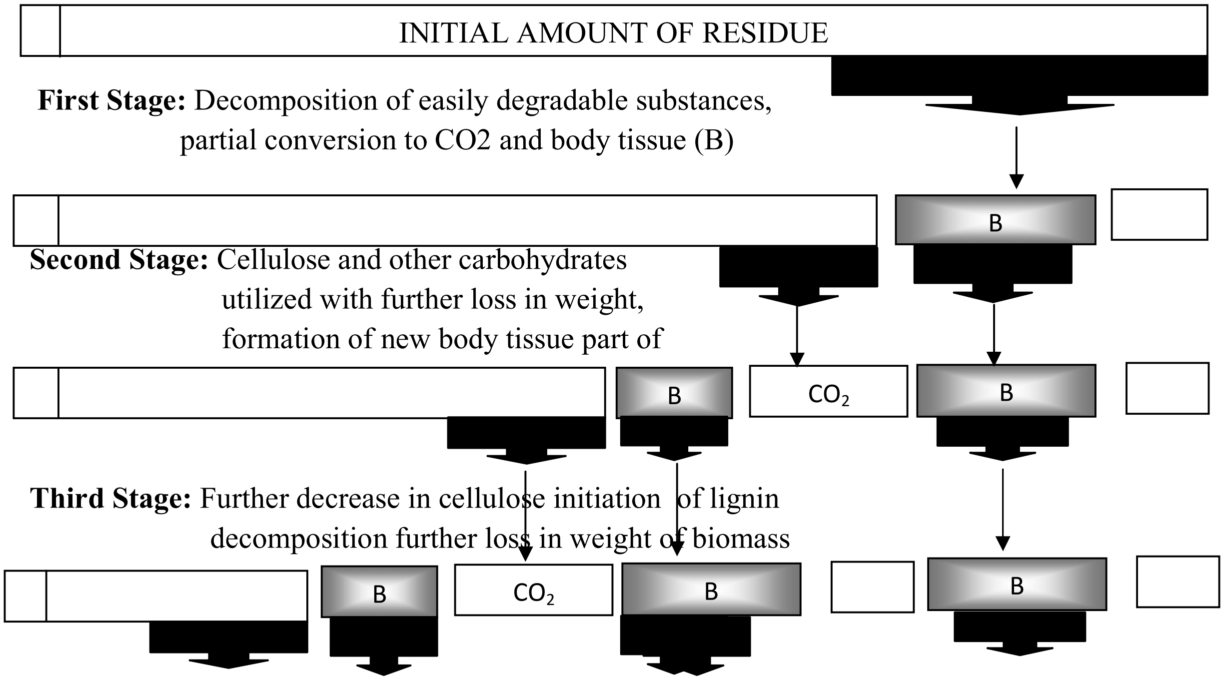
5.1 Transformation reaction of organic manures in soil

The organic materials incorporated in the soil do not remain as such very long. They are at once attacked by a great variety of microorganisms, worms and insects present in the soil especially if the soil is moist. The microorganism for obtaining their food, break up the various constituents of which the organic residues are composed, and convert them into new substances, some of which are very simple in composition and others highly complex. The whole of the organic residues is not decomposed all at once or as a whole. Some of the constituents are decomposed very rapidly, some less readily, and others very slowly.

A tentative scheme for the different stages of microbial decomposition of organic residues are shown in fig-1.

It is evident that different constituents of organic residues decompose at different rates. Simple sugars, amino acids, most proteins and certain polysaccharides decompose very quickly and can be completely utilized within a very short period. Large macro-molecules which make up the bulk of plant residues must first be broken down into simpler forms before they can be utilized further for energy and cell synthesis. This process is carried out by certain specific enzymes excreted by microorganisms.

The utilization of residue componenets and their brokendown products (sugar, aminoacids, phenolic compounds and others) leads to the production of microbial cells, which are further degrades following death of organisms.



First Stage: Decomposition of easily degradable substances, partial conversion to CO2 and body tissue (B)

Second Stage: Cellulose and other carbohydrates utilized with further loss in weight, formation of new body tissue part of

Third Stage: Further decrease in cellulose initiation of lignin decomposition further loss in weight of biomass

Fourth Stage: Further cycling. For plant residue about one-third of the carbon will remain in the soil at the end of the growing season.

Fig-1: Stage of decomposition of organic residues

5.2 Importance of C:N ratio in rate of decomposition

The ratio of the weight of organic carbon (C) to the weight of total nitrogen (N) in a soil (or organic material), is known as C: N ratio. When fresh plant residues are added to the soil, they are rich in carbon and poor in nitrogen. The content of carbohydrates is high. This results in wide carbon-nitrogen ratio which may be 40 to 1. Upon decomposition the organic matter of soils changes to humus and have an approximate C: N ratio of 10:1.

The ratio of carbon to nitrogen in the arable (cultivated) soils commonly ranges from 8:1 to 15:1. The carbon-nitrogen ratio in plant material is variable, ranging from 20:1 to 30:1. Low ratios of carbon to nitrogen (10:1) in soil organic matter generally indicate an average stage of decomposition and resistance to further microbiological decomposition. A wide ratio of C: N (35:1) indicates little or no decomposition, susceptibility to further and rapid decomposition and slow nitrification.

► **Significance of C:N Ratio**

(1) Keen competition for available nitrogen when organic residues (with high C: N ratio) are added to soils. When organic residues with a wide C/N ratio (50:1) are incorporated in the soil, decomposition quickly occurs. Carbon dioxide is produced in large quantities. Under these conditions, nitrate-nitrogen disappears from the soil because of the instant microbial demand for this element to build up their tissues. And for the time being, little (or no) nitrogen is an available to plants. As decomposition occurs, the C/N ratio of the plant material decrease since carbon is being lost and nitrogen conserved. Nitrates-N again appear in quantity in the soil, thus, increases plant growth.

(2) *Consistency of C: N Ratio*. As the decomposition processes continue, both carbon and nitrogen are now subject to loss the carbon as carbon dioxide and the nitrogen as nitrates which are leached or absorbed by plants. At a point carbon-nitrogen ratio, becomes more or less constant, generally stabilizes at 10:1 or 12:1.

5.3 Integrated Nutrient Management (INM)

Modern agricultural production practices have emphasized the wide spread us of fertilizer and this approach has certainly increased grain yield in many countries in the last two decades. However, long-term use of chemical fertilizers also led to a decline in crop yields and soil fertility in the intensive cropping system. There is evidence that over fertilization has increased the concentration of many plant nutrients in both surface and ground water, which has created a potential health hazards.

In order to safeguard the environmental from further degradation and to maintain the purity of air, water and food. We should opt for less use of chemicals and shift from chemical to ecological agriculture to fertilize our fields. Hence, in recent years integrated use of inorganic fertilizers and organic manures has become important for higher agricultural production. No single source of plant nutrients. be it chemical fertilizer, organic manure, crop residue, green manure or even biofertilizers can meet the entire nutrient needs of crops in present day agriculture.

Farmyard manure and compost are limited in supply and have low nutrient content. However, green manure is a potential source of organic manure. The use of plant residues and biofertilizers is also being advocated in nutrient management. Organic manure, however, can not used as a substitute for chemical fertilizer but only as a component in the whole nutrient management system as the nutrient needs essential for higher yield nutrient management system as the nutrient needs essential for higher yield goal can not be met exclusively through them particularly for reasons of insufficiency.

Therefore, to maintain production at high levels, resource has to be made to the application of fertilizer and manure not only provide essential plant nutrients but also build up the organic carbon and improve soil physical as well as biological conditions. As " sustainable plant nutrition to increase food production" has been identified as one of the priorities directly linked to land and water management resources in relation to environment. Therefore, for the sustained growth, the soil health is very important to achieve national food security targets. In addition to this, for maximizing fertilizer use efficiency and ensure a balanced and optimum supply of essential plant nutrients, INMs has got special emphasizes in present day of agriculture.

The concept of integrated nutrient management (INM) is the maintenance of soil fertility and health, sustaining agricultural productivity and improving farmers' profitability through the judicious and efficient use of mineral fertilizers together with organic manures industrial/farm wastes and biofertilizers. Thus, the objectives of INM are to ensure efficient and judicious use of all the major sources of plant nutrients in an integrated manner so as to get maximum economic yield from a specific cropping system.

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CHAPTER-6
CHEMICAL FERTILIZERS

"Fertilizer may be defined as materials having definite chemical composition with a higher analytical value and capable of supplying plant nutrients in available forms."

6.1 : Characteristics of fertilizer

Usually fertilizers are inorganic in nature and most of them are the products of different industries. Only exception to the inorganic nature. Urea and $CaCN_2$ (calcium cynamide) and solid organic nitrogenous fertilizers. Required in less quantity concentrated and cheaper. Nutrients are readily available. Very less residual effect. Salt effect is high. Adverse effects are observed when not applied in time and in proper proportion.

Complete Fertilizer: Complete fertilizer is referred to a fertilizer material which contains all three major nutrients, N, P and K.

Incomplete Fertilizers: This fertilizer is referred to a fertilizer material which lacks anyone of three major nutrient elements.

Straight Fertilizer: Straight fertilizers may be defined as chemical fertilizers which contain only one primary or major nutrient element. e.g. ammonium sulphate,$(NH_4)_2SO_4$, Urea$(CO(NH_2)_2)$.

Mixed or Complex fertilizer: This fertilizer may be defined as a fertilizer material which contains more than one primary or major nutrient elements produced by the process of chemical reactions.

There are generally three types of chemical fertilizers available in the market namely nitrogenous, phosphatic and potassic fertilizers. These types of fertilizers are mostly used by the Indian farmers for the crop cultivation. The most important nitrpgenous, phosphatic and potassic fertilizers used by the farmers are ammonium sulphate, urea as N sources, superphosphate and rockphosphate as P sources and muriate of potash as K sources. Sometimes micronutrient fertilizers like $ZnSO_4$ as Zn, Borax as B-sources etc. are used by the farmers.

6.2 Nitrogenous Fertilizers

Nitrogen is present in soil as (i) Organic form and (ii) inorganic form. Inorganic form includes ammonical (NH_4^+), Nitrite (NO_2^-) and Nitrate (NO_3^-). Plant absorbs N in the form of NO^-_3 and NH^+_4 forms by paddy in early stages. Nitrogen in NH^+_4 form goes on exchange complex on clay and organic colloids and hence, this part is not lost due to leaching, while NO^-_3 is lost due to leaching as it does not go on exchange complex under neutral to higher pH values of soil. But it goes on exchange under highly acidic conditions. The nitrate fertilizers are hygroscopic in nature, it is for this reason, nitrate fertilizers are not commonly used even though plant absorbs N as NO^-_3. Therefore, organic form (urea) and fertilizers of NH_4 form like ammonium sulphate are widely used.

Most of Indian soils are low in N and the requirement of N by crop is throughout its growing period, therefore N should be applied in such a way that plant gets it throughout its life period. It becomes absolutely necessary to apply nitrogenous fertilizers to every soil and crop. For this, the total quantity of nitrogenous fertilizers requirement is more compared to fertilizers of other nutrients.

Commercial Nitrogenous Fertilizers: Commercial nitrogenous fertilizers are those fertilizers that are sold for their nitrogen content and are manufactured on a commercial scale.

6.2.1 Classification of Nitrogenous Fertilizers:

Nitrogenous fertilizers may be classified into four groups on the basis of the chemical form in which nitrogen is combined with other elements with a fertilizer.

Nitrogenous Fertilizers

- Nitrate Fertilizers
- Ammonical Fertilizers
- Nitrate and Ammonical Fertilizers
- Amide Fertilizers

1) Nitrate Fertilizers:

Nitrogen is combined as NO_3^- with other elements. Such fertilizers are

i) Sodium nitrate or Chilean nitrate ($NaNO_3$) – 16% N

ii) Calcium nitrate [$Ca(NO_3)_2$] – 15.5% N.

Out of these, sodium nitrate is an imported commercial fertilizer.

2) Ammonical Fertilizers:-

In these fertilizers, nitrogen is combined in ammonical (NH_4) form with other elements. Such fertilizers are

i) Ammonium sulphate [$(NH_4)_2 SO_4$] – 20% N

ii) Ammonium Chloride (NH_4Cl) - 24 to 26% N

iii) Anhydrous ammonia - 82% N

3) Nitrate and ammonical Fertilizers:

These fertilizers contain nitrogen in the form of both nitrate and ammonical. Such fertilizers are

i) Ammonium nitrate ($NH_4 NO_3$) - 33 to 34% N

ii) Calcium ammonium nitrate - 26% N

iii) Ammonium sulphate nitrate - 26% N

4) Amide fertilizers:

These fertilizers contain nitrogen in amide or cynamide form. Such fertilizers are

i) Urea [$CO(NH_2)_2$]– 46% N

ii) Calcium cynamide ($CaCN_2$) – 21% N

6.2.2 General Properties of Nitrogenous Fertilizers:

1) Nitrate fertilizers:

Most of the field crops except paddy in early stages of their growth, take up nitrogen in nitrate form as such,

i) Nitrate fertilizers are readily absorbed and utilized by these crops. Nitrate fertilizers are very often used as top and side dressings.

ii) The great mobility of the nitrate ion in the soil has the advantage that, even by broadcasting the fertilizer on the surface of the soil, the nitrogen reaches the root zone quickly.

iii) On the other hand, there is also the increased danger of leaching of these fertilizers. On dry soils, nitrate fertilizers are superior to the other forms of nitrogenous fertilizers.

iv) All nitrate fertilizers are basic in their residual effect on the soils and their continued use may play a significant role in reducing soil acidity. Sodium nitrate, for example, has a potential basicity of 29 pounds of calcium carbonate per 100 pounds of fertilizer material.

2) Ammonical Fertilizers:

i) Ammonical fertilizers are water soluble.

ii) It is less rapidly used by plant than NO^-_3, as it is to be changed to NO^-_3 before use by crop.

iii) It is resistant to lost due to leaching as being cation goes on exchange complex.

iv) Any fertilizers which contain N as NH^+_4 or which is changed as NH^+_4 produced acidity in soil due to production of HNO_3.

v) Ammonium (NH^+_4) of fertilizer goes on exchange complex, used by crop like paddy.

vi) Used by microorganisms nitrified to NO_3 and lost due to volatilization from soil.

3) Nitrate and Ammonical Fertilizers:

i) Fertilizers of this group are soluble in water.

ii) Nitrate part can readily be used by crop.

iii) NH^+_4 can go on exchange and hence, this is best type but did not over take ammonium sulphate and urea, as they are hygroscopic in nature.

iv) They are acidic in their residual effect on soil

4) Amide Fertilizes:

i) Fertilizers of this group are readily soluble in water. They are easily decomposed by microorganisms due to presence of oxidisable carbon.

ii) They are quickly changed to NH^+_4 then in to NO^-_3.

6.2.3 Manufacturing process of ammonium sulphate and urea:

Most of the nitrogenous fertilizes like ammonium sulphate, urea, ammonium nitrate, ammonium sulphate nitrate and even DAP are manufactured by using Anhydrous Ammonia gas (NH_3) as one of the important compound. Most of the commercial NH_3 is prepared by Haber's process by the fixation of atmospheric N by means of H_2.

The reaction is:

$$N_2 + 3H_2 \xrightarrow[\substack{\text{at } 550^\circ\text{C temp} \\ \text{Fe and Mo as catalysts}}]{\text{200 atm. Pressure}} 2NH_3 + 24.4 \text{ KCal}$$

Ammonia can also be obtained from natural gas, coal gas and naphtha. Therefore, cost of fertilizer production in fertilizer factory installed near a petrochemical will be low.

The NH_3 gives ammonium sulphate with sulphuric acid, NH_4Cl with HCl; NH_4NO_3 with HNO_3; urea with CO_2; MAP and DAP with H_3PO_4. Thus, NH_3 is chief compound for most of the nitrogenous fertilizers.

i) Preparation of Ammonium sulphate (A/S) :-

It is prepared by

(a) reacting NH_3 with H_2SO_4

(b) gypsum process

(c) by-product of coal and steel industries.

a) **NH_3 with H_2SO_4** :- NH_3 is reacted with H_2SO_4 giving A/S. The liquid is crystallized and crystals of A/S are obtained.

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$

Since the sulphur used in sulphuric acid is to be imported, the source of H_2SO_4 becomes costlier and hence, gypsum a cheaper source of sulphur is used in gypsum process.

b) Gypsum process: The main raw materials required in gypsum process is NH_3, pulverized gypsum, CO_2 and water. NH_3 is obtained by Haber's process. This NH_3 when reacts with CO_2, gives $(NH_4)_2 CO_3$. The ground gypsum when reacts with $(NH_4)_2 CO_3$ solution gives $(NH_4)_2 SO_4$ and $CaCO_3$. The reactions are :

$N_2 + 3H_2 \rightarrow 2NH_3$

$2NH_3 + H_2O + CO_2 \longrightarrow (NH_4)_2 CO_3$

$(NH_4)_2 CO_3 + CaSO_4 \longrightarrow (NH_4)_2 SO_4 + CaCO_3$

ii) Preparation of Urea :-

The main principle involved in the process of manufacture is combining pure ammonia with pure CO_2 and removing one molecule of H_2O from the resulting NH_4CO_3 to form Urea. The CO_2 and NH_3 are allowed to react in the liquid phase under greatly elevated pressure and temperature in presence of suitable catalysts and this process requires highly specialized equipment. The CO_2 and NH_3 are compressed and heated as they enter the converter where urea is formed. A large excess of NH_3 is used in order to increase the conversion rate.

Urea is manufactured by reacting anhydrous ammonia with CO_2 under higher pressure in presence of suitable catalyst. The intermediate unstable product ammonium carbamate is decomposed to urea :

$N_2+3H_2 \rightarrow 2NH_3$

$2NH_3+CO_2 \xrightarrow[30 \text{ atm}]{} NH_2COONH_4$

(Ammo. Carbomate, Unstable intermediate product)

The unreacted NH_3 and CO_2 are removed by means of an evaporator still and are then recycled. The urea solution is pumped to the crystalizer where cooling and crystallization take place. The urea crystals are centrifuged and dried. This unstable intermediate product is decmposed and urea is recovered. The urea solution is then concentrated to 99 per cent and is sprayed into a chamber where urea crystals are formed.

$NH_2COONH_4 \longrightarrow NH_2 CONH_2 + H_2O$

(Ammo. Carbomate) (Urea, white crystalline substance)

During the preparation of urea, biuret is formed which is harmful. This biuret is formed when two molecules of urea are reacted eliminating NH_3.

$NH_2.CO.N (H_2 + H.N) HCO.NH_2 = NH_2 CO. NH.CO NH_2 + NH_3$

Urea Urea Biuret

In urea biuret should not be more than 1.5%.

Reactions of urea in soil

After application of urea in soil, it undergoes enzymatic hydrolysis mediated by Urease enzyme to produce an unstable compound designated as ammonium carbamate.

$NH_2\text{- } CO\text{- } NH_2 + H_2O \xrightarrow{\text{Urease Enzyme}} NH_2COONH_4$

(Urea) (Water) (Ammo. Carbamate)

$NH_2COONH_4 \longrightarrow NH_3 + CO_2$

(Ammo. Carbamate) (Ammonia) (Carbon dioxide)

This NH_3 is converted to NH_4^+ ions by accepting one proton (H^+) from proton donor and subsequently forms of NH_4OH or any other NH compound depending upon the nature of the donor. Then after ammonical-N (NH_4^+) form undergoes nitrification so as to produce nitrite and nitrates subsequently which is available for the plant growth.

Now a days urea is used as fertilizer more compared to other nitrogenous fertilizers due to the following reasons:

a) Higher N content (44 to 46 per cent).
b) Good physical conditions.
c) Less acidic in residual effect compared to A/S.
d) Less cost per unit of N in production, storage and transport.
e) Lack of corrosiveness.
f) Suitable for foliar application, and
g) It is having of equal agronomical value compared to other nitrogenous fertilizers.

Slow release N fertilizers

Slow-release fertilizers are excellent alternatives to soluble fertilizers. Because nutrients are released at a slower rate throughout the season, plants are able to take up most of the nutrients without waste by leaching. A slow-release fertilizer is more convenient, since less frequent application is required. Fertilizer burn is not a problem with slow-release fertilizers even at high rates of application; however, it is still important to follow application recommendations. Slow-release fertilizers may be more expensive than soluble types, but their benefits outweigh their disadvantages.

Slow-release fertilizers are generally categorized into one of several groups based on the process by which the nutrients are released. Application rates vary with the different types and brands, with recommendations listed on the fertilizer label.

Pelletized:

One type of slow-release fertilizer consists of relatively insoluble nutrients in pelletized form. As the pellet size is increased, the time it takes for the fertilizer to breakdown by microbial action is also increased.

Chemically Altered:

A fertilizer may be chemically altered to render a portion of it water insoluble. For instance, urea is chemically modified to make **Ureaform (ureaformaldehyde)** -- a fertilizer that is 38 percent nitrogen, 70 percent of which is water-insoluble. This percentage is often listed on fertilizer labels as the Percent W.I.N., or the percent of water-insoluble nitrogen. This form of nitrogen is released gradually by microbial activity in the soil. Because microbial activity is greatly affected by soil temperature, pH, aeration, and texture, these variables can affect the release of nitrogen from Ureaform. For example, there will be less fertilizer breakdown in acid soils with poor aeration -- an environment unfavorable to soil microorganisms.

IBDU (isobutylidene diurea) is similar to Ureaform, but contains 32 percent nitrogen, 90 percent of which is insoluble. However, IBDU is less dependent on microbial activity than

Ureaform. Nitrogen is released when soil moisture is adequate. Breakdown is increased in acid soils.

Coated fertilisers

Controlled- or slow-release fertilizers are broadly divided into uncoated and coated products. Uncoated products rely on inherent physical characteristics, such as low solubility, for their slow release. Coated products mostly consist of quick-release N sources surrounded by a barrier that prevents the N from releasing rapidly into the environment.

Few examples of coated N fertilizers:

Neem coated Urea is prepared by mixing Neem oil with Urea granules before application. As per the Fertilizer Control Order (1985) amendment, neem oil @ 0.350 kg is required to coat one tonne of urea fertilizer.

Sulfur-coated urea (SCU), which is manufactured by coating hot urea with molten sulfur and sealing with a polyethylene oil or a microcrystalline wax.

6.3 Phosphatic Fertilizers

The phosphorus (P) nutrient of all phosphatic fertilizers is expressed as P_2O_5. In soil, P is present as (i) Organic P and (ii) Inorganic P. The forms of inorganic P are $H_2PO^{-}_4$; HPO^{-2}_4; and PO^{-3}_4; Out of which, H_2PO_4 and HPO_4 ions are available to plant. In soil, water in is changed to HPO^{-2}_4 and PO^{-3}_4 ions with increase in pH.

$$H_2PO^{-}_4 \xrightarrow{-H^+} HPO^{-2}_4 \xrightarrow{-H^+} PO^{-3}_4$$

Firstly, the P in soil is immobile or slightly mobile around one cm diameter and therefore, they should be applied in root zone.

Secondly, the requirement of P is maximum in the initial crop growth stages. The crop takes up 2/3 of total P when the crop gains 1/3 of total dry matter and hence, the entire quantity should be applied at one time that is at the time of sowing as a basal dose.

Thirdly, water soluble-P is changed to insoluble form as Fe and Al –PO_4 (Phosphate) under acidic and calcium phosphate in calcareous or high Ca content or in higher pH soils and hence, there is no danger for the loss due to leaching and volatilization. The applied P remain as in available form in less quantity while greater quantity is changed to insoluble form.

Chemistry of P compounds:

Phosphorus when burns gives P_2O_5 and with water, it forms HPO3 (Metapohosphoric acid) and H_3PO_4 (orthophosphoric acid) $P_2O_5 + H_2O=2\ HPO_3$; $HPO_3 + H_2O = H_3PO_4$. These H_3PO_4 is important in agriculture as it forms three compounds (salts) by replacing one hydrogen every time.

$$H_3PO_4 \xrightarrow{-H^+} H_2PO^{-}_4 \xrightarrow{-H^+} HPO^{-2}_4 \longrightarrow PO^{-3}_4$$

When H_3PO_4 combines with calcium, it forms three salts.

They are – i) $Ca(H_2PO_4)_2$ Monocalcium phosphate
ii) $CaHPO^{-}_4$ Dicalcium phosophate
iii) $Ca_3\ (PO_4)^{-}_2$ Tricalcium phosophate

6.3.1 Classification of phosphatic fertilizers:

The phosphatic fertilizers are classified into three classes depending on the form in which H_3PO_4 combined with Ca.

Phosphatic fertilizers

I	II	III
Water soluble P containing	**Citric acid soluble P containing**	**Citrate and water insoluble-P containing**
Super phosphate (SSP) (16 to18% P_2O_5)	Basic slags (14 to 18% P_2O_5)	Rock phosphate (20 to 40% P_2O_5)
Double Super phosphate (DSP) (32 to 36% P_2O_5)	Dicalcium phosphate (34 to 39% P_2O_5)	Raw bone meal (20 to 25% P_2O_5 and 3 to 4% N)
Triple Super phosphate (TSP) (46 to 48% P_2O_5)	Rhenania phosphate (23 to 26% P_2O_5)	
Mono ammonium phosphate (20% N and 20% P_2O_5)	Steamed bone meal (22% P_2O_5)	
Diammonium phosphate (18% N and 46% P_2O_5)	(Part of P_2O_5 soluble in citric acid)	

6.3.2 General Properties of Phosphatic Fertilizers:

i) Water soluble P containing fertilizer:

a) They contain water soluble-P as H_2PO_4 ion which can be absorbed quickly and available to plants when root system is not fully developed.

b) Water soluble-P is rapidly transformed into water insoluble form in soil and hence there is no danger of loss due to leaching.

c) These fertilizers should be used on slightly acidic, neutral to alkaline soils but not on acidic soils as the water soluble-P is changed to unavailable Fe and A1-PO_4.

d) These fertilizers are applied when a crop requires quick start and for short duration crops.

ii) Citric acid (1%) soluble P containing fertilizers:

a) They contain citrate soluble-P and hence this P is less available than water soluble-P.

b) They are suitable for moderately acid soils because it gets converted into water soluble form. They are basic in reaction and Ca content.

c) There are less chances of getting fixed by Fe and Al.

d) They are suitable for long term crops and where immediate and quick start to crops is not important.

iii) Citrate and water insoluble P fertilizers :

a) They are suitable for strongly acidic soils

b) They contain insoluble P and hence not available to crops

c) The P is available when ploughed with green manuring crop or organic residues.

d) They are used for long duration crops and in large quantity 500 to 1000 kg/ha

e) They are used where immediate effects are not important

6.3.3 Manufacturing of Phosphatic fertilizers:

i) Single super phosphate (SSP):

SSP is manufactured by mixing equal amounts of rock phosphate and concentrated H_2SO_4 (approximately 70%) and allowing to react for one minute in mechanical rotators. It is left for 12 hrs to harden and to cool down. It is then matured and after some weeks, it becomes ready for use. Due to free H_2SO_4 present in it, it is responsible for destroying gunny bags and hence first fill in polythene bags and then in gunny bags.

$Ca_3(PO_4)_2 + H_2SO_4 + 5H_2O = Ca(H_2PO_4)_2 . H_2O + 2CaSO_4 . 2H_2O$

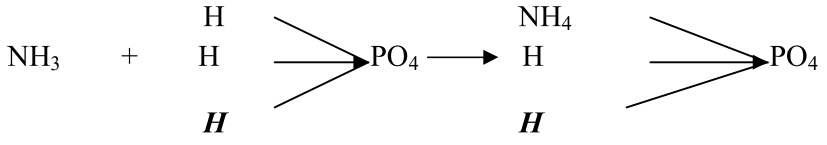
It contains two part by weight Ca $(H_2PO_4)_2$ monoalcium phosphate (16 to 18% water soluble-P) and three parts by weight gypsum. The formula of superphosphate is $Ca(H_2PO_4)_2 . H_2O$, $CaSO_4 . 2H_2O$. Superphosphate supplies P, Ca and S and due to gypsum, it improves physical conditions of soil when added to soil.

In double superphosphate, there is no separate process but gypsum is removed and when the P_2O_5 per cent of the content comes to 32 to 36, it is called double super phosphate.

In triple super phosphate, phosphoric acid is used instead of H_2SO_4 with calcium phosphate.

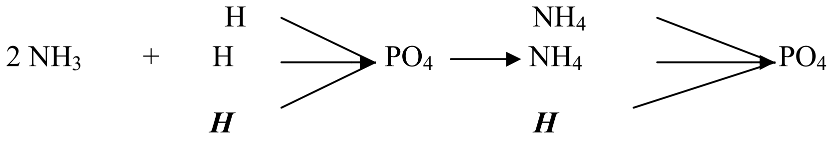
ii) Diammonium phosphate: (DAP) :

DAP or monoammonium phosphate is prepared by reacting phosphoric acid (H_3PO_4) with NH_3. In this if one H^+ ion of H_3PO_4 reacts with NH_3 if forms MAP ($NH_4H_2PO_4$) and NH_3 reacts with two H^+ ions of H_3PO_4 forms DAP [$(NH_4)_2 HPO_4$].



$$NH_3 + \left.\begin{matrix}H\\H\\H\end{matrix}\right\rangle PO_4 \longrightarrow \left.\begin{matrix}NH_4\\H\\H\end{matrix}\right\rangle PO_4$$

Mono ammonium phosphate
($NH_4 H_2PO_4$)



$$2\,NH_3 + \left.\begin{matrix}H\\H\\H\end{matrix}\right\rangle PO_4 \longrightarrow \left.\begin{matrix}NH_4\\NH_4\\H\end{matrix}\right\rangle PO_4$$

DAP $(NH_4)_2 HPO_4)$

6.4 Potassic Fertilizers

Potassium (K) is present in soil as:

i) Readily available forms as in soil solution and as exchangeable. These forms are available and plant absorbs these K forms as K^+ ion.
ii) Slowly available form as non-exchangeable i.e. fixed
iii) Relatively unavailable in the form of minerals (feldspars and micas etc.)

Firstly, the potash behaves partly like N and partly like P. From view point of the rate of absorption, it is required (absorbed) upto harvesting stage like N and like P, it becomes slowly available. Therefore, the entire quantity is applied at sowing time.

Secondly, potash being cation adsorbed on clay complex and hence leaching loss reduces. Leaching is greater in light soils than heavy textured soils. Therefore, like N, some time split application of K is desirable in sandy soil.

Thirdly, even though the soil contains enough potash or does not give response to crops, it becomes necessary to apply for the following reasons:

a) Maintaining K status of soil
b) For improving burning quality of tobacco
c) For neutralizing harmful effects of chloride in plant
d) For sugars or starch producing crops like potato, sweet potato, sugar cane, sugar beet, banana etc. for formation of sugar and starch.
e) For fibrous crops like sann, flex etc. to give strength to fibre
f) For the formation of pigments in crops like tomato, brinjal etc for quality purpose and it improves the luster and gives more colouration to the fruits of these crops by which more price can be fetched of the said products.

6.4.1 Classification of potassic fertilizers :

Potassic fertilizer

Fertilizer containing Chlorine .	**Fertilizer containing other than chlorine.**
Eg. KCl (Muriate of potash 58% K_2O). This is cheaper fertilizer and used extensively by cultivators for all crops except where chlorine is not desired in fertilizer	Eg. Sulphate of potash (K_2SO_4 48% K_2O) Potassium Nitrate (KNO_3 44% K_2O, 13% N) Sulphate of potash and magnesium (double salt of K and Mg, (Schoenite) K_2SO_4, $MgSO_4$ (25 to 30% K_2O)

Chemistry of K compounds:

Potassium is not found in free state in soil. As metal, it reacts with CO_2 forming K_2O and K_2O with H_2O gives KOH. For this reason, K in elemental form is not used as fertilizer. It must be combined with other element like chlorine or group of elements.

6.4.2 General Properties and manufacturing of Pottasic fertilizers:

1. Muriate of Potash (KCl):

It is commonly marketed as a commercial fertilizer in granular form. However, it is also available in powder form. It is easily soluble in water. On application to the soil, it ionizes to dissociate into K^+ and Cl ions. K^+ like NH_4^+ gets attached or absorbed on the soil complex. As such, though muriate of potash is readily soluble in water, it is not leached.

The KCl is commercially manufactured using any one of the minerals; 1. Sylvinite or sylvite and 2. Carnallite .

There are two main steps involved in the manufacture of this fertilizer.

1. Mining of the K mineral
2. Separation of the main ingredient and purifying.

After purification, the desired sized sylvinite / carnallite mineral is dissolved in water to get a pulp and the reagent is added to the pulp. The reagent will form a coating or film round the

NaCl molecules and this reagent added pulp is allowed to pass through a series of floatation cells in which air is introduced at the bottom in such a manner as to form a small bubble froth that attaches to NaCl. The commonly used reagents are (1) Sulphonated aliphatic alcohols of KCl and (2) 20% of mono-n-octadecyl- amines neutralized with acetic acid and a 0.5% solution of this is used for NaCl. Finally, the resultant product is Muriate of Potash.

It is found that at least 90% of the potassic fertilizers consumed is in the form of muriate of potash. It contains 48 to 62% K_2O and 35 to 47% Cl. The commercial product is either granular or powdery having white or red colour.

2. Potassium sulphate – K_2SO_4

This is manufactured from kainite (KCl. Mg SO4, $3H_2O$) or langbeinite (K_2SO_4, Mg SO_4), the latter being commonly used. The raw materials required are the mineral langbeinite and KCl.

$$K_2SO_4.MgSO_4 + 2\ KCl \text{ ------------ } 2\ K_2SO_4 + MgCl_2.$$

The $MgCl_2$ is rejected. The KCl is used in the form of a mother liquor obtained from KCl manufacturing process. The method is found to be efficient only in the presence of a proper ratio between K_2SO_4 and $MgSO_4$ of the raw material and to maintain a proper ratio, KCl or Kainite is added. The reactions are found to take place in different ways.

Langbeinite, ground to pass through a 200 mesh sieve and the mother liquor from the KCl process is mixed and then the salts are recycled with water and fresh quantity of langbeinite. The reactions are allowed to take place in interconnected tanks and the crystallized K_2SO_4 is separated out by means of centrifuge. The used K_2SO_4 is separated out by means of centrifuge. The wet K_2SO_4 is dried and conveyed to storage place. It contains 48% K_2O. Only limited quantities of K_2SO_4 are manufactured, as the cost of manufacture is more, but is preferred for those crops where quality is desired or where chlorine toxicity will result when K Cl is used.

6.5 Secondary and Micronutrient fertilizers

6.5.1 Secondary nutrients fertilizers:

The secondary plant nutrients are Ca, Mg and S. Out of these, three nutrients, Ca and Mg are added indirectly in soil through fertilizes and soil amendments. Soil contains Ca and Mg as exchangeable and as $CaCO_3$ and dolomite. Normally, it is not necessary apply Ca and Mg fertilizers in soils of India.

Formerly, the use of FYM, A/S and superphosphate sources of S were used and now their use is either restricted or their replacement by other fertilizers which are devoid of S. Therefore, sulphur now becomes necessary to apply in soil because of the following reasons:

i) A/S a source of S is replaced by urea
ii) Another source of S, superphosphate is replaced by DAP
iii) Use of KCl instead of K_2SO_4
iv) Decrease in the use of FYM and
v) Use of high yielding varieties which absorb more quantity of nutrients.

The soils deficient in sulphur are supplied with the sources of S like elemental S. Elemental S when applied to soil, it is changed to $SO_2 \longrightarrow SO_3$ and H_2SO_4. This H_2SO_4 with basic material of soil gives its sulphate salt. Plant absorbs S as SO^{-2}_4.

6.5.2 Micronutrient fertilizers:

The micro-nutrients are zinc (Zn), iron (Fe), copper (Cu), Manganese (Mn), Boron (B), Molybdenum (Mo) and Chlorine (Cl). These nutrients are present in available forms in soil in very small quantity and the requirement by crops is also less.

Application of micronutrient fertilizers now becomes necessary as their deficiencies are observed in soil. The deficiency of micronutrients was observed in soil because of the following reasons.

i) Due to increase in irrigation facility, the number of crops taken in an year are increased.
ii) Use of hybrid varieties which absorb more nutrients
iii) Intensive cultivation
iv) Reduction in the use of organic manures like FYM, which supply these nutrients,
v) Use of high analysis fertilizers which are devoid of these nutrients.

Out of these micronutrients, chlorine is not applied as its fertilizer because it is indirectly applied through irrigation water. Mo is required in very small quantity and is also present in sufficient in some of seeds and soils and hence generally its fertilizers are not used. Boron is found to be deficient in calcareous soil as it is changed to calcium borate which is insoluble and hence boron is applied as its fertilizers. All these nutrients are present as anions.

These four micronutrients are generally applied both soil and foliar as their sulphates at the time of deficiency. Now a days the micronutrient carriers which contain all two to three in one. It is not advisable to use such types of materials as the nutrients which are in sufficient in soil will reduce the availability of other nutrients. In fact, for micronutrient, only the deficient nutrient from soil test value should only be applied.

6.5.3 Micronutrient fertilizers and their contents

Zinc fertilizer:

Zinc sulphate ($ZnSO_4.7H_2O$) - 21%Zn or $ZnSO_4.H_2O$-33%Zn
Zinc-EDTA chelate -12%Zn
Zinc oxide ZnO -55% Zn

Iron fertilizers:

Ferrous sulphate - $FeSO_4.7H_2O$ -19% Fe
Ferrous ammonium sulphate $(NH_4)_2SO_4.FeSO_4.6H_2O$ - 16% Fe
Iron polyflavonoides -10%Fe
Fe-EDTA (Ethylenediamine tetraacetic acid) - 5-12 %Fe (Fe^{2+})
Fe-EDDHA (Ethylenediamine di(o-hydroxyphenyl) acetic acid- 6% Fe(Fe^{3+})

Copper fertilizer:

Copper sulphate($CuSO_4.5H_2O$) - 24% Cu
Copper sulphate($CuSO_4.H_2O$)- 35% Cu
Copper chelate Na_2Cu-EDTA -12-13%Cu

Manganese fertilizer:

Manganese sulphate ($MnSO_4.H_2O$) - 30.5% Mn
Manganese oxide (MnO) - 41-68% Mn

Manganese frits- 10 - 35% Mn
Mn-chelate -5-12% Mn

Boron fertilizer:

Sodium tetraborate or borax($Na_2B_4O_7.10H_2O$)-10.5B
Bodic acid(H_3BO_3)-17% B
Solubor($Na_2B_4O_7.5H_2O + Na_2B_{10}O_{16}.10H_2O$)- 19%B

Molybdenum fertilizer:

Sodium molybdate($Na_2MoO_4.2H_2O$) -40% Mo
Ammonium molybdate ($(NH_4)_6Mo_7O_{24}.4H_2O$)-54% Mo
Molybdenum oxide(MoO_3)-66% Mo

The micronutrients are soon changed to insoluble forms when they are added to soil and hence chelates are used as one of the sources. Chelates (meaning "Claw") is a compound in which metallic cation is bounded to an organic molecule. In chelates form, the cations are protected from reactions with inorganic constituents that would make them unavailable for uptake.

The common chelating agents are:

EDTA	:	Ethylene Diamine Tetra Acetic Acid
DTPA	:	Diethylene Triamine Penta Acetic Acid
HEDTA	:	Hydroxy Ethylenthylene diamine Triacetic Acid
NTA	:	Nitricotriacetic acid

6.6 Complex Fertilizers

Due to uneconomical and labour cost of using individual fertilizer, the fertilizer mixtures were prepared and they were used. These fertilizer mixtures were not homogenous, containing less quantity of N, P, K and many times inferior quality of material were used. For these difficulties, complex fertilizers have been prepared. These complex fertilizers contain the nutrients of grade mentioned, homogenous, granular and good physical conditions.

Complex Fertilizers:

Commercial complex fertilizers are those fertilizers which contain at least two or three or more of the primary essential nutrients. When it contains only two of the primary nutrients, it is designated as incomplete complex fertilizer. While those contain three nutrients are designated as complete complex fertilizers. At present, the complex fertilizers obtained by chemical reaction are more important than fertilizer mixtures. Complex fertilizers being manufactured in India are Nitrophosphate DAP and Ammonium phosphate sulphate **Characteristics of complex fertilizers:**

1. They usually have high content of plant nutrients more than 30 kg/100 kg of fertilizer. As such they are called **high analysis fertilizers.**
2. They usually have uniform grain size and good physical condition.
3. They supply N and P in available form in one operation. Nitrogen is present as NO^-_3 and NH^+_4 forms and P as water soluble form upto 50 to 90% of total P_2O_5.
4. They are cheaper compared to individual fertilizer on the basis of per Kg of nutrient.
5. Transport and distribution cost is reduced on the basis of per kg of nutrients.

Fertilizers grades: The grades of complex fertilizers are given below:

Sr. No.	N	P	K	Sr. No.	N	P	K
1	10	26	26	**8**	11	22	22
2	12	32	16	**9**	19	19	19
3	14	36	12	**10**	14	14	14
4	22	22	11	**11**	11	11	11
5	14	35	14	**12**	17	17	16
6	17	17	17	**13**	20	10	10
7	14	28	14	**14**	13	13	20

6.7 Mixed fertilizer:

A mixture of two or more straight fertilizer materials is referred to as fertilizer mixture. The term complete fertilizer refers to these fertilizers that contains three major (N, P and K) nutrients.

Advantages of fertilizer mixtures :

1) Less labour is required to apply a mixture than to apply its components separately.
2) Use of fertilizer mixture leads to balanced manuring.
3) The residual acidity of fertilizers can be effectively controlled by the use of proper quantity of lime in fertilizer mixture.
4) Micronutrients can be incorporated in fertilizer mixture.
5) Mixture have better physical condition.

Disadvantages of fertilizer mixtures:

1) Use does not permit individual nutrient application which oat specific growth stage of crop.
2) Unit cost of plant nutrients in mixtures is usually higher than those of straight fertilizers.
3) Farmers use mixtures without careful study of their needs.

Materials and methods of preparing fertilizer mixtures:

The type of grade of fertilizer mixture to be prepared should be decided. The straight fertilizers are chosen according to compatibility in mixture. The quantity of each fertilizer is calculated for the preparation of desired quantity of preparing fertilizer mixture. It happens that there is a gap in weight of fertilizers taken on the basis of nutrient content and the total weight of fertilizer mixture. The gap is filled by using **filler**. A filler is the make weight material added to a fertilizer mixture. The common fillers used are: sand, soil, ground coal, ash and other waste products. It is also necessary to add the **conditioners** to avoid caking. For this low grade organic materials like tobacco stem, peat, groundnut and paddy hulls are added at the rate of 100 lbs/ton of mixture. If the fertilizers used leave acidic residual effect when it is added in soil then liming materials like lime stone, dolomite etc. are added.

The fertilizer materials can be mixed without using special equipments. Mixing should be done on cement floor and it preferably on the date of application or a day before its application.

Incompatibility in fertilizer mixtures:

1. Fertilizers containing NH_3 should not be mixed with basically reactive fertilizers, otherwise there will be loss of N as NH_3.

2. All water soluble phosphatic fertilizers should not be mixed with those fertilizers that contain free lime, otherwise a portion of soluble phosphate is converted into an insoluble form.
3. Easily soluble and hygroscopic fertilizers tend to cake or form slums after mixing. Such fertilizers should be mixed shortly before use.

Considering the incompatibility, the chart is given below which can be used while preparing fertilizer mixture.

1	2	3	4	5	6	7	8	9	10	11	
√	√	X	X	*	√	√	√	X	√	√	1. Muriate of Potash
√	√	X	X	*	√	√	X	X	√	√	2.Sulphate of potash
X	X	√	√	*	X	*	*	√	√	√	3.Sulphate of ammonia
X	X	√	√	*	X	*	*	√	√	√	4.Calcium amm.nitrate
*	*	*	*	*	*	*	*	*	*	*	5.Sodium nitrate
√	√	X	X	*	√	*	X	X	X	*	6.Calcium cynamide
√	√	*	*	*	*	√	√	√	*	*	7.Urea
√	X	*	*	*	X	*	√	√	*	*	8.Superphosphate single or triple
X	X	√	√	*	X	*	√	√	√	√	9.Ammon.Phosphate
√	√	√	√	*	√	*	*	√	√	√	10.Basic slag
√	√	√	√	*	*	*	*	√	√	√	11.Calcium carbonate

Guide for mixing fertilizers

√	Fertilizer which can be mixed
*	Fertilizer which may be mixed shortly before use
X	Fertilizer which can not be mixed

Calculation of quantity of fertilizers to be used in mixture :

Example :- Prepare 600 kg of a 4-8-10 fertilizers mixture in which half the nitrogen is in ammonium sulphate (20 per cent N) and the other half divided between nitrate of soda (16 per cent N) and tankage (6 per cent N and 6 per cent P_2O_5). P_2O_5 and K_2O are to be added in the form of superphosphate (16 per cent P_2O_5) and muriate of potash (60 per cent K_2O) respectively.

In the present example, 4 Kg of nitrogen in every 100 Kg of mixture is supplied with
2 Kg N as ammonium sulphate ; 1 Kg N as nitrate of soda ; 1 Kg N as tankage

For N $= \frac{2 \times 100}{20}$ = ***10 Kg of ammonium sulphate***

N $= \frac{1 \times 100}{16}$ = 6.25 kg of nitrate of soda

N $= \frac{1 \times 100}{6}$ = 16.66 kg of tankage

Since, tankage contains nitrogen and phsophoric acid, 16.66 kg of tankage, mixed in every 100 Kg of fertilizer.

Mixture wil also add $\frac{16.66 \times 6}{100}$ = 1 Kg of P_2O_5.

This means that out of 8 Kg of P_2O_5, 1 Kg is supplied through tankage and the remaining 7 Kg comes from superphosphate.

For P_2O_5 = $\frac{7x100}{16}$ = 43.75 Kg of superphosphate

K_2O = $\frac{10x100}{60}$ = 16.66 Kg of muriate of potash

Thus, the total quantity of various fertilizers required to prepare 100 kg of a 4-8-10 fertilizer mixture will be

Ammonium sulphate…….	10.00 Kg
Nitrate of soda	6.25 Kg
Tankage	16.66 Kg
Superphosphate	43.75 Kg
Muriate of potash	16.66 Kg
Total quantity of straight fertilizer	*93.32 Kg*
Filler	6.68 Kg
Mixed fertilizer	100.00 Kg

For preparing 600 kg of the fertilizer mixture of the 4-8-10 grade, the following quantities of fertilizers and filler will be required:

Ammonium sulphate	**:**	**10x6**	**= 60.0 kg**
Nitrate of soda	**:**	**6.25x6**	**= 37.5 Kg**
Tankage	**:**	**16.66x6**	**= 100.00 Kg**
Superpohosphate	**:**	**47.75x6**	**= 262.5 Kg**
Muriate of potash	**:**	**6.68x6**	**= 40.0Kg**
Total	**:**		**600.00 Kg**

Fertiliser mixtures available in the market:

1. *Sufla (15:15:15)*
2. *Sufla (20:20:0)*
3. *Lakshmi (12:12:12)*
4. *Lakshmi (8:8:8)*
5. *IFFCO-1 (10:26:26)*
6. *IFFCO-2 (12:32:16)*

6.8 Liquid fertilizers:

For intensive high yield and quality crop production, liquid fertilizers are preferred. This helps when both water and soluble fertilizers are delivered to crops simultaneously through a Drip Irrigation System ensuring complete plant nutrition such as N, P, K, Ca, Mg, S & Micronutrients which are directed to the active root zone in well balanced proportion.

Advantages of liquid fertilizer:

- Nutrient availability to the plant is improved
- Nutrient uptake efficiency is increased
- Fertilizer Application rates & Water Requirements are reduced
- Losses by Leaching are minimized
- Salt Injuries & damages to Root & Foliage are prevented
- Soil Compaction is reduced due to less field operations
- Weed population is decreased

Liquid fertilizers and their solubility

Sr. no.	Fertilizer	Grade (N-P-K)	Solubility (g/lit) at 20 ^{0}C
Water soluble special fertilizers			
1.	Mono Ammonium Phosphate (MAP)	12-61.0	282
2.	Mono Potassium Phosphate (MKP)	0-52-34	230
3.	potassium Nitrate (Multi-K)	13-0-46	316
4.	Sulphate of Potash	0-0-50	111
5.	Ortho Phosphoric Acid	0-52-0	457
Conventional WS Fertilizers			
1	Urea	46-0-0	1100
2	Potassium Chloride (Red)	0-0-60	347
3	Potassium sulphate (White)	0-0-50	110
4	Ammonium Sulphate	21-0-0	760

6.9 Nano-Fertilizers:

Nanotechnology has progressively moved away from the experimental into the practical areas, like the development of slow/controlled release fertilizers, conditional release of pesticides and herbicides, on the basis of nanotechnology has become critically important for promoting the development of environment friendly and sustainable agriculture.

Indeed, nanotechnology has provided the feasibility of exploiting nanoscale or nanostructured materials as fertilizer carriers or controlled release vectors for building of so-called **"smart fertilizer"** as new facilities to enhance nutrient use efficiency and reduce costs of environmental protection.

Encapsulation of fertilizers within a nanoparticle is one of these new facilities which are done in three ways

a) the nutrient can be encapsulated inside nanoporous materials,

b) coated with thin polymer film and

c) delivered as particle or emulsions of nanoscales dimensions.

In addition, nanofertilizers will combine nanodevices in order to synchronize the release of fertilizer-N and -P with their uptake by crops, so preventing undesirable nutrient losses to soil, water and air via direct internalization by crops, and avoiding the interaction of nutrients with soil, microorganisms, water, and air. Among the latest line of technological innovations, nanotechnology occupies a prominent position in transforming agriculture and food production.

Some of the major evident benefits of nano fertilizer are as under:

- The quantity required for nano fertilizer application is considerably reduced as compared to conventional fertilizers.
- Nano fertilizer will help to boost the crop production efficiently besides reducing nutrient losses into the surrounding water bodies (Eutrophication).
- Nano-structured formulation might increase fertilizer efficiency and uptake ratio of the soil nutrients in crop production, and save fertilizer resource.
- Nano-structured formulation can reduce loss rate of fertilizer nutrients into soil by leaching and/or leaking.

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CHAPTER-7
SOIL AMENDMENTS

7.1. Soil amendments

Soil amendments are substances which when added to the soil help plant growth indirectly by augmenting physical, chemical or biological changes in the soil. Soil amendment usually contains plant nutrient. But they cannot be classified along with fertilizers as their main aim is not to supply the nutrient directly, but they are very helpful for plant growth (Rai, 1965).

The organic amendments**:** The organic amendments as such do not help in replacing the exchangeable Na as against the gypsum or other amendments. Primarily, they improves the physical condition of the soil by improving the aggregation in the soil. The most common organic amendment is the FYM which is added in the first year of reclamation @ 50 tones/ha and is reduced to half in succeeding years. The efficiency of gypsum has been found to increase when it is applied along with FYM. Molasses and pressmud, which are sugar factory waste, have also been used. Pressmud, a byproduct from sugar factories, contains $CaCO_3$. Since Ca is present as $CaCO_3$, it is slow acting amendment requiring acid or acid formers. As against carbonation process, pressmud from sugar factories employing sulphitation process has superior reclamation value, as it contains sulphate of lime instead of its carbonate.

Green manuring with Dhaincha (*Sesbania aculeata*) has been found most successful. The juice of green plants can neutralize high alkalinity, its initial pH being 4.01, with only slight rise even within a month. In black cotton soil, it thrives well under moderately saline conditions and can with stand high alkalinity, water logging or drought so that it is remarkably suited in that region to alkali soils, characterized by such adverse conditions. Sulphurated hydrogen is generated by the decomposition of Dhaincha.

Paddy straw or rice husk have also been used at a rate varying between 15 to 30 tones/ha. Weeds like *Argemone mexicana* has been found very suitable for alkali soils. The other weeds found suitable for the purpose of green manuring are *Ipomea grandiflora* and *Pongamia glabra*. The Russian workers have suggested the addition of cellulose with sufficient addition of nitrogen for easy decomposition.

A. ***Different types of chemical amendments:***

1. Soluble calcium salts e.g.

(i)	Calcium chloride	($CaCl_2.2H_2O$)
(ii)	Gypsum	($CaSO_4.2H_2O$)
(iii)	Calcium sulphate	($CaSO_4$)

2. Acid or acid formers e.g.

(i)	Sulphur	(S)
(ii)	Sulphuric acid	(H_2SO_4)
(iii)	Iron sulphate	($FeSO_4.7H_2O$)
(iv)	Aluminium sulphate	($Al_2(SO_4)_3.18H_2O$)
(v)	Lime sulphur (calcium poly sulphide)	(CaS_5)
(vi)	Pyrites	(FeS_2)

The kind and amount of chemical amendment to be used for the replacement of exchangeable Na in soils depend upon the soil characteristics, the desired rate of replacement and economic considerations. Soluble calcium salts are preferred when soil does not contain alkaline earth carbonates or calcium carbonate. Acid or acid formers are preferred when soil contains alkaline earth carbonates or $CaCO_3$. Acid or acid formers are also used along with calcium salt of low solubility but the rate of reaction is very low.

B. ***Advantages and disadvantages of amendments:***

The $CaCl_2$ is highly soluble and Ca is readily available but its cost is a prohibitive factor. Iron and aluminium sulphates also hydrolyze readily in the soil to form H_2SO_4 but here also the cost is acting. Amendment, which can be used in calcareous soils but it requires special equipments and is hazardous in handling. Sulphur is a slow acting amendment and large applications are needed. It requires more time for complete oxidation. In cool winter season, the oxidation rate is too slow to give satisfactory results. Since the oxidation process is fully microbial, an optimum amount of moisture has to be maintained continuously in the soil. The soil should not be leached until sufficient time has been allowed for most of the sulphur to oxidize. Limestone is a low cost amendment but the solubility is affected by pH of the soil and particle size of the amendment. Like S, pyrite has to be oxidized first which is a slow process and the rate of reaction depends on particle size. Again the application of pyrites at higher rate markedly decreases its oxidation rate. It is a cheap amendment.

Gypsum is the most common amendment used for reclaiming saline-sodic as well as non-saline sodic soils. It is a low cost amendment and the rate of reaction in replacing Na is limited on its solubility in water, which is about 0.25 % at ordinary temperature. While applying gypsum, mixing it in shallow depth (upper 10 cm depth) is more effective. It is applied by broadcast method or incorporated by disc plough. Gypsum is applied at the time of ponding or leaching. Gypsum directly prevents crust formation, swelling, dispersion and acts as mulch in case of surface application and indirectly increases porosity, structural stability, infiltration and hydraulic properties, soil tilth, drainage and leaching and reduces dry soil strength.

C. Chemical reactions of amendments in soil: The following chemical reactions illustrate the manner in which various amendments react in the different classes of alkali soils. In these equations the letter **X** represents the soil exchange complex.

Reclamation of saline-alkali soils

Class 1. Soils Containing Alkaline-Earth Carbonates

GYPSUM: $2Na\mathbf{X} + CaSO_4 \leftrightarrow Ca\mathbf{X}_2 + Na_2SO_4$

SULPHUR: (1) $2S + 3O_2 \leftrightarrow 2SO_3$ (microbiological oxidation)

(2) $SO_3 + H_2O \leftrightarrow H_2SO_4$

(3) $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + CO_2 + H_2O$*

(4) $2Na\mathbf{X} + CaSO_4 \leftrightarrow Ca\mathbf{X}_2 + Na_2SO_4$

LIME-SULPHUR (CALCIUM POLYPHOSPHATE):

(1) $CaS_5 + 8O_2 + 4H_2O \leftrightarrow CaSO_4 + 4H_2SO_4$

(2) $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + CO_2 + H_2O$*

(3) $2Na\mathbf{X} + CaSO_4 \leftrightarrow Ca\mathbf{X}_2 + Na_2SO_4$

IRON SULPHATE:

(1) $FeSO_4 + H_2O \leftrightarrow H_2SO_4 + FeO$

(2) $H_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + CO_2 + H_2O$*

(3) $2Na\mathbf{X} + CaSO_4 \leftrightarrow Ca\mathbf{X}_2 + Na_2SO_4$

* The reaction of H_2SO_4 and $CaCO_3$ may also be written as follows : $H_2SO_4 + 2CaCO_3 \leftrightarrow CaSO_4 + Ca(HCO_3)_2$. Under these conditions the $Ca(HCO_3)_2$ as well as the $CaSO_4$ would be available for reaction with exchangeable sodium and 1 atom of sulphur when oxidized to H_2SO_4, could theoretically result in the replacement of 4 sodium ions by calcium.

D. ***Quantity of amendments to be added:*** These are evidences to show that even 50 % of the theoretical gypsum requirement for replacement of exchangeable Na in alkali soils has improved their physical properties and assisted response to management practices. Generally, 50 to 75 % of GR (as determined by Schoonover's method) has been found most satisfactory in many types of soils.

The equivalent proportion of different amendments in relation to 1 ton of gypsum is as follows:

Amendments	**Weight in tones equivalent to 1 tone gypsum**
Gypsum	1.000
Sulphuric acid	0.570
Sulphur	0.186
$FeSO_4.7H_2O$	1.620
Aluminium sulphate	1.290
Limestone ($CaCO_3$)	0.580
Lime sulphur (Calcium polysulfide containing 24 % S)	0.756

Among all the amendments, gypsum is the most common amendment that is used for the purpose of reclamation. The rate of addition of gypsum can be determined by estimating the gypsum requirement (GR) of a soil. Alternatively, the GR can also be determined by knowing the exchangeable Na in soil and working out the extent of reduction of Na on equivalent basis. The gypsum requirement for replacing 1 me of Na upto a soil depth of 15 cm comes to about 1.92 tones/ha. Since an ESP of 10 and below is considering safe for tolerable physical condition of the soil, replacement by calcium to this level is all that is attempted in practice.

E. ***The organic amendments*****:** The organic amendments as such do not help in replacing the exchangeable Na as against the gypsum or other amendments. Primarily, they improves the physical condition of the soil by improving the aggregation in the soil. The most common organic amendment is the FYM which is added in the first year of reclamation @ 50 tones/ha and is reduced to half in succeeding years. The efficiency of gypsum has been found to increase when it is applied along with FYM. Molasses and pressmud, which are sugar factory waste, have also been used. Pressmud, a byproduct from sugar factories, contains $CaCO_3$. Since Ca is present as $CaCO_3$, it is slow acting amendment requiring acid or acid formers. As against carbonation process, pressmud from sugar factories employing sulphitation process has superior reclamation value, as it contains sulphate of lime instead of its carbonate.

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Reclamation of Acidic Soils

Principles of Liming Reactions: The reclamation of acidic soils is done by addition of liming material which may be calcitic limestone ($CaCO_3$) or dolomitic limestone [$CaMg(CO_3)_2$]. The rate of lime requirement is determined in the laboratory by method of Shoemaker (1961). The particle size of liming material affects the rate of neutralization reaction. Both these limestones are sparingly soluble in pure water but do become soluble in water containing CO_2. The greater the partial pressure of CO_2 in the system, the more soluble the limestone becomes. Dolomite is somewhat less soluble than calcite. The reaction of limestone ($CaCO_3$) can be written as:

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 \rightarrow Ca^{2+} \downarrow + 2HCO_3^-$$

(Takes part in cation exchange reactions)

$$H^+ + CO_3^{2-} \rightarrow H_2CO_3^- \leftrightarrow H_2O + CO_2$$

(From soil solution) (from lime)

In this way hydrogen ions (H^+) in the soil solution react to form weakly dissociated water, and the calcium (Ca^{2+}) ion from limestones is left to undergo cation exchange reactions. The acidity of the soil is, therefore, neutralized and the per cent base saturation of the colloidal material is increased.

Why Gypsum is not considered as a Liming Material?

Gypsum is not considered as liming materials because on its application to an acid it dissociates into (Ca^{2+}) and sulphate (SO_4^{2-}) ions:

$$CaSO_4 \leftrightarrow Ca^{2+} + SO_4^{2-}$$

The accompanying anion is sulphate and it reacts with soil moisture produces mineral acid (H_2SO_4) which also increases soil acidity instead of reducing soil acidity.

Beneficial effect of lime

1. Lime makes P_2O_5 more available.
2. Lime increase availability of N, increase nitrification and nitrogen fixation.
3. Increase soil pH favours the microbial activity and increase organic matter decomposition and nutrient transformation for root growth.
4. Mo an essential element to *rhizobium* in N fixation process increases with increase in soil pH following lime.
5. Reduce toxicity of Al, Fe and Mn.
6. Lime is essential source of essential Ca as well as Mg if dolomitic lime stone has been applied as liming material.

7. It causes an increase in CEC, which reduces the leaching of base cations, particularly K.

(**Source:** Soil Fertility and Nutrient Management. S. S. Singh)

SOLVED EXAMPLES:

Example 1: *A soil contains 12 me Na/100 g soil. The CEC of the soil is 20. Exchangeable Na percentage is to be reduced to 10. Workout the gypsum requirement.*

ESP = Exch. Na/CEC x 100 = 12/20 x 100 = 60 %
Initial ESP – Final ESP = 60 – 10 = 50 % ESP to be reduced
Exch. Na = 12 x 50/60 = 10 me exch. Na/100 g to be replaced
GR = 1 me exch. Na/100 g = 86 mg gypsum/100 g
= 860 mg/1000 g
= 860 ppm
= 860 x 2.24 = 1926.4 kg/ha
10 me exch. Na = 10 x 1926.4 = 19264 kg/ha = 19.2 t/ha
If purity is 80 then,
GR = 19.2 x 100/80 = 24 t/ha

The GR in this example is 19.2 tones/ha. To get the net value of weight of gypsum, the value has to be multiplied by purity percentage i.e. if the purity of the commercial gypsum is 80 %, then the exact weight in the above example would be 24 tones/ha.

Example 2: *Calculate GR of alkali soils containing CEC 20 me/100 g [cmol(p^+)kg^{-1}] and 10 me exch. Na/100 g soil, ESP reduced to 10.*

CEC = 20 me/100 g
Exch. Na = 10 me/100 g
ESP reduced to = 10 %
ESP = [Exch. Na/CEC] x 100
= [10/20] x 100
= 50
Initial ESP – Final ESP = 50 – 10 = 40 ESP to be reduced
ESP 50 = Exch. Na 10
So ESP 40 =10 x 40/50 = 8 Exch. Na me/100 g to be reduced
1 me Exch. Na/100 g = 86 mg Gypsum/100 g
= 860 mg Gypsum/1000 g
= 860 ppm Gypsum
= 860 x 2.24 = 1926 kg/ha Gypsum
= 1.926 t/ha Gypsum
So 8 me Exch. Na/100 g = 8 x 1.926 = 15.41 t/ha

Example 3: *Soil having CEC 40 me/100 g. It has Na 20 me/100 g in exch. form. Bring down exch. Na to 10 %. Calculate % Na. How much Na to be replaced as to bring its saturation to 10 % and calculate GR in kg/ha. Gypsum purity is 80 %.*

(1) ESP = (Exch. Na/CEC) x 100 = (20/40) x 100 = 50 ESP
Initial ESP – Final ESP = 50 – 10 = 40 ESP to be reduced

(2) Exch. Na = (ESP x CEC)/100 = (40 x 40)/100 = 16 me Na/100 g to be replaced
(3) GR = 1 me Na/100 g = 86 mg gypsum/100 g
= 860 ppm
= 860 x 2.24 kg/ha
16 me Na/100 g = 16 x 860 x 2.24 = 30822 kg/ha
(4) 80 % purity = 30822 x 100/80 = 38528 kg/ha

Example 4: *A soil have CEC = 25 me/100 g soil which possesses 5, 8 and 3 me/100 g of Ca, Mg and K, respectively. Calculate quantity of Na in me/100g and kg/ha and* K_2O *kg/ha.*

(1) Na me/100 g = CEC – (Ca + Mg + K)
= 25 – (5 + 8 + 3) = 9 me/100 g
= 9 x 23 mg/100 g = 207 mg/100 g
= 2070 mg/1000 g = 2070 ppm
(2) Na (kg/ha) = 2070 x 2.24 = 4636.8 kg/ha
K = 3 me/100 g
= 3 x 39 mg/100 g = 117 mg/100 g
= 1170 mg/1000 g = 1170 ppm
= 1170 x 2.24 = 2620.8 kg/ha
(3) K_2O (kg/ha) = 2620.8 x 1.20 = 3144.96 kg/ha

Example 5: *Workout the GR from following observations*

(1) Weight of alkali soil = 5 g
(2) Sat. gypsum soln. = 100 ml
(3) Aliquate taken = 5 ml
(4) Difference of 0.02 N EDTA reading between blank and sample = 0.4

GR t/ha = Z x (1.72/1000) x (100/5) x (100/5) x 10,000 x 2.24/1000
= 0.4 x 15.411 = 6.16 t/ha

7.2 Soil Conditioner

These are material, which are used to bring about required physical properties of soil or it is used to improve and maintain the physical conditions of the soils. Crop residues, organic manures and other organic materials are the organic soil conditioners. Other synthetic organic materials which are used as soil conditioners are Polyvinyl alcohol (PVA), Carboxymethyl cellulose (CMC) and Krillium conditioners. These materials use to form soil aggregates or they use to stabilize soil aggregate formed by mechanical manipulations. However, its application is found restricted to green house, glass house or in growing high value crops like vegetables, ornamental plants or spices and condiments etc.

(**Source**: Soil Fertility and Nutrient Management. S. S. Singh)

CHAPTER-8

FERTILIZER STORAGE AND FERTILIZER CONTROL ORDER

Warehousing and storage of fertilizers is a very important and massive activity. Ideally a marketer would like the fertilizer to spend minimum time in a godown because storage costs money, blocks money, occupies space, needs supervision and inspite of precautions, some fertilizer can be stolen or damaged. **Storage can be called a necessary evil.** People who pay for storage, often think whether it is better to spend on this item or to give off- season rebate to the farmer and let him do the storage.

8.1 The principles of good storage at the field level are:

(i) The fertilizers should be stored in a cool, dry and damp proof godown. The rain water must not get entered in the godwon and there is no need to have windows in the godown. But they should have proper ventilation for regulating for exit of gases from the store. The ventilators should be sealed in rainy season.

(ii) The bags should not be piled up directly on the floor as moisture of the floor causes the damage to the fertilizer. The wooden racks should be used for pilling the fertilizer bags.

(iii) The bags should not be piled together in a row of 8-10 bags.

(iv) The bags should not touch the wall of the godwon.

(v) Proper space should be allowed between two of piled fertilizers for convenience of lifting the fertilizers.

(vi) The fertilizer that are hygroscopic in nature such as Urea, Ammonium Nitrate, Ammonium Sulphate Nitrate, Calcium Ammonium Nitrate must be stored in water proof bag and the entire bag should be used in one lot. Otherwise, the bag should be tied tightly and stored in a dry and damp proof godwon after taking required fertilizers.

(vii) The fertilizers that are fire hazardous such as Ammonium Sulphate must be handled very carefully.

(viii) All types of fertilizers such as Nitrogenous, Phosphatic and Potassic fertilizers should not be piled together. But they should be piled separately so that their handling is easy and gas fumes release from one group may not affect the quality of others.

(ix) The bag should not be kept open at any time to avoid the formation of cakes or lumps.

(x) The home mixed fertilizer should not be stored. Rather it should be used immediately after mixing of different fertilizers.

(xi) Prolonged storage of fertilizer should be avoided.

8.2 Fertilizer Control Order:

The history of the Indian fertilizer industry dates back to 1906, when the first fertilizer factory opened at Ranipet (Tamil Nadu). Since then, there have been major developments in terms of both the quantity and the types of fertilizers produced, the technologies used and the feedstocks employed. The fertilizer industry in India is in the core sector and second to steel in terms of investment.

Prior to 1960/61, India produced only straight nitrogenous fertilizers [ammonium sulphate (AS), urea, calcium ammonium nitrate (CAN), ammonium chloride and single superphosphate (SSP)]. The production of NP complex fertilizers commenced in 1960/61. Currently, India produces a large number of grades of NP / NPK complex fertilizer. These include 16–20–20, 20–20–0, 28–28–0, 15–15–15, 17–17–17, 19–19–19, 10–26–26, 12–32–16, 14–28–14, 14–35–14 and 19–19–19. In addition, India produces various grades of simple and granulated mixtures.

The fertilizer was declared as an Essential Commodity in 1957 in India. To control the trade, price, quality of fertilizers and their distribution, "The fertilizers (Control) Order" came in to force in 1957. Since then the The Fertilizer (Control) order (FCO) has been amended periodically. It is useful for the personnels engaged in: Fertilizer manufacture, fertilizer business, fertilizer analysis and fertilizer inspection.

8.3 FERTILIZER LEGISLATION

Chemical fertilizers are becoming increasingly expensive day by day due to hike of prices of petroleum, inflation etc., which tempts dealers to adopt malpractices for earning more profits through adulteration, supplies of underweight materials or blending of degraded fertilizers etc. Thus, the farmers are ditched and often they fail to get good response of applied fertilizers. Therefore, the laws regulating the manufacture and sale of various fertilizers are essential to ensure that the consumer or the farmer is supplied with fertilizers of standard quality.

Keeping these points in mind, the Government of India brought in the fertilizer Control Act.

8.4 FERTILIZER CONTROL ACT

The Union Government of India promulgated the fertilizer Control Act (F.C.O) in 1957 under the Essential Commodities Act, 1955 (section 3) with a view to regulate fertilizer business in India.

The F.C.O. keeps a strict watch on quality control of fertilizers, provides for the registration of dealers and statutory control of fertilizer prices by Government. Therefore, everybody involved in fertilizer business as a manufacturer, dealer or a salesperson, must have proper understanding of the F.C.O. in order to avoid infringement of Government regulations.

The provisions given in the Order will also help the consumers/ farmers to know their rights and privileges in respect of fertilizer quality and Authorities to be approached for their grievances regarding supply of substandard materials, overcharging or containers of underweight supplies.

The F.C.O. is published by the Fertilizer Association of India (F.A.I.), updated when ever felt necessary. The Order has provisions on quality for each consumed fertilizer product and F.C.O. should be consulted under infringement of any of them.

Control of Quality of Fertilizers

The F.C.O. has provisions to penalize manufactures, distributors, and dealers for supply of spurious or adulterated fertilizers to consumers or farmers. The F.C.O. has fixed specifications for various fertilizers, which must be present in them failing which the legislation comes in force, and guilty is punished.

8.5 Specifications of fertilizers

To control the quality of fertilizers "The Fertilizer Control Order, 1985" has laid down specifications for the fertilizers. The parameters of the specifications are as follows:

i. Moisture, per cent by weight maximum
ii. Total nutrient content, percent by weight
iii. Forms of nutrient, per cent by weight
iv. Impurities, per cent by weight
v. Particle size.

1. Ammonium Sulphate

(i) Moisture per cent by weight, maximum	1.0
(ii) Ammoniacal nitrogen per cent by weight, minimum	20.6
(iii) Free acidity (as H2SO4.) per cent by weight, maximum (0.04 for material obtained from by product ammonia and by-product gypsum)	0.025
(iv) Arsenic as (As2O3) per cent by weight, maximum	0.01
(v) Sulphur (as S) ,per cent by weight, minimum	23.0

2. Urea (46% N) (While free flowing)

(i) Moisture per cent by weight, maximum	1.0
(ii) Total nitrogen, per cent by weight, (on dry basis) minimum	46.00
(iii) Biuret per cent by weight, maximum	1.5
(iv) Particle size—Not less than 90 per cent of the material shall pass through 2.8 mm IS sieve and not less than 80 per cent by weight shall be retained on 1 mm IS sieve	

3. Potassium Chloride (Muriate of Potash)

(i) Moisture per cent by weight, maximum	0.5
(ii) Water soluble potash content (as K_2O) per cent by weight, minimum	60.0
(iii) Sodium as NaCI per cent by weight (on dry basis) maximum	3.5
(iv) Particle size -—minimum 65 cent of the material shall pass through 1.7 mm IS sieve and be retained on 0.25 mm IS sieve.	

4. Diammonium Phosphate (18-46-0)

(i) Moisture per cent by weight, maximum	1.5
(ii) Total nitrogen per cent by weight, minimum	18.0
(iii) Ammonical nitrogen form per cent by weight, minimum	15.5
(iv) Total nitrogen in the form of urea per cent by weight, maximum	2.5
(v) Neutral ammonium citrate soluble phosphates (as P_2O_5) per cent by weight, minimum	46.0
(vi) Water soluble phosphates (as P_2O_5) per cent by weight, minimum	41.0
(vii) Particle size -– not less than 90 per cent of the material shall pass through 4 mm IS sieve and be retained on 1 mm IS sieve. Not more than 5 per cent shall be below than 1 mm size.	

5. Zinc Sulphate Heptahydrate ($ZnSO_4.7H_2O$)

(ii) Matter insoluble in water per cent. by weight, maximum	1.0
(iii) Zinc (as Zn) per cent. by weight, minimum	21.0
(iv) Lead (as Pb) per cent by weight, maximum	0.003
(v) Copper (as Cu) per cent by weight, maximum	0.1
(vi) Magnesium (as Mg) per cent by weight, maximum	0.5
(vii) pH not less than	4.0
(viii) Sulphur (as S),percent by weight, minimum	10.0
(ix) Cadmium (as Cd), percent by weight, maximum	0.0025
(x) Arsenic (as As),percent by weight, maximum	0.01

8.6 SPECIFICATIONS OF MANURE

Example : **Vermicompost :**

(i) Moisture, per cent by weight	15.0-25.0
(ii) Colour	Dark brown to black
(iii) Odour	Absence of foul odour
(iv) Particle size Minimum material should pass through 4.0 mm IS sieve	90%
(v) Bulk density (g/cm^3)	0.7-0.9
(vi) Total organic carbon, per cent by weight, minimum	18.0
(vii) Total Nitrogen (as N), per cent by weight, minimum	1.0
(viii) Total Phosphates (as P_2O_5), per cent by weight, minimum	0.8
(ix) Total Potash (as K_2O), per cent by weight, minimum	0.8
(x) C:N ratio	<20
(xi) pH	6.5-7.5
(xii) Pathogens	Nil
(xiii) Conductivity (as dsm^{-1}),not more than	4.0
(xiv) Heavy metal content, (as mg/kg), maximum	
Cadmium (as Cd) Chromium (as Cr) Nickel (as Ni) Lead (as Pb)	5.0 50.00 50.00 100.00

Fertilizer Movement Control Order

The Fertilizer Movement Order (F.M.O.) was promulgated by Government of India in April 1973 to ensure an equitable distribution of fertilizers in various States. According to the fertilizer movement order, no person or agency can export chemical fertilizers from any State. However, Food Corporation of India, Warehousing Corporation of India and Indian Potash Limited; materials like Rock phosphate, bone meal (both raw and steamed) and zinc sulphate are exempted from the movement restriction.

Agency responsible for Enforcement of F.C.O

The Controller of Fertilizers for India, usually a Joint Secretary to the Government of India (Ministry of Agriculture) is responsible for the enforcement of F.C.O. throughout the country.

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CHAPTER-9

FERTILIZER RECOMMENDATIONS AND APPLICATION

9.1 Blanket Recommendation

Based on the fertilizer experiments conducted in different regions with improved varieties, fertilizer dose is recommended for each environment.

This approach does not consider soil contribution. However, it is suitable for recommendation of nitrogen since residual effect of fertilizer N applied to previous crop is negligible and soils are generally low in nitrogen content.

Problem: Let the recommended fertilizer dose for low land rice be, 120, 60, 40kg N-P_2O_5 and K_2O per hectare, respectively. The amount of fertilizer required in the form of urea, single super phosphate (SSP) and muriate of potash (MOP) is calculated as shown below:

Urea contain 46%N

To supply 46kg N, 100kg urea is necessary

To supply 120kg N/ha, $\frac{100}{46}$ x 120 =260.9 kg or 261 kg urea is required

Similarly,

SSP contain 16% P_2O_5

To supply 60kg P_2O_5/ha, $\frac{100}{16}$ x 60 =375kg SSP is required

MOP contain 58% K_2O

To supply 40kg K_2O/ha, $\frac{100}{58}$ x 40 =68.9 or 69kg MOP is required

Problem: In above example, fertilizer dose of paddy is 120, 60, 40kg N-P_2O_5 and K_2O per hectare, respectively. The recommendation of fertilizer is given below

► Nutrient application

Category	N	P_2O_5	K_2O
Low	150	75	50
Medium	120	60	40
High	90	45	30

Fertilizer application

Category	Urea	SSP	MOP
Low	326	469	86
Medium	261	375	69
High	196	281	52

9.2 Soil Test Crop Response (STCR) Approach

In this approach, soil contribution and yield level are considered for recommending fertilizer dose. This approach is also called as rationalized fertilizer prescription. From the soil test crop response experiments, following parameters are available.

$$\text{Nutrient requirement (kg nutrient/q of grain)} : \frac{\text{Total uptake of nutrient (kg/ha)}}{\text{Grain yield (q/ha)}}$$

% contribution from soil (CS) :

$$\frac{\text{Total uptake of nutrient in control plot(kg/ha)}}{\text{Soil test value of nutrient In control plot (kg/ha)}} \times 100$$

Contribution from fertilizer (CF) :

$$\text{Total uptake of nutrient inTreated plot} - \text{Soil test value of nutrient In treated plot (kg/ha)} \times \frac{\text{CS}}{100}$$

% Contribution from fertilizer :

$$\frac{\text{CF (kg/ha)}}{\text{Fertilizer dose}} \times 100$$

Fertilizer dose(kg/ha) :

$$\frac{\text{Nutrient requirement in kg/q of grain } \mathbf{x}100}{\text{\% Contribution from fertilizer}} \times T - \frac{\text{\% contribution from soil}}{\text{\% contribution from fertilizer}} \times \text{STV (kg/ha)}$$

Fertilizer dose (kg/ha): Constant(kg/ha)x T(q/ha)- Constant x STV(kg/ha)

Based on this, fertilizer recommendations are developed for different regions. One such equation developed to recommend P and K, fertilizers for sugarcane in south Gujarat is given below:

Dose of P_2O_5 (kg/ha) = 2.24T - 3.97 x STV for available P_2O_5

Dose of K_2O (kg/ha) = 2.67T - 0.383 x STV for available K_2O

Nutrient use efficiency (NUE):

"Nutrient use efficiency defined as yield (biomass) per unit input (Fertilizer, nutrient content)". The nutrient most limiting plant growth are N, P,K and S. NUE depends on the ability to efficiently take up the nutrient from the soil, but also on transport, storage, mobilization, usage within the plant and even on the environment. Two major approaches may be taken to understand NUE. Firstly, the response of plants to nutrient deficiency stress can be explored to identify processes affected by such stress and those that may serve to sustain growth at low nutrients input. A second approach makes use of natural or induced genetic variation.

Increasing nutrient efficiency is the key to the management of soil fertility. The proportion of the added fertilizer actually used by plants is a measure of fertilizer efficiency. Soil characteristics, crop characteristics and fertilizer management techniques are the major factors that determine fertilizer efficiency.

9.3 Factors influencing nutrient use efficiency (NUE)

9.3.1 Soil characteristics

(1) Nutrient Status of Soil: The response of any crop or a cropping system to added nutrient depends largely upon the inherent capacity of soil to supply that nutrient as per the requirement of crop. In a low nutrient soil, the crop responds remarkably to its application. On the other hand, in a high nutrient soil, the crops may show little or no response. In medium test soil, the response is intermediate. Soil testing helps in adjusting the amount of fertilizer and thus improves the efficiency of fertilizers use. By demarcating the areas responding differently to different plant nutrients, right type and proper amount of fertilizers can be applied to them.

(2) ***Nutrient Losses and Transformations****:* The amounts of nutrients estimated by soil tests may not be entirely available to plants because of their leaching, volatilization, denitrification and transformations to unavailable forms. Leaching losses are important for nitrate nitrogen because it is not held by exchange sites in the soil, it is lost. Such losses are of particular significance in sandy soils and in situations if heavy rain or irrigation follows its application. In acid soils, leaching losses of calcium, sulphate, potassium and magnesium are more common. Volatilization of ammonia in high pH surface soils is considerable when urea is applied at the surface. Denitrification loss of nitrogen mainly occus under waterlogged conditions prevailing during rice cultivation, particularly under higher temperatures and in the presence of easily decomposable organic materials.

The conversion of a portion of available nutrients into insoluble mineral forms is also important. Thus, the efficiency of added phosphorus is 20 to 30 per cent. Microbial immobilization also converts temporarily the soluble forms of nutrients into unavailable forms. Similarly, the efficiency of zinc applied to soil is less than 3%.

Soil characteristics play a dominant role in the transformation of nutrients. Soil reaction (pH) is one of the important soil properties that affects plant growth. The harmful effects of soil acidity are more due to secondary effects except in extreme case. The important secondary effects of high acidity or low pH in a soil are the inadequate supply of available calcium, phosphorus and molybdenum on one hand and the excess of soluble aluminum, manganese and iron on the other. Likewise, in saline-alkali soil, the deficiency of Ca, Mg, P, Zn, Fe and Mn is very common. The fertilizers practices are, therefore, to be modified accordingly for soils with different soil reactions. The main aim of liming of acid soils and addition of gypsum to alkali soils is to change the soil pH suitable for the availability of most plant nutrients.

(3) ***Soil Organic Matter****:* Soil organic matter content is generally considered as the index of soil fertility and sustainability of agricultural systems. It improves the physical and biological properties of soil, protects soil surface from erosion and provides a reservoir of plant nutrients. In tropics, the maintenance of soil organic matter is very difficult because of its rapid decomposition under high temperatures. The cultivation of soils generally decreases its organic carbon content because of increased rate of decomposition by the current agricultural practices. In cultivated soils, prevalent cropping system and associated cultural practices influence the level at which organic matter would stabilize in a particular agro-eco-system. Long-term fertilizer experiments have shown that the integrated use of organic manures and chemical fertilizers can maintain high productivity and sustainable crop production. Recent studies have indicated that a periodic addition of large quantity of crop residue to the soil maintains the nitrogen and organic matter at adequate levels even without using legumes in the rotation. The application of FYM, compost and cereal residues effectively maintains the soil organic matter. There is a significant increase in soil organic matter due to incorporation of rice or wheat straw into the soil instead of removing or burning it. Yields are, however, low in residue incorporated treatments due to wide C:N ratio of the residues. This ill effect, however, can be avoided if the rice straw is incorporated at least 20 days before seeding wheat.

(4) ***Soil moisture***: Fertilizer application facilitates root extension into deeper layers and leads to grater root proliferation in the root zone. Irrigated wheat fertilized with nitrogen used 20-38 mm more water than the unfertilized crop on loamy sand and sandy loam soils and increased dry matter production Soil moisture also affects root growth and plant nutrient absorption. The nutrient absorption is affected directly by soil moisture and indirectly by the effect of water on metabolic activities of plant, soil aeration and concentration of soil solution. If soil moisture becomes a limiting factor during critical stage of crop growth, fertilizer application may adversely affect the yield.

(5) Physical Conditions of Soil**:** Despite adequate nutrient supply, unfavorable physical conditions resulting form a combination of the size, shape, arrangement and mineral composition of the soil particles, may lead to poor crop growth and activity of microorganisms. Soil nitrogen generally increases as the texture becomes finer. The basic requirements for crop comes finer, The basic requirements for crop growth in terms of physical conditions of soil are adequate soil moisture and aeration, optimum soil temperature and freedom from mechanical stress. Tillage, mulching, irrigation, incorporation of organic matter and other amendments like liming of acid soils and addition of gypsum to sodic soils are the major field management techniques that aim at creating soil physical environment suitable for crop growth. Tillage affects water use by crops not only through its effect on root growth but also affects the hydrological properties of soils. Mulching with residues, plastic film *etc.,* influences evaporation losses from soil by modifying the hydro-thermal regime of the soil and affects root growth and rooting pattern. Use of organic mulch also decreases maximum soil temperature in summer and increases minimum soil temperature in winter and help in the conservation of soil moisture.

9.3.2 Crop Characteristics

(i) Nutrient Uptake: The total amount of nutrients removed by a crop may not serve as an accurate guide for fertilizers recommendations; it does indicate the differences in their requirement among crops and the rate at which the nutrients reserves in the soil are being depleted. The nutrient uptake may vary depending upon the crops and its cultivars, nutrient level in the soil, soil type soil and climatic conditions, plant population and management practices. It is estimated that 8t of rice grain remove 160 kg N, 38 kg P, 224 kg K, 24 kg S and 320 g Zn as compared to a removal of 125 kg N, 20 kg P, 125 kg K, 23 kg S and 280 g Zn by 5t of wheat from one hectare field.

(ii) Root Characteristics: Roots are the principal organs of nutrient absorption. A proper understanding of their characteristics helps in developing efficient fertilizer practices. The absorption of nutrients depends upon the distribution of roots in soil. The shallower the root system, the more dependent the plant is on fertilizers. Hence, any soil manipulation, which encourages deep rooting, will encourage better utilization of fertilizers. It is well known that some plants are better scavengers of certain nutrients than others. This is mainly because of the preferential absorption of these nutrients by the roots of those plants. For example, legumes have a marked preference for divalent cations like Ca^{2+} whereas grasses feed better on monovalent cations like K^{+}.

The efficiency of the applied fertilizer can be improved considerably if the rooting habits of various plants during early growth stages are known. This is particularly true for relatively immobile nutrients and for situations where the fixation of applied nutrients is very high. If a plant produces tap root system early, fertilizer can best be placed directly below the seed. On the other hand, if lateral roots are formed early, side placement of fertilizer would be helpful.

Mycorrhizal fungi often associated with plant roots, increase the ability of plants to absorb nutrients particularly under low soil fertility. However, fertilizer additions generally reduce their presence and activity.

9.3.3 Crop Rotation: The nature of cropping sequence has a profound effect on the fertilizer requirement and its efficiency. Crops are known to differ in their feeding capacities on applied as well as native nutrients. The crops requiring high levels of fertilizers such as maize, potato may not use the applied fertilizers fully and some amount of the nutrient may be left in the soil which can be utilized by the succeeding crop. Phosphorus, among the major nutrients, is worthy of consideration because only less than 20 per cent of the applied phosphatic fertilizer is utilized by the first crop. Similarly, less than 3% of the applied zinc is used by the first crop. The magnitude of the residual effect is, however, dependent on the rate and kind of fertilizer used, the cropping and management system followed and to a great extent on the type of soil. Crops have a tendency of luxury consumption of N and K and may not leave any residual effect unless doses in excess of the crop requirement are applied. On the other hand, if sub-optimal doses of fertilizers are applied to a crop, they may leave the soil in a much exhausted condition and the fertilizer requirement of the succeeding crop may increase. The legumes leave nitrogen rich root residues in the soil for the succeeding crop and thus reduce its nitrogen requirement.

9.4 Methods of fertilizer application

An important item in efficient use of fertilizer is that of placement in relation to plant.

(1) Solid fertilizers

Broadcasting is the method of application of fertilizer uniformly over the entire field. It may be at planting or in standing crop as top dressing.

(i) Broadcasting at planting is adopted under certain conditions.

1. Soils highly deficient, especially in nitrogen,
2. Where fertilizers like basic slag, dicalcium phosphate, bone meal and rock phosphate are to be applied to acid soils, and
3. When potassic fertilizers are to be applied to potash deficient soils.

(ii) Top dressing is application of fertilizer to the standing crop. Usually, nitrate nitrogen fertilizers are top dressed. Depending on the duration of the crop and soil type, top dressing may be more than one to meet the crop needs at times of greatest need of the crop.

(iii) Placement: Fertilizers are placed in the soil either before sowing or after sowing the crop.

(a) Plough-sole placement consists of placing the fertilizer in a continuous band at the bottom of the furrow during the process of ploughing, which is usually covered by the next furrow adjacent to it.

(b) Deep placement is application of fertilizers, especially nitrogen, in the reduced zone to avoid nitrogen losses in low land rice.

(c) Localized placement: In this method fertilizer are applied close to the seed or plant. It is usually adopted when relatively small quantizes of fertilizers are be applied.

(d) Contact placement or drill placement refers to drilling seeds and fertilizer simultaneously at sowing. Care must be taken to place the seed and fertilizer at different depths to avoid salt injury to the germinating seed.

(e) Band placement consists of applying the fertilizer in continuous bands, close to the seed or plant. This method is ideal for crops grown in wide space *i.e.,* cotton, castor, sugarcane, tobacco, maize *etc.*

(f) Pellet placement is application of fertilizer, especially nitrogen in pellet from in the low land rice avoid nitrogen loss from applied fertilizer.

(2) Liquid Fertilizers

(i) Starter solution: These are solutions of fertilizers prepared in low concentrations used for soaking seed, dipping roots or spraying on seedlings for early establishment and growth.

(ii) Foliar application: This method, nutrients are applied are to the standing crops in the from of spray for quick recovery from the deficiency. It avoids fixation of nutrients in the soil.

In the case of calcium, transport from roots to fruit is limited, so foliar applications are the best method we know of go get more calcium into fruit tissue to reduce post harvest disorders. The expense of the calcium sprays is more than justified by the potential post harvest losses.

If soil pH limits nutrient availability, and ground applied fertilizes are not taken up, foliar fertilizers may be a valid option. In this case, a soil sample should be taken to determine pH, and a leaf tissue sample taken to determine the need for addition foliar fertilization. In some cases poor root health from compaction, replant disease, crown rot, mouse damage, water logging or other problem may warrant foliar feeding of trees. However, the fertilizer in the required amount cannot be phototoxic as a foliar spray, and uptake must have been demonstrated with the product under consideration.

Zinc uptake deserves special attention. In our soils zine is largely immobile and it is difficult to supply roots with adequate amounts of available Zn. As a result of limited soil availability, zine is applied as a foliar spray. Research has shown that only a small amount of Zn can be taken up by leaves, however foliar application are still more successful than soil applied Zn.

(iii) Soil application: Liquid fertilizer such as anhydrous ammonia are applied directly to the soil with special injecting equipment. Liquid manures such as urine, sewage water and shed washing are directly let into the field.

(iv) Fertigation: This is the application of fertilizer in irrigation water in either open or closed system. The open system includes lined and unlined open ditches and gated pipes that are used for furrow and flood irrigation. Sprinkler and trickle systems are main closed systems. Nitrogen and sulphur are the principal nutrients applied by fertigation.

The fertigation allows to apply the nutrients exactly and uniformly only to the wetted root volume, where the active roots are concentrated. This remarkably increases the efficiency in the application of the fertilizer, which allows reducing the amount of applied fertilizer. This not only reduces the production costs but also lessens the potential of groundwater pollution caused by the fertilizer leaching.

Other advantage of the fertigation are: (1) the saving of energy and labor, (2) the flexibility of the moment of the application (nutrients can be applied to the soil when crop of soil conditions would otherwise prohibit entry into the field with conventional equipment), (3) convenient use of compound and ready-mix nutrient solutions containing also small concentrations of micronutrients which are otherwise very difficult to apply accurately to the soil, and (4) the supply of nutrients can be more carefully regulated and monitored. When fertigation is applied through the drip irrigation system, crop foliage can be kept dry thus avoiding leaf burn and delaying the development of plant pathogens.

Fertilizers management under rainfed conditions:

In dryland agriculture, limited water availability is usually the factor that ultimately limits crop production. However, it is not unusual for limited availability of one or more soil nutrients to further decrease production potential. Often, the effects of water and nutrient deficiencies are additive. Because soil used under dryland agriculture are developed under widely varying conditions, their ability to supply nutrients is highly variable.

Fertilizer practices greatly affect nutrient cycling and availability in rainfed conditions. Because of frequent dry periods, placement of soluble fertilizers with the seed is extremely hazardous in dryland soils. The higher rates of fertilizer application may result in high osmotic potentials near the germinating seed. For oil crops, applying no fertilizer N with the seed is usually recommended. however, up to 20 to 30 kg P/ha can be applied with the seed because of the considerably lower solubility of most P fertilizer. It is also reported that P availability is particularly critical for an eroded soil.

In dryland soils, the surface layers often remain dry for a major part of the growing season. Such a condition might suggest that fertilizers should be placed deeper in the region of the active root zone for more of the growing season.

Timing of fertilizer application could also affect nutrient cycling. Applying N fertilizers near the time of maximum N uptake rate of the crop results in the most efficient uptake of the fertilizer.

Fertilizer sources also determine the growth the crops under rainfed conditions. Most dryland experiments showed that ammonium nitrate is usually one of the most efficient N sources for dryland crops. At the other extreme, these experiments showed that urea is the least efficient form of N fertilizers. One must exercise considerable caution when using urea on dryland to avoid excessive losses by ammonia volatilization.

By concentrating the urea (liquid or solid) in a band or pellets, surface contact is reduced, reducing volatilization. Injecting or incorporating urea beneath the soil surface is by far the best way in which to apply this material to dryland soils.

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Chapter 1

Soil Quality and Soil Health

It takes half a millennia to build two centimeters of living soil and only seconds to destroy it - Anne Glover

"The multiple roles of soils often go unnoticed. Soils don't have a voice, and few people speak out for them. They are our silent ally in food production."

Jose Graziano da Silva, FAO Director-General

Soil is a natural finite resource base which sustains life on earth. It is a three phase dynamic system that performs many functions and ecosystem services and highly heterogeneous. Soil biota is the biological universe which helps the soil in carrying out its functions. Often soil health is considered independently without referring to interlinked soil functions and also based on soil test for few parameters. Physical condition of soil and biological fertility are overlooked in soil health management which needs revisiting of soil users. Recognizing the importance of soil health in all dimensions, 2015 has been declared as the International Year of Soils by the 68th UN General Assembly. Food and Agriculture organization of the United Nations has formed Global soil partnership with various countries to promote healthy soils for a healthy life and world without hunger. India, the second most populous country in the world faces severe problems in agriculture. It is estimated that out of the 328.8 m ha of the total geographical area in India, 173.65 m ha are degraded, producing less than 20% of its potential yield (Govt. of India, 1990).

Soil is the essence of life on earth. It serves as a natural medium for the growth of plants that sustains human and animal life. Healthy soils provide us with a range of ecosystem services such as resisting erosion, receiving and storing water, retaining nutrients and acting as an environmental buffer in the landscapes. Soils have undergone unabated degradation at an alarming rate by wind and water erosion, desertification and salinization resulting from misuse and improper farming practices. Soil quality, antonym for soil degradation, has deteriorated due to the natural and anthropogenic activities particularly with the advent of the intensive management practices. Present day need is to understand the definition and concept of soil quality and soil health and associated concepts, computation and assessment of soil quality and finally the influence of management practices on the soil quality with an overall objective of identifying the soil-quality-promoting practices. An attempt has been made in this chapter to elucidate different facets associated with soil quality and soil health.

Soil Functions

Five soil functions as enunciated by Karlen *et al.* (1997) are:

- Sustaining biological activity, diversity and productivity
- Regulating and partitioning water and solute flow
- Filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric decomposition
- Storing and cycling nutrients and other elements within the earth's biosphere
- Providing support to socio-economic structures and protection for archaeological treasures associated with human habitation.

Thus, soil acts to supply nutrients and offer favorable physico-chemical conditions to plant growth, promote and sustain crop production, provide habitat to soil organisms, ameliorate environmental pollution, resist degradation and maintain or improve human and animal health.

Soil Health and Soil Quality

Soil health Defined

Soil health is defined as the continued capacity of soil to function as a vital living system, by recognizing that it contains biological elements that are key to ecosystem function within land use boundaries. The functions are able to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal and human health.

Soil Quality Defined

The term and concept of soil quality evokes various responses depending on our scientific and social backgrounds. For some, soil quality evokes an ethical or emotional tie to the land. To others, soil quality is an integration of soil processes and provides a measure of change in soil condition as related to factors such as land use, climate patterns, cropping sequences and farming systems. Most comprehensive and accepted definition of soil quality is the one given by Soil Science Society of America (Karlen *et al.* 1997) which inter alia reads *'Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation'.*

Soil Quality Vs Soil Health

The term soil quality and soil health are often used interchangeably in the scientific literature and popular articles, with agricultural and environmental scientists in general preferring the term soil quality and *farmers or producers preferring the term soil health*. Some others prefer the term soil health because it depicts soil as a living, dynamic organism that functions holistically rather than as an inanimate or non-living mixture of sand, silt and clay. Others prefer the term soil quality as descriptor of its innate quantifiable physical, chemical and biological characteristics. Soil quality is the capacity of soils within landscapes to sustain biological productivity, maintain environmental quality and promote plant and animal health.

On the other hand, soil health is the 'fitness' (or condition) of soil to support specific uses (e.g. crop growth) in relation to its potential as determined by the inherent soil quality and is more sensitive to anthropogenic disturbance and is severely limited in extreme environments. Both of these terms relate soil to other concepts of health such as environmental health, human health, plant health, and animal health. Soil health and soil quality are functional concepts that describe how fit the soil is to support the multitude of roles that can be defined for it. Therefore, soil quality can be regarded as soil health.

Characteristics of a healthy soil

1. Good soil tilth
2. Depth of the soil
3. Sufficient but not excess supply of nutrients
4. Small population of plant pathogens and insect pests
5. Good soil drainage
6. Large population of beneficial organism
7. Low weed pressure
8. Free of chemical and toxins that may harm the crop
9. Resistant to degradation
10. Resilience when unfavorable conditions occur

Soil Quality indicators

Soils have chemical, biological and physical properties that interact in a complex way to give a soil its quality of capacity to function of performs. Thus, soil quality cannot be measured directly, but must be inferred from measuring changes in its attributes or attributes of the ecosystem, referred to as indicators.

A. Chemical

1) Soil organic carbon
2) Top soil pH
3) Cation exchange capacity (CEC)
4) Anion adsorption capacity
5) Base saturation

B. Biological

1) SOC (Soil organic carbon)
2) Microbial biomass carbon
3) Soil biomass
4) Microbial diversity index and enzyme assays

C. Physical

1) Integrated air capacity
2) Texture
3) Bulk density
4) Aggregation
5) Pore size distribution and continuity
6) Available water capacity
7) Non-limiting water range
8) Infiltration rate
9) Effective rooting depth
10) Soil temperature

D. Visual

1) Soil colour
2) Ephemeral gullies
3) Ponding
4) Runoff
5) Plant response
6) Weed species

Soil constraints

1. **Soil compaction**: It can happen from soil wetness/excessive moisture/heavy traffic, tillage under wet soil conditions. Due to such compaction, it can cause reduced root growth, poor infiltration, poor aeration, runoff and erosion, stagnation of water, drought sensitivity, increased cost of tillage, low crop yields.
2. **Poor aggregation and soil crusting:** Arising from poor aggregate stability, very low/ no application of organic matter, intensive tillage, limited use of soil building crops. All these can result poor seedling emergence as well as poor establishment of crops, poor infiltration causing soil erosion, poor aeration, reduced root growth, low microbial activity.
3. **Weed pressure:** It happens from poor crop rotations, resistance to herbicides; poor weed management practices etc. which can cause poor crop growth, reduced yield with poor quality, increased pests and disease infestations, increased cost of weed control, aired, cultural practices and harvest.
4. **Soil borne pathogens and root diseases**: Poor crop rotations, poor sanitary practices, ineffective/poor timing of manage- physical quality, low organic matter, poor soil physical quality, low microbial diversity etc, cause all these.

5. **Low water and nutrient retention**: Low organic matter, poor retention/recycling of nutrients, poor structure, excess tillage, low water holding capacity are the contributing factors. All these can result ground water pollution, reduced microbial activity, nutrient deficiencies and poor plant growth, drought stress etc.

Strategies for improving soil quality

The properties of soil which represent the dynamic soil quality can be improved by several management practices which are described as follows:

Enhancement of organic matter: Organic matter is considered as the main stay of good soil quality. Regular additions of organic matter improve soil structure, enhance water and nutrient holding capacity, protect soil from erosion, hard setting and compaction and support a healthy community of soil organisms.

Reduction in the intensity of tillage: Reducing tillage minimizes the loss of organic matter and protects the soil surface with plant residue. Tillage is used to loosen surface soil, prepare the seedbed and control weeds and pests. But tillage can also break up soil structure, speed up the decomposition and loss of organic matter, increase the threat of erosion, destroy the habitat of helpful organisms and cause compaction.

Efficient management of pests and nutrients: Efficient pest and nutrient management means testing and monitoring soil and pests; applying only the necessary chemicals, at the right time and place to get the job done; and taking advantage of non-chemical approaches to pest and nutrient management such as crop rotations, cover crops and manure management. The terms integrated pest management (IPM) and integrated nutrient managements (INM) are very much popular nowadays.

Prevention of soil compaction: Soil compaction reduces the amount of air, water and space available to roots and soil organisms. Compaction is caused by repeated traffic, heavy traffic or traveling on wet soil.

Maintenance of ground cover: Soil without adequate cover or bare soil is very much susceptible to wind and water erosion and to drying and crusting. Ground cover protects soil; provides habitats for larger soil organisms, such as insects and earthworms and can improve water availability.

Diversification of cropping systems: Diversity is beneficial for several reasons. Each plant contributes a unique root structure and type of residue to the soil. A diversity of soil organisms can help control pest populations and a diversity of cultural practices can reduce weed and disease pressures.

Factors affecting soil quality

The major causes of poor soil quality are:

1. Wider gap between nutrient demand and supply
2. Emerging deficiency of secondary and micronutrients
3. Decline in organic matter content in soil
4. Acidification and Al^{3+} toxicity
5. Development of salinity and alkalinity in soils
6. Development of adverse soil conditions such as heavy metal toxicity
7. Natural and man-made disaster

Chapter 2

Distribution of Waste Land and Problem soils in India

Introduction

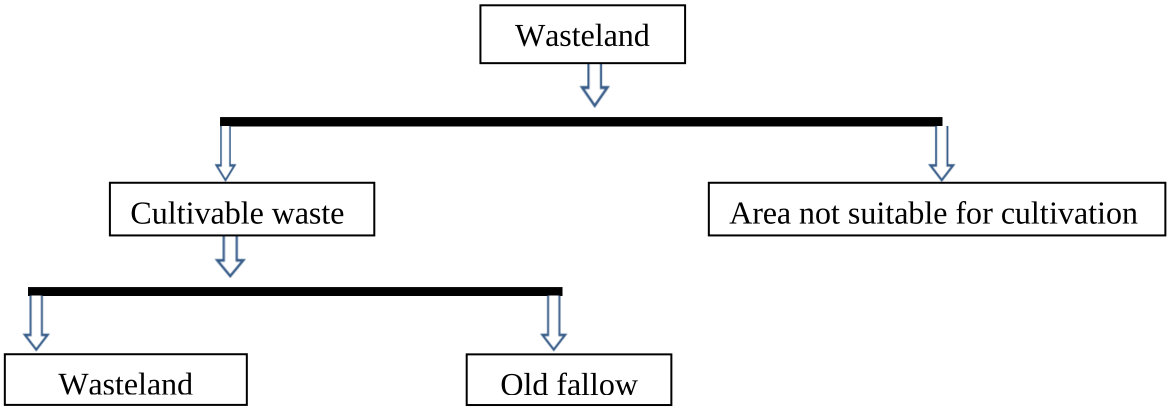
Wastelands include degraded forests, overgrazed pastures, drought-struck pastures, eroded valleys, hilly slopes, waterlogged marshy lands, barren land etc. Wastelands are lands which are economically unproductive, ecologically unsuitable and subject to environmental deterioration. The official estimate of wasteland in India in 2004 was nearly 63.85 million ha — more than 20% of the country's geographical area. According to the state wise break up, the state with the greatest percentage of its area that is classified is Rajasthan with 45 per cent, followed by the hill states Jammu and Kashmir, Tripura, Himachal Pradesh, Manipur, Sikkim, Mizoram, Meghalaya and Nagaland. This predominance of the hill states at the top of the list is because of the extent of snow-covered and glacial land in these states.

The extent of land degradation in the country is 120.4 M ha comprising of water and wind erosion, and chemical and physical degradation. Most of the degraded lands need immediate attention. However, health and quality of the salt-affected and acid soils needs to be restored on priority basis as there are otherwise potentially productive soils. Total salt-affected area in the country is 6.73 M ha; of which 3.70 M ha suffers from sodicity and 2.03 M ha is afflicted with salinity problems. Nearly 25 M ha of cultivated lands less than 5.5 are critically degraded. The productivity of these soils is very low (<1 t ha^{-1}) due to deficiencies of P, Ca, Mg, Mo B, and toxicities of Al and Fe. Since the deficiencies of micro- and secondary nutrients are progressively emerging as the yield-limiting factors of acid soils, in addition to the soil acidity-related constraints, soil tests need to be calibrated for recommending fertilizer dose for a whole cropping sequence based on initial soil test values for these soils.

What is essentially a wasteland?

The non technical definition of wasteland from the Cambridge Advanced Learner's Dictionary is 'An empty area of land, especially in or near a city, which is not used to grow crops or built on, or used in any way and/or a place, time or situation containing nothing positive or productive, or completely without a particular quality or activity'.

ICAR proposed that wastelands are lands which due to neglect or due to degradation are not being utilized to their full potential. These can result from inherent or imposed disabilities or both, such as location, environment chemical and physical properties, and even suffer from management conditions.



Categories of wasteland for identification

Table 2.1: Category-Wise Wastelands of India (2004)

Sr. No.	Category	Total Wastelands	Total Geographical Area covered (%)
1.	Guilled and/or Ravinous land	20553.35	0.65
2.	Land with or without scrub	194014.29	6.13
3.	Waterlogged and Marshy land	16568.45	0.52
4.	Land affected by salinity/alkalinity-coastal/ Inland	20477.38	0.65
5.	Shifting Cultivation Area	35142.20	1.11
6.	Underutilized/degraded notified forest land	140652.31	4.44
7.	Degraded pastures/grazing land	25978.91	0.82
8.	Degraded land under plantation crop	5828.09	0.18
9.	Sands-Inland/Coastal	50021.65	1.58
10.	Mining/industrial wastelands	1252.13	0.04
11.	Barren rocky/stony waste/sheet rock area	64584.77	2.04
12.	Steep sloping area	7656.29	0.24
13.	Snow covered and/or glacial area	55788.49	1.76
Total Wasteland Area		**638518.31**	20.17

Culturable Wasteland: The land which has potential for the development of vegetative cover and is not being used due to different constraints of varying degrees, such as erosion, water logging, salinity etc.

Unculturable Wasteland: The land that cannot be developed for vegetative cover, for instance the barren rocky areas and snow covered glacier areas.

Wasteland status in India

Table 2.2: Estimated Area under the Wasteland provided by different organization

Sr. No.	Source	Area (m. ha.)
1.	Ministry of Agriculture and the JNU, Deptt. of Geography (1986)	175
2.	National Land Use and Wasteland Development Council (1986)	123
3.	Society for Promotion of Wasteland Development (1982)	145
4.	Ministry of Rural Development & NRSA (2000)	64

Table 2.3: State wise wastelands of India-NRSA

Sr. No.	State	Wasteland (Area: In square km)
1.	Andra Pradesh & Telangana	45267.15
2.	Arunachal Pradesh	18175.95
3.	Assam	14034.08
4.	Bihar	5443.68
5.	Chhattisgarh	7584.15
6.	Goa	531.29
7.	Gujarat	20377.74
8.	Haryana	3266.45
9.	Himachal Pradesh	28336.80
10.	J & K	70201.99

11.	Jharkhand	11165.26
12.	Karnataka	1788.80
13.	Kerala	57134.03
14.	Madhya Pradesh	49275.41
15.	Maharashtra	13174.74
16.	Manipur	3411.41
17.	Meghalaya	4469.88
18.	Mizoram	3709.40
19.	Nagaland	18952.74
20.	Odisha	1172.84
21.	Punjab	101453.86
22.	Rajasthan	3808.21
23.	Sikkim	1322.97
24.	Tripura	17303.29
25.	Tamil Nadu	16097.46
26.	Uttarakhand	16097.46
27.	Uttar Pradesh	16984.16
28.	West Bengal	4397.56
29.	Union Territory	314.38
Total		**555253.14**

Formation of wasteland

Wasteland is formed either by natural ways or by man-made activities. The undulating upland, sandy area, snow covered area, coastal saline area *etc.*, are natural formation while gullied or Ravinous land, Jhum or Forest blank, Barren Hill-Ridges *etc.*, are formed by man-made activities.

There are four major anthropogenic activities that lead to the formation of wasteland areas *viz.*, deforestation, overgrazing, over cultivation and unskilled irrigation. The first three activities strip the land of its protective vegetation cover, accelerating the process of soil erosion and land degradation, while unskilled irrigation causes special problems of water logging and salinity.

In addition, both cultivated and uncultivated lands suffer from soil erosion and degradation. Mining is another important activity that causes deforestation and land degradation too.

India has only 2.4% of the world's geographical area and 0.5% grazing area but supports over 16% of the world's population and over 18% of world's cattle population. The degradation of environment in the fragile Indian sub-tropical, eco-system is basically attributed to increasing biotic and abiotic pressure; absence of adequate investment and appropriate management practices; high rate of population growth and high incidence of poverty in rural areas; over exploitation of natural resources; the break-down of traditional institutions for managing common property resources and failure of new institutions to fill the vacuum and. faulty land use practices. All these have resulted into soil and wind erosion; depletion of natural resources; lower productivity; groundwater depletion; shortage of drinking water; reduction in species diversity and increase in the extent of wastelands.

Assessment

As early as mid sixties scientists working on wasteland management realized the need to categorize the wasteland in accordance with their intrinsic characteristic and causative factors. They stated that among various characteristics, data on soil texture, soil depth, pH values, slope, erosion status and other inhibiting factors like salts, water-logging, flooding rockiness, stoniness, etc. are essential. They presented a complete inventory of the reasons responsible for lands lying Waste by collecting information from various sources. They serve as points for assessment of any wasteland.

1. Poor fertility of the soil due to rocky gravely, sandy, saline, alkali, water logged shallowness and eroded nature of the soil
2. Steep and undulated slopes
3. Shifting cultivation
4. Frequent droughts
5. Lack of irrigation facilities
6. Frequent submergence and flooding hazards
7. Lack of resources
8. Poor economic conditions of Ryat
9. Lack of labour during peak periods
10. Uneconomical return under cultivation
11. Certain domestic and legal difficulties
12. Absentee landlord’s holdings.

Reclamation of Wasteland

With the gradual rise of land resource demand, reclamation of wasteland appears to of the major tasks of the country.

The reclamation and development of wasteland has four objectives:

1. To improve the physical structure and the quality of the soil,
2. To improve the availability and quality of water,
3. To prevent the shifting of soil, landslides and flooding,
4. To conserve the biological resources of the land for sustainable use.

The capacity of the land to produce food, fodder, fuel and industrial raw materials is determined both by biological factors the Climate, soil, hydrological system_ etc.—and by social and economic factors such as land management practices and inputs like irrigation, fertilizers and seeds.

What is the potential productivity of wastelands and how can this be measured? This depends on what is meant by productivity, which like many other ecological terms is often confused in common usage. One definition of the productivity of an ecosystem is the amount of biomass "fixed" in a given time. This is a continuous process, but is measured as the amount of food manufactured per unit of time.

Land degradation

Degradation (or “desertification”) is the broad sense to mean impoverishment of the land by human activities and by natural causes. We will focus on human activities as causal agents. Land is considered “degraded” when its productivity is diminished.

Land degradation caused by agriculture takes many forms and has many causes. Some of the most important types of land degradation include

1. Degradation related to overgrazing by livestock
2. Degradation related to soil erosion
3. Degradation attributable to soil salinization
4. Degradation attributable to waterlogging

Causes of Land Degradation

The causes of land degradation due to various factors with area and components of water shed are depicted in table given below:

Table 2.4: Causes of land degradation

Sr. No.	Causes of Degradation	Area (million hectares)	Percentage of total area
1.	Water erosion	107.12	61.7
2.	Wind erosion	17.79	10.24
3.	Ravines	3.97	2.28
4.	Salt affected	7.61	4.38
5.	Waterlogging	8.52	4.90
6.	Degraded land due to shifting cultivation	4.19	2.82
7.	Degraded forest lands	19.49	11.22
8.	Special problems	2.73	1.57
9.	Coastal sandy areas	1.46	0.84
	Total	**173.64**	**100.0**

Range lands, degradation and management

Rangelands are grasslands, shrublands, woodlands, wetlands, and deserts that are gazed by domestic livestock or wild animals. Types of rangelands include tallgrass and shortgrass prairies, desert grasslands and shrublands, woodlands, savannas, chaparrals, steppes, and tundras. Rangelands do not include forests lacking grazable understory vegetation, barren desert, fland, or land covered by solid rock, concrete and/or glaciers.

Types of rangeland

The United States Environmental Protection Agency defines rangeland as "land on which the native vegetation (climax or natural potential plant community) is predominantly grasses, grasses like plants, forbs, or shrubs suitable for grazing or browsing use”. The EPA classifies; natural grassland and savannas as rangeland and in some cases includes wetlands, desert, tundra and certain forb and shrub communities." The primary difference between rangeland and pasture is management; rangelands tend to have natural vegetation along with a few introduced plant species, but all managed by grazing, while pastures have forage that is adapted for livestock and managed, by seeding, mowing, fertilization and irrigation.

Prairie: - Prairies are considered part of the temperate grasslands, savannas and shrublands biome by ecologists, based on similar temperate climates, moderate rainfall, and grasses, herbs, and shrubs, rather than trees, as the dominant vegetation type. Temperate grassland regions include the Pampas of Argentina, and the steppes of Eurasia.

Grasslands: - Grasslands are areas where the vegetation is dominated by grasses (Poaceae) and other herbaceous (non-woody) plants (forbs). However, sedge (Cyperaceae) and rush

(Juncaceae) families can also be found. Grasslands occur naturally on all continents except Antarctica.

Steppe: - Steppe in physical geography refers to a biome region characterized by grassland plan without trees a part from those near lacks and rivers. The term is also used to denote the climate encountered in regions too dry to support a forest, but not dry enough to be a desert.
Pampas:- Pampas are the fertile South American lowlands that include that Argentine provinces of Buenos Aires, La Pampa, Santa Fe, Entre Rios and Cordoba, most Uruguay and the state of Rio Grande do Sul, in the southernmost end of Brazil covering more than, 750,000 km^2. This area is also one of the distinct physiography provinces of the larger Parana-Paraguay Plain division. These plains contain unique wildlife because of the different terrains around it.

Shrubland: - Shrubland is a plant community characterized by vegetation dominated by shrubs, often including grasses, herbs, and geophytes. Shrubland may either occur naturally or be the result of human activity. It may be the mature vegetation type in a particular region and remain stable over time, or a transitional community that occurs temporarily as the results of a disturbance, such as fire. A stable state may be maintained by regular natural disturbance such as fire or browsing.

Woodland: - Woodland is a low-density forest forming open habitats with plenty of sunlight and limited shade. Woodlands may Support an understory of shrubs and herbaceous plant including grasses. Woodland may form a transition to shrublands under drier conditions or during early succession. Higher densities and areas of trees, with largely closed canopy, provide extensive and nearly continuous shade is referred to as forest.

Savanna: - Savanna is a grassland ecosystem characterized by the trees being sufficiently small or widely spaced so that the canopy does not close. The open canopy allows sufficient light to reach the ground to support an unbroken herbaceous layer consisting primarily of C4 grasses.

Desert: - Desert is a landscape or region that receives an extremely low amount of precipitation, defined as areas with an average annual precipitation of less than 250 mm per year, or as areas where more water is lost by evapotranspiration than falls as precipitation. In the Koppen climate classification system, deserts are classed as *BWh* (hot desert) or *BWk* (temperate desert). In the Thornthwaite climate classification system, deserts would be classified as arid megathermal climates.

Tundra: - Tundra is a biome where the tree growth is hindered by low temperatures and short growing seasons. The term *tundra* comes through Russian TyHpa from the Kildin Sami word *tundar* "uplands," "treeless mountain tract." There are three types of tundra: Arctic tundra, alpine tundra, and Antarctic tundra. In tundra, the vegetation is composed of dwarf shrubs, sedges and grasses, mosses, and lichens. Scattered trees grow in some tundra. The ecotone (or ecological boundary region) between the tundra and the forest is known as the tree line or timberline.

Management of Range Lands

Management for yield improvement: Success of a program is, largely dependent on the soundness of research technology advanced. This is all the more of vital importance in rangeland management where limitations are of good land, adequate rainfall, favorable climatic conditions *etc*. Research work done earlier at this Institute has revealed that adoption of suitable range management technology can go a long way in improving land and vegetation types in both arid and semi-arid areas of western Rajasthan.

(1) **Fencing: -** For protection against biotic factors, angle iron posts with barbed wire (four to five strands) fencing have proved to be most durable and economical in the long run although the initial cost is high. The fact to be reckoned with is that fencing is a must before any management program is launched at least in and regions of western Rajasthan where pressure on land is maximum both from human and animal as compared to elsewhere in the desert areas of the world. Moreover, larger the area, cheaper it is to go for fencing and as such, initial coverage of area between 100 to 1000 ha is desirable for range management program.

(2) **Adoption of soil and water conservation measures: -** Rangeland management area generally comprise of land falling in class IV to class VIII which are mostly highly eroded their by exposing rocky surface, stones and boulders.

(3) **Reseeding in rangelands: -** Natural succession of the high yields perennial grasses in the arid regions is rather a time consuming process.

(4) **Genetically improved strains of grasses: -** Improved strains of grasses have the genetic production potential of even higher than 40q/ha and therefore, should be used for reseeding program.

(5) **Fertilization**: - The nutrient content and production- potential of forage species on the rangelands in western Rajasthan is quite low and, therefore, for optimum production, it is essential to provide adequate nutrients to the soils as these are often subjected to erosion hazards and are highly u depleted.

(6) **Role of legumes**: - The key role of legumes in soil enrichment in the absence of the manuring needs no emphasis. However, their importance is twofold; firstly, they constitute a high protein component in Indian dietary and secondary, they provide nutritious forage for livestock.

(7) **Silvi-pastoral management: -** Since livestock husbandry occupies the most important place in the economy of the arid region and that frequent droughts results in loss of livestock’s owing to the shortage of fodder resources, it is necessary that range improvement program is also complemented by raising fodder tree and shrub species.

Chapter 3

Salt affected Soils, Problems, Reclamation and Management of Saline and Sodic Soils

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The soils which possess characteristics that make them uneconomical for the cultivation of crops without adopting proper reclamation measures are known as problem soils. Often we resort to chemical means of reclamation that leads to impairment of ecosystem functions. Resorting to natural means and integrated methods will resolve the issue and prevent causing irreparable damage.

DEFINITION

(1) **Saline (Solonchak, Russian term) soil:** Saline soil is defined as a soil having a conductivity of the saturation extract greater than 4 dSm^{-1} (0.4 dSm^{-1} or 4 mm hos cm^{-1}) and an exchangeable sodium percentage (ESP) less than 15. The pH is usually less than 8.5. Formerly these soils were called ***white alkali*** soils because of surface crust of white salts.

(2) **Alkali (Non-saline alkali (sodic) or sodic or solonetz, a Russian term) soil :** Alkali or sodic soil is defined as a soil having a conductivity of the saturation extract less than 4 dSm^{-1} (0.4 Sm^{-1} or 4 mmhos cm^{-1}) and an exchangeable sodium percentage (ESP) greater than 15. Their pH is usually between 8.5-10.0. Formerly these soils were called ***black alkali*** soils and soil so formed is called *solod, soloth* or degraded alkali or sodic soil.

Black alkali soil: Sodic or alkali soils were formerly called ***black alkali*** soils. Due to high pH and the dominance of sodium (Na^+) ions in alkali or sodic soils, part of the soil organic matter dissolves and comes into the soil solution. Extracts of such soils have a characteristic dark brown or black colour. The dissolved organic matter in the soil solution becomes deposited as a thin film on the soil surface. The prevalence of such black stains in such soils are called “Black alkali” soils.

Chemical reactions resulting high pH in alkali or sodic soils:

Since alkali or sodic soils contain adequate amount of sodium carbonate (Na_2CO_3), so the hydrolysis of Na_2CO_3 results in high pH.

$$2Na^+ + CO_3^{2-} + 2H_2O == 2Na^+ + 2OH^- + H_2CO_3$$

(Causes high pH)

Hydrolysis of Na-clay (in absence of free $CaCO_3$)

$$Na\,[\,\text{clay} + H_2O == H\,[\,\text{clay} + NaOH$$

$$2NaOH + CO_2 == Na_2CO_3 + H_2O$$

(free soil) (Soils more alkali)

Hydrolysis of Na-clay (in presence of free $CaCO_3$)

$$Na\,[\,\text{clay} + H_2O == H\,[\,\text{clay} + NaOH$$

$$\begin{array}{l}H\\H\end{array}\Big[\,\text{clay} + 2\,NaOH + CaCO_3 == Ca\,[\,\text{clay} + Na_2CO_3 + 2\,H_2O$$

(causes high pH)

(3) **Saline – alkali soils:** Saline-alkali soil is defined as a soil having a conductivity of the saturation extract greater 4 dSm^{-1} (0.4 Sm^{-1} or 4 mm hos cm^{-1}) and an exchangeable sodium percentage (ESP) greater 15. The pH is variable and usually above 8.5 depending on the relative amounts of exchangeable sodium and soluble salts. When soils dominated by exchangeable sodium, the pH will be more than 8.5 and when soils dominated by soluble salts, the pH will be less than 8.5.

(4) **Degraded alkali or sodic soils:** If the extensive leaching of a saline-sodic soil occurs in the absence of any source of calcium or magnesium, part of the exchangeable sodium is gradually replaced by hydrogen. The resulting soil may be slightly acid with unstable structure. Such a soil is degraded alkali or sodic soil.

clay] Na + H_2O === H [clay + NaOH |
(Acid soil on ↓ leaching
the surface horizon)
$NaOH + CO_2$ = $Na_2CO_3 + H_2O$
(from soil) (alkali soil in the sub-surface horizon)

Sodium carbonate (Na_2CO_3) dissolves humus and is deposited in the lower layer. The lower layer thus acquires a black colour. At the same time H-clay formed in this way does not remain stable. The process of break-down of H-clay under alkaline condition is known as solodisation.

Distribution:

In India estimated that about 7 million hectares of land are salt affected *i.e.* saline and alkaline soils. State wise distribution of salt affected soils in India is given in table 3.1.

Table 3.1: Extent (ha) of salt affected soils in India

States	**Saline**	**Sodic**	**Total**
Andhra Pradesh	77598	196609	274207
Andaman & Nicobar Island	77000	0	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	183399	232556
Karnataka	1893	148136	150029
Kerala	20000	0	20000
Madhya Pradesh	0	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	0	147138
Punjab	0	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	0	441272
Total	2956809	3770659	6727468

In Gujarat out of 196 lakh ha of geographical area of the state, about 109 lakh ha (55.6%) is gross cultivated. Irrigated area constitutes only 26 percent of this while remaining 74 per cent is left as rainfed. Even after full of commissioning of the giant Sardar Sarovar Project, more than 50 percent of the cultivated area will still have to depend upon the mercy of weather's vagaries. At present, contribution of ground water towards irrigated area is 70 per cent while that of canal water is only 30 per cent. In spite of the fact that about 26 lakh ha of cultivated land is under irrigation, the expected level of crop productivity has not been achieved. On the other hand, deterioration has been observed in the soil health under canal as well as ground water commands. Some such soil related constraints are enumerated in table 3.2.

Table 3.2: Agroclimatic zone wise soil related water management constraints

Sr. No.	Agro climatic Zone	Physiographic Location	Constraints
I.	South Gujarat Heavy Rainfall	Piedmont slope and valley plains	Shallow Depth, highly erosive, low to moderate WHC, highly permiable.
		Mid alluvial plains	High WHC, severe cracking, low to very low permeability, poor internal drainage, secondary salinazation, water logging in parts.
		Coastal Alluvial plains	Salt affected, highly dispersive, poor drainage, low permeability, mild cracking.
II.	South Gujarat	Piedmont slope and valley plains	Highly erosive, low to medium WHC, highly permeable.
		Alluvial plains	Prone to erosion, moderate to poor drainage, medium to low permeability, secondary salinazation and water logging in parts.
		Coastal alluvial plains	Same as those of coastal alluvial plains of zone I.
III.	Middle Gujarat	Eastern hilly belt	Prone to erosion, low to WHC, shallow depth.
		Mid alluvial plains	Erosion adjoining river beds, secondary salinization and water logging in canal command areas.
		Coastal plains	Salt affected, poor to medium drainage.
IV.	North Gujarat	Border high lands	Highly erodible, deep with low WHC, excessively drained.
		Mid plains	Low WHC, salinity excessive permeability, very low AMC.
		Western paints	Salt affected, low permeability, poor drainage in some pockets.
V.	North West	Eastern plain	Excessive permeability poorly drained and salt affected in pockets, low WHC and AMC.
			Poorly drained and hydromorphic in pockets, salt affected, low to medium WHC.
VI.	North Saurashtra	Southern plains	Highly calcareous, salt affected soil in patches, erodible in hilly areas.
		Northern plains (including hilly areas)	Salt affected
		Coastal belt	
VII.	South Saurashtra	Inland areas (including hilly areas)	Highly calcareous, poor permeability, poor WHC in hilly areas.
		Coastal areas (including Ghed)	Salt affected, highly dispressive and water logged in Ghed.
VIII.	Bhal and Coastal Area	Whole zone	Salt affected, poor drainage, water logging in monsoon.

Sources of soluble salts:

There are various sources from which soluble salts are accumulated in the soil.

(i) **Primary minerals:** It is the original and important source of all the salt constituents. During the process of chemical weathering, which involves hydrolysis, hydration, solution, oxidation and carbonation, various constituents like Ca^{2+}, Mg^{2+} and Na^+ are gradually released and made soluble.

(ii) **Arid and semi-arid climate:** Salt affected soils are mostly formed in arid and semi-arid regions where low rainfall and high evaporation prevails. The low rain fall or precipitation in these regions is not sufficient to leach out the soluble weathered products and hence the salts accumulate in the soil. During rain, the salts dissolve in rainwater and migrate downward. However, due to limited rainfall, the downward movement is restricted to a short distance only. In dry weather, the salts move up with the water and are brought up to the surface where they are deposited as the water evaporates.

(iii) **Ground water:** Ground water contains large amounts of water soluble salts which depend upon the nature and properties of the Geological material with which water remains in contact where water table and evapotranspiration rate is high, salts along with water move upward through capillary activity and the salts accumulate on the soil surface in the form of crystallization.

(iv) **Ocean or sea water:** Sea water enters into the land by inundation a deposited on the soil surface as salts.

(v) **Irrigation water:** The application of irrigation water without proper management (i.e. lack of drainage and leaching facilities) increases the water table and surface salt content in the soil.

(vi) **Salt blown by wind:** In arid regions near the sea, appreciable amount of salts are blown by wind year after year and get deposited on the surface soil. Due to low rainfall the deposited salts are not washed back to the sea or leached to the lower soil horizon and thereby develop salinity in the soil. The salinity of Rajasthan are mostly developed through this source.

(vii) **Excessive use of back fertilizers:** Use of basic fertilizers like sodium nitrate ($NaNO_3$), basic slag etc. may develop soil alkalinity.

Nature of soluble salts in saline soils

Soluble salts, as referred to in soil science, are those inorganic chemicals that are more soluble than gypsum ($CaSO_4 . 2H_2O$), which has a solubility of 0.241 gm per 10 ml of water at 0^0C. Common table salt (NaCl) has solubility nearly 150 times greater than gypsum (35.7 gm per 100 ml). Most of soluble salts in saline soils are composed of the cations sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) and the anions chloride (Cl^-), sulphate (SO_4^{2-}), and bicarbonate (HCO_3^-). Usually smaller quantities of potassium (K^+), ammonium (NH_4^{2-}), nitrate (NO_3^-), and carbonate (CO_3^{2-}) also occur, as do many other ions.

Among all these salts, the dominant anions are chloride (Cl^-) and sulphate (SO_4^{2-}) and cations are Na^+, Ca^{2+} and Mg^{2+}. Boron may also be present in saline soils which in small concentrations is also toxic to plant.

CHARACTERISTICS OF SALT AFFECTED SOILS

The most important characteristics of salt affected soils like saline, non-saline-alkali, saline-alkali and degraded alkali soils are given in table 3.4.

Table 3.4: Important characteristics of salt affected soils

Characteristics	Saline soil	Non-saline alkali soil	Saline-alkali soil	Degraded alkali soil
Content of soil	Excess soluble salts of sodium	Absent of soluble salt and presence of excess exchangeable sodium on the soil complex.	Thee soils are both saline and non-saline alkali soil.	Hydrogen (H^+) ions in the upper layer and sodium (Na^+) in the lower layer
Exchangeable calcium/sodium	Exchangeable calcium	Exchangeable sodium	--	--
Colour	White	Black	--	Black in lower layer
Dominant salts	Sulphate (SO_4^{2-}) chloride (Cl^-) and nitrate (NO_3^-) of sodium	Sodium carbonate (Na_2CO_3)	--	Sodium carbonate (Na_2CO_3) lower layer
Sodium adsorption ratio (SAR)	Less than 13	More than 13	More than 13	< 13 in the surface and > 13 in the lower horizon
Exchangeable sodium percent-tage (ESP)	Less than 15 of total CEC	More than 15 of total CEC	More than 15 of total CEC	Usually more than 15 of total CEC
Soil pH	Less than 8.5	8.5-10.0	More than 8.5	pH about 6.0 in the surface soil and pH 8.5 in the lower layer constituting the main soil body
Physical condition of the soil	Flocculated condition, permeable to water and air. Soil structure optimum	Deflocculated condition, permeability to water and air is poor. Very poor soil structure	Flocculated deflocculated depending upon the presence of sodium salts and Na-clay	Compact low infiltration & permeability. It develops columnar structure
Morphological character	White crust on the soil surface	Due to presence of high amount of exch. Na^+ and high pH clay	--	--

		colloids get dispersed & migrated downward through the soil profile.		
Organic matter	Slightly less than normal soils	Very low due to the presence of sodium carbonate (Na_2CO_3)	Variable	Low
Total soluble salt content	More than 0.1 percent.	Less than 0.1 percent	More than 0.1 percent	Less than 0.1 percent
EC of the saturation extract	>4 dSm^{-1} or >4 mmhos cm^{-1}	>4 dSm^{-1} or >4 mmhos cm^{-1}	>4 dSm^{-1} or >4 mmhos cm^{-1}	>4 dSm^{-1} or >4 mmhos cm^{-1}

FORMATION OF SALT AFFECTED SOILS

Saline Soils

The process by which the saline soil formed is called "Salinization", Saline soils occur mostly in arid or semi-arid regions. Under humid conditions soluble salts originally present in soil materials and those formed by weathering of minerals generally are carried downward into the ground water and are transported ultimately by streams or oceans. Saline soils are, therefore, practically non-existent in humid regions, except when the soil has been subjected to sea water in river deltas and low lying lands near the sea. In arid regions saline soils occur not only because there is less rainfall available to leach and transport the salt but also because of high evaporation rates, which tend further to concentrate the salts in soils and in surface waters. Restricted drainage is another factor that usually contributes to the salinization of soils and may involve the presence of a high ground water table or low permeability of the soil. Low permeability of the soil causes poor drainage by impeding the downward movement of waters. Low permeability may be the result of an unfavorable soil texture or structure or the presence rated layers may consist of a clay pan or a caliche layer of a silica hardpan.

Alkali or Sodic Soil

It is evident that soil colloids adsorb and retain cations on their surfaces. Cation adsorption occurs as a consequence of the electrical charges at the surface of the soil colloids. While adsorbed cations are combined chemically with the soil colloids, they may be replaced by other cations that occur in the soil solution. The reaction whereby a cation in solution replaces an adsorbed cation is called cation exchange and is expressed as milliequivalent per 100 g soil. Calcium and magnesium are the principal cations found in the soil solution and on the exchange complex of normal soils in arid regions. When excess soluble salts accumulate in these soils, sodium frequently becomes the dominant cation in the soil solution. In arid regions as the soil solution becomes concentrated through evaporation or water absorption by plants, the solubility limits of calcium sulphate ($CaSO_4$), calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) are often exceeded, in which case they are precipitated with a corresponding increase in sodium concentration. Under such conditions, a part of the original exchangeable calcium (Ca^{2+}) and magnesium (Mg^{2+}) is replaced by sodium (Na^+) resulting alkali or sodic soils.

$$\mathrm{Ca\,[Clay} + 2\mathrm{Na}^+ \leftrightarrow \begin{matrix}\mathrm{Na}^+\\ \mathrm{Na}^+\end{matrix}\sum\mathrm{Clay} + \mathrm{Ca}^{2+}$$

Saline-Alkali or Saline-Sodic Soil

These soils form as a result of the combined processes of salinization and alkalization. If the excess soluble salts of these soils are leached downward, the properties of these soils may change markedly and become similar to those of sodic soil. As the concentration of these salts in the soil solution is lowered, some of the exchangeable sodium hydrolyzes and form sodium hydroxide (NaOH). This may change to sodium carbonate upon reaction with carbon dioxide (CO_2) absorbed from the atmosphere.

$$\begin{array}{ll} \mathrm{Na\,[Clay} + H_2O \leftrightarrow \mathrm{Na}^+\,\mathrm{[Clay} & + \mathrm{NaOH} \\ \qquad\qquad\qquad\quad \mathrm{Na}^+ & \downarrow + CO_2 \\ & NaHCO_3 \rightarrow Na_2CO_3 \end{array}$$

(forming alkali soil)

On extensive leaching, the soil may become strongly alkaline, the particles disperse and the soil becomes unfavorable for the entry and movement of water and for tillage operation. At the same time sodium toxicity to plants is increased. These soils sometimes contain gypsum ($CaSO_4.2H_2O$) and when it is subjected to intense leaching, calcium dissolves and the placement of exchangeable sodium by calcium takes place concurrently with the removal of excess salts.

APPRAISAL OF SALINE AND SODIC SOILS

Saline Soil

Different criteria are employed for characterizing soil salinity and those are given below:

(i) Soluble salt concentration in the soil solution: - In saline soil the soluble salt concentration in the soil solution is very high and as a result the osmotic pressure of the soil solution is also very high. As a result of which the plant growth is affected due to wilting and nutrient deficiency. Salt content more than 0.1 per cent is injurious to plant growth.

(ii) Osmotic Pressure: Osmotic pressure of the soil solution is closely related to the rate of water uptake and the growth of plants in saline soils. The osmotic pressure of soil solutions is usually calculated from the freezing point depressions as follows:

$$\text{Osmotic Pressure (O.P.)} = 12.06\,\Delta T - 0.021\,\Delta T^2$$

Where, ΔT = depression of freezing point in soil solution

It should be assessed of field capacity soil moisture regimes. Besides the relation between OP and electrical conductivity (EC) for salt mixtures found in saline soils, is given below:

$$\text{OP (in atmospheres or bars)} = 0.36 \times EC$$

Where, EC expressed as dSm^{-1}.

(iii) Electrical conductivity (EC) of the soil saturation extract:- Measurement of EC of the soil saturation extract is also essential for the assessment of the saline soil for the plant growth and is expressed as dSm^{-1} (formerly mmhos cm^{-1}).

EC values (dSm^{-1})

< 2 — Salinity effects mostly negligible
2- 4 — Yields of very sensitive crops may be restricted
4-8 — Yields of many crops restricted
8-16 — only tolerant crops yields satisfactorily
> 16 — only a few very tolerant crops yield satisfactorily

(iv) Concentration of water soluble boron: - The determination of water soluble boron concentration is also another criterion for characterization of saline soils. The critical limits of boron concentration for the plant growth is given below:

Boron concentration (ppm)
< 0.7 — Crops can grow (safe)
0.7-1.5 — Marginal
> 1.5 — Unsafe

(v) Soil texture: - A sandy soil with 0.1 per cent salt would be saline enough to injure the growth of common crops, while a clayey soil with the same amount of salt may be just a normal soil in wh. fields of even sensitive crops would not be affected. The U.S. Salinity Laboratory (USDA, Hand book, 60) has developed the concept of saturation percentage (SP), as a characteristic property of each soil, which depends on the texture of the soil and the' electrical conductivity of saturation extract (EC) as a means of salinity appraisal. The recent technique developed by the U.S. Salinity Laboratory is to use pressure membrane apparatus for extracting soil solution at any desired level in the entire field moisture range.

Alkali Soil

There are various methods employed for its approval that are as follows:

(i) Development of a quick and accurate method for determining exchangeable sodium in saline—sodic and sodic soils, to serve as a guide for reliable appraisal of the alkali conditions, has always been a problem. A direct determination of exchangeable sodium in saline-alkali soils is best with many difficulties because of the presence of sodium salts in equilibrium with exchangeable sodium in the soil-water system.

$$\underset{\text{Approximately}}{\text{Exchangeable sodium}} = \underset{\text{(exchangeable soluble)}}{\text{Total sodium}} - \text{Soluble sodium}$$

(ii) Sodium Adsorption Ratio (SAR):- The U.S. Salinity Laboratory developed the concept of Sodium Adsorption Ratio (SAR) to define the equilibrium between soluble and exchangeable cations as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

(Na^{+}, Ca^{2+} and Mg^{2+} are concentrations in saturation extract in mel^{-1})

The value of SAR can be used for the determination of Exchangeable Sodium Percentage (ESP) of the saturation extract by using the following formula:

$$ESP = \frac{100\,(-\,0.0126 + 0.01475\ SAR)}{1 + (-\,0.0126 + 0.01475\ SAR)}$$

Sometimes the following regression equation is used for the appraisal of alkali soil by determining the value of ESP from the value of SAR.

$$Y = 0.0673 + 0.035\ X$$

Where, Y indicates ESP and X indicates SAR

Soils having SAR value greater than 13 are considered as alkali or sodic soil.

Calcareous Soils

In the context of agricultural problem soils, calcareous soils are soils in which a high amount of calcium carbonate dominates the problems related to agricultural land use. They are characterized by the presence of calcium carbonate in the parent material and by a calcic horizon, a layer of secondary accumulation of carbonates (usually Ca or Mg) in excess of 15% calcium carbonate equivalent and at least 5% more carbonate than an underlying layer.

Calcareous soils cover more than 30% of the earth surface, and their $CaCO_3$ content varies from a few percent to 95%. Hagin and Tucker (1982) defined calcareous soil as a soil that its extractable Ca and Mg levels exceed the cation exchange capacity.

Origin of Calcareous Soils

1. Calcareous soils occur naturally in arid and semi-arid regions because of relatively little leaching
2. They also occur in humid and semiarid zones if their parent material is rich in $CaCO_3$, such as limestone, shells or calcareous glacial tills, and the parent material is relatively young and has undergone little weathering.
3. Some soils that develop from calcareous parent materials can be calcareous throughout their profile. This will generally occur in the arid regions where precipitation is scarce. In other soils, $CaCO_3$ has been leached from the upper horizons, and accumulated in B or C horizons. These lower $CaCO_3$ layers can be brought to the surface after deep soil cultivation.
4. In some soils, the $CaCO_3$ deposits are concentrated into layers that may be very hard and impermeable to water. These *caliche* layers are formed by rainfall leaching the salts to a particular depth in the soil at which water content is so low that carbonates precipitate.
5. Soils can also become calcareous through long period of irrigation with water containing dissolved $CaCO_3$

Main production constraints

1. Calcareous soils develop in regions of low rainfall and must be irrigated to be productive. Therefore one of the main production constraints is the availability of water for irrigation.
2. The quality of the irrigation water is of crucial importance for sustainable agricultural production on calcareous soils. Frequently, the irrigation water is the cause of many management problems. Almost all waters used for irrigation contain inorganic salts in solution. These salts may accumulate within the soil profile to such concentrations that they modify the soil structure, decrease the soil permeability to water, and seriously injure plant growth.
3. Crusting of the surface may affect not only infiltration and soil aeration but also the emergence of seedlings.
4. Cemented conditions of the subsoil layers may hamper root development and water movement characteristics.
5. Calcareous soils tend to be low in organic matter and available nitrogen.
6. The high pH level results in unavailability of phosphate (formation of unavailable calcium phosphates as apatite) and sometimes reduced micronutrient availability *e.g.* zinc and iron (lime induced chlorosis). There may be also problems of potassium and magnesium nutrition as a result of the nutritional imbalance between these elements and calcium.

Role of $CaCO_3$ in plant nutrition

The carbonates are characterized by a relatively high solubility, reactivity and alkaline nature; their dissolution resulting in a high solution HCO_3^- concentration which buffers the soil in the pH range of 7.5 to 8.5:

$$CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^- + OH^-$$

Symptoms of impaired nutrition in calcareous soils are chlorosis and stunted growth. This is attributed to the high pH and reduced nutrient availability, as direct toxicity of bicarbonate ions (HCO_3^-) to physiological and biochemical systems are much less likely. The availability of P and Mo is reduced by the high levels of Ca and Mg that are associated with carbonates. In addition, Fe, B, Zn, and Mn deficiencies are common in soils that have a high $CaCO_3$ due to reduced solubility at alkaline pH values.

PROBLEMS OF SALT AFFECTED SOILS

Saline Soils

There are various problems of saline soils that interfere with the plant growth.

(i) Soils are usually barren but potentially productive
(ii) Wilting coefficient of saline soil is very high
(iii) Amount of available soil moisture is low
(iv) Absorption of water and nutrients
(v) Excessive salts in the soil solution increase the osmotic pressure of soil solution in comparison to cell sap. This osmotic effect increases the potential forces that hold water in the soil and makes it more difficult for plant roots to extract moisture. During a drying period, salt in soil solutions may be so concentrated as to kill plants by pulling water from them (exoosmosis).
(vi) Due to high salt concentration plants have to spent more energy to absorb water and to exclude salt from metabolically active sites. At the same time various nutrient elements become unavailable to plants.
(vii) Salt toxicity: - When the concentration of soluble salts increases to a high level then it produces toxic effect directly to plants such as root injury, inhibition of seed germination etc.

Alkali or Sodic Soils

Excess exchangeable sodium in alkali soils affects both the physical, and chemical properties of soils.

i. **Dispersion of soil colloids.** Under alkali conditions, the damage is not due to salt concentration. The influence of exchangeable sodium on the over-all physical properties of soils is associated mainly with the behavior of the clay and organic matter, in which most of the cation exchange capacity (CEC) is concentrated. The sodium (Na^+) ion adsorbed by clay colloids causes deflocculation or dispersion of clay which result in a loss of desirable soil structure and helps for the development of compact soil.
ii. **Other physical properties:** - Due to dispersion and compactness of soil, aeration, hydraulic conductivity, drainage and microbial activity are reduced.

iii. **Caustic influence**: - It results high sodicity caused by the sodium carbonate (Na_2CO_3) and bicarbonate ($NaHCO_3$).

iv. **Concentration of hydroxyl (OH^-) ion: -** High hydroxyl (OH^-) ion concentration no doubt has direct detrimental effect on plants. Damage from hydroxyl ions occurs at pH 10.5 or higher.

v. **Specific ion effect: -** The presence of excess sodium in sodic soils may induce deficiencies of other cation like calcium (Ca^{2+}) and magnesium (Mg^{2+}). The action of sodium in inducing deficiencies of Ca^{2+} and Mg^{2+} appears to be three fold:

a. because sodium is comparatively loosely held in exchangeable form, the ions released to the soil solution in a fractional exchange are mostly sodium ions if the soil has a high exchangeable sodium percentage,

b. at the high pH values (sodic soil) usually associated with excess exchangeable sodium in the absence of excess salts, the soil solution contains bicarbonate and carbonate ions that tend to form insoluble precipitates of calcium and magnesium carbonates as follows :

$$\underset{\text{Soil solution}}{Ca^{2+}} \quad + \quad \underset{\text{Soil solution}}{CO_3^{2-}} \quad = \quad \underset{\text{(Insoluble precipitation)}}{CaCO_3}$$

c. Exclusion of calcium and magnesium from absorption on competitive basis.

d. Availability of Plant nutrients. The high pH in alkali or sodic soils decreases the availability of many plant nutrients like P, Ca, N, Mg, Fe, Cu, Zn.

RECLAMATION OR AMELIORATION OF SALINE AND ALKALI OR SODIC SOILS

Before reclamation of saline and alkali or sodic soils, the following important points are to be considered:

a. Quality of irrigation water *i.e.* total soluble salt, SAR or sometimes boron determination is essential.
b. Quality of the soil *i.e.* saline or alkaline and the degree of salinity or alkalinity.
c. Nature and distribution of salts in the root zone.
d. Level of sub-soil water
e. Drainage conditions

Besides these the following technical requirements are necessary for the reclamation of saline and alkali soil.

i. Adequate drainage
ii. Availability of sufficient water to meet the demand of crop and also leach the salt below1he root zone in the soil.
iii. Perfect land levelling, good bonding for irrigation and advanced agronomic practices.
iv. Good quality of irrigation water.

Methods

There are three general ways by which saline and alkali soils can be ameliorated in order to avoid injurious effect to plants.

Eradication: The most common methods generally used to free the excess salts of saline soils are: (i) under drainage and (ii) Leaching or flushing.

A combination of the two, flooding after tile drain is the most effective. Leaching method is very much effective in ameliorating saline soil whose soluble salts are largely neutral and high in Ca^{2+} and Mg^{2+} and very little exchangeable Na^+. Leaching saline-alkali or sodic soils with water high in soluble but low in exchangeable Na^+ may be effective.

Physical method

This is not actually removes sodium from exchange complex but inprove physical condition of soil through improvement in infiltration and aeration. The vcommonly followed physical methods include:

- Construction of embankment to prevent tidal see water
- Land leveling and contour bunding
- Establishment of drainage network
- Breaking of hardpan in the subsurface layer through boring auger hole
- Scrapping of salt crust
- Deep tillage, sub soiling, profile inversion
- Use of soil conditioners e.g. sand, *tanch*, ash, manures and synthetic polymers like PVAC, PAM, and PVPC

Cultural method

- Providing proper drainage if the soil is not free draining artificial drains are opened or tile drains laid underground to help wash out the salts.
- Little of salt free irrigation water good quality of irrigation should be given.
- Proper use of irrigation water, it is known that as the amount of water in the soil decrease the concentration of the salts in the soil solution of the salts in the soil solution is increases thus moisture should be kept at optimum field capacity.
- Planting or sowing of sees in furrow: The salt concentration even in smaller amounts is a most harmful to the germinating seeds. Water generally evaporates from the highest surface by capillary and hence these points have maximum concentration. If the seeds or seedling are planted inside the furrow they escape the zone of maximum salt concentrations and thus can germinate and develop properly during their early growth stage
- Use of acidic fertilizes: In saline soil acid fertilizers such as ammonium sulphate should be used
- Use of organic manures: When sufficient amount of manures are added the water holding capacity of soil increased and as a result the conductivity of the soil solution decreases.
- Ploughing and leveling of the land: Ploughing increasing the infiltration and percolation rate. Therefore salts leached down to the lower levels.
- Returning of water evaporation: Mulching with crop residues or plastic sheet helps in decrease evaporation.

- **Growing of the salt tolerance crops:**
    a. High salt tolerance crop: Barley, Sugar beet, Para grass etc
    b. Moderately salt tolerant crops: Wheat, rice, maize, sorghum
    c. Low salt tolerance crops: Beans, radish, white clover etc
    d. Sensitive crops: Tomato, potato, onion, carrot etc.

LEACHING REQUIREMENT (LR)

The leaching requirement may be defined as the fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level.

The leaching requirement (LR) is simply the ratio of the equivalent depth of the drainage water to the depth of irrigation water and may be expressed as a fraction or as per cent. Under the assumed conditions (uniform aerial application of irrigation water, no rainfall, and no removal of salt in the harvested crop and no precipitation of soluble constituents in the soil), this ratio is equal to the inverse ratio of the corresponding electrical conductivities as follows:

$$LR = \frac{D_{dw} \times 100}{D_{iw}} = \frac{EC_{iw} \times 100}{EC_{dw}}$$

Where LR = Leaching requirement expressed in percentage

D_{dw} = Depth of drainage water in inches

D_{iw} = Depth of irrigation water in inches

D_{iw} = Electrical conductivity of the irrigation water in dSm^{-1}

D_{dw} = Electrical conductivity of the drainage water in dSm^{-1}

In applying this equation, a value is usually assumed in EC_{dw} (8 dSm^{-1} for most of the field crops) to represent the maximum soil salinity that can be tolerated, for irrigation water with conductivities of 1, 2 and 3 dSm^{-1}, respectively, the leaching requirement will be 13, 25 and 38 per cent (taking the value EC_{dw} as 8 dSm^{-1}).

Chemical method

In case of saline sodic and sodic soils, the exchange complex is saturated to varying degree with Na. The reclamation procedure in such cases also involves the use of amendments for replacing exchangeable Na.

Different types of chemical amendments:

A. Soluble calcium salts e.g.

1. Calcium chloride ($CaCl_2.2H_2O$)
2. Gypsum ($CaSO_4.2H_2O$)
3. Calcium sulphate ($CaSO_4$)

B. Acid or acid formers e.g.

1. Sulphur (S)
2. Sulphuric acid (H_2SO_4)
3. Iron sulphate ($FeSO_4.7H_2O$)
4. Aluminium sulphate ($Al_2(SO_4)_3.18H_2O$)
5. Lime sulphur (calcium poly sulphide (CaS_5)
6. Pyrites FeS_2)

Chemical reactions involving reclamation of salt affected soils

(i) Gypsum ($CaSO_4.2H_2O$)

When gypsum is applied to ameliorate salt affected soils, the following reaction will take place and loss of exchangeable sodium (Na^+) occurs and calcium will take the place of sodium on the exchange complex.

Gypsum reacts with both Na_2CO_3 and the adsorbed sodium as follows:

$$Na_2CO_3 + CaSO_4 \quad === \quad CaCO_3 + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

$$\text{Clay}\,]^{Na}_{Na} + CaSO_4 \quad === \quad Ca\,[\,\text{clay} + \underset{\text{leachable}}{Na_2SO_4 \downarrow}$$

(ii) Sulphur

When sulphur is applied to salt affected soils (alkali and salin alkali) the following reaction take place.

$2\ S + 3O_2 = 2SO_3$ (By the action of sulphur oxiding bacteria in soil)

$SO_3 + H_2O = H_2SO_4$

$H_2SO_4 + Na_2\ CO_3 = CO_2 + H_2O + Na_2SO_4 \downarrow$
leachable

On calcareous alkali soil

The production of H_2SO_4 is common for all soils as mentioned above.

(a) $H_2SO_4 + CaCO_3 === CO_2 + H_2O = CaSO_4$

$CaSO_4 + {}^{Na}_{Na}[\text{ clay} === Ca\ [\text{ clay} + Na_2SO_4 \downarrow$
leachable

(b) $H_2SO_4 + 2CaCO_3 === CaSO_4 + Ca\ (HCO_3)_2$

$CaSO_4 + {}^{Na}_{Na}[\text{ clay} === Ca\ [\text{ clay} + Na_2SO_4 \downarrow$
leachable

$Ca\ (HCO_3)_2 + {}^{Na}_{Na}[\text{ clay} === Ca\ [\text{ clay} + 2\ NaHCO_3$

On non-calcareous alkali soil

$H_2SO_4 + {}^{Na}_{Na}[\text{ clay} === {}^{H}_{H}[\text{ clay} + Na_2SO_4 \downarrow$
leachable

(iii) Iron pyrite (FeS_2). When iron pyrite is applied to sodic soils, the following reaction takes place.

$Fe\ S_2 + 3\frac{1}{2}\ O_2 + H_2O === FeSO_4 + H_2SO_4$

$FeSO_4 + 2H_2O === H_2SO_4 + Fe\ (OH)_2$

$H_2SO_4 + CaCO_3 === CaSO_4 + H_2O + CO_2$

$CaSO_4 + {}^{Na}_{Na}[\text{ clay} === Ca\ [\text{ clay} + Na_2SO_4 \downarrow$
leachable

(iv) Iron sulphate ($FeSO_4$). When iron sulphate is applied to the soil, the following chemical reaction will occur.

$FeSO_4 + H_2O === H_2SO_4 + FeO$ (Ferrous oxide)

In calcareous soil

$H_2SO_4 + CaCO_3 === CaSO_4 + CO_2 + H_2O$

$CaSO_4 + {}^{Na}_{Na}[\text{ clay} === Ca\ [\text{ clay} + Na_2SO_4 \downarrow$
leachable

In non-calcareous soil

$H_2SO_4 + {}^{Na}_{Na}[\text{ clay} === {}^{H}_{H}[\text{ clay} + Na_2SO_4 \downarrow$
leachable

(v) Lime sulphur (CaS_5). When lime sulphur is applied to soils, the following reaction takes place.

$CaS_5 + 8O_2 + 4\ H_2O === CaSO_4 + 4H_2SO_4$

If the soil is calcareous then the production of gypsum will take place from H_2SO_4 as follows :

$H_2SO_4 + CaCO_3 === CaSO_4 + CO_2 + H_2O$

$CaSO_4 + {}^{Na}_{Na}[\text{ clay} === Ca\ [\text{ clay} + Na_2SO_4 \downarrow$
leachable

If the soil is non-calcareous then the following reaction will take place.

$10\ Na\text{-clay} + 4\ H_2SO_4 + CaSO_4 === 8H\text{-clay} + Ca - \text{clay} + 5Na_2SO_4 \downarrow$
leachable

Other Methods (Salt Precipitation Theory)

Besides these, recently salt precipitation theory is employed satisfactorily for the reclamation of sodic soils. The elimination of salts and exchangeable sodium from soils by leaching is presently practising, but the leached salts have been washed into groundwaters or streams, making those waters more salty and again that too much salty water is used for irrigation purpose. Due to such use the soils are further subjected to salt problems. With this view, a new concept in managing salty soils has been developed and that is known as precipitation of salts.

This idea suggests that instead of leaching salts completely away, they can be leached to only 0.9-1.8 m deep (3-6 ft) where much of the salt would form slightly soluble gypsum ($CaSO_4$**.** $2H_2O$) or carbonates ($CaCO_3$, $MgCO_3$) during dry periods and not react any longer as soluble salts.

The amount of salt precipitating out will vary with the cation and anion composition of those salts. The ions precipitating will be mostly those of calcium, magnesium, carbonate, bicarbonate and sulphate. Estimates are that 30 per cent of the total salts may eventually precipitate. The rest two-third of salts cause very little effect on the yields of corn and tomatoes.

The management technique is simply to apply less water, but to do it more carefully to ensure uniform depth of wetting.

GYPSUM REQUIREMENT (GR)

The main principle for the reclamation of sodic or alkali soils is to replace exchangeable Na by another cation calcium (Ca^{2+}). Of all calcium compounds, gypsum ($CaSO_4.2H_2O$) is considered the best and cheapest for the reclamation purpose. Calcium (Ca^{2+}) solubilized from gypsum replaces sodium (Na^+), leaving soluble sodium sulphate (Na_2SO_4) in the water, which is then leached out. Gypsum requirement (GR) is expressed as me of Ca^{2+} per 100 gm soil.

The gypsum requirement (GR) is the calculated amount of gypsum necessary to add to reclaim the soil. For calculating the dosage of gypsum needed to reclaim a particular alkali soil, advantage is taken of the assumption that through the use of calcareous amendment, the desired level of quantitative replacement of exchangeable sodium from the soil by calcium is possible. Since an exchangeable sodium percentage (ESP) of 10 and below is considered safe for tolerable physical condition of the soil, replacement by calcium to this level (ESP, 10) is all that is attempted in practice, through for certain tolerant crops like paddy, wheat and barley the replacement may be attained to higher ESP level than 10. Gypsum requirement is determined from the formula

Gypsum requirement (GR) i.e. me of Ca^{2+}/100 g soil

$$= \frac{[\text{ESP (initial)} - \text{ESP (final)}] \times \text{CEC}}{100}$$

ESP (initial) is obtained from the analysis of soil before reclamation or application of gypsum; ESP (final) is usually kept at 10 and CEC is the cation exchange capacity in me / 100g or C mol (P^+) kg^{-1} of the soil.

For example, the gypsum requirement of a soil having initial ESP 60, final ESP 10 and CEC 30 C mol (P^+) kg^{-1} will be:

$$\text{me of } Ca^{2+}/100\text{g soil} = \frac{[60 - 10] \times 30}{100} = \frac{50 \times 30}{100} = 15$$

Since one hectare of soil to a depth of 15 cm (6 inches) weighs approximately 2×10^6 kg and 1 me of replaceable gypsum as $CaSO_4.2H_2O$ equals 860 ppm of amendment, the theoretical amount of gypsum required per hectare will be:

$$\text{Theoretical amount of gypsum (kg) ha}^{-1} = \frac{860}{106} \times 2 \times 10^6 \times 15$$

$$= 1720 \times 15$$

$$= 25800 \text{ kg}$$

$$= 25.80 \text{ tons}$$

Quantity of amendments to be added: These are evidences to show that even 50 % of the theoretical gypsum requirement for replacement of exchangeable Na in alkali soils has improved their physical properties and assisted response to management practices. Generally, 50 to 75 % of GR (as determined by **Schoonover's method**) has been found most satisfactory in many types of soils. The equivalent proportion of different amendments in relation to 1 ton of gypsum is as follows:

Amendment	Weight in tones equivalent to 1 tone gypsum
Gypsum	1.000
Sulphuric acid	0.570
Sulphur	0.186
$FeSO_4.7H_2O$	1.620
Aluminium sulphate	1.290
Limestone ($CaCO_3$)	0.580

The amount of gypsum ($CaSO_4.$ $2H_2O$) and sulphur (S) required to ameliorate the sodic soil on the basis of exchangeable sodium is given in table 3.5.

Table 3.5: Amount of amendments required to reclaim sodic soils on the basis of exchangeable sodium

Exchangeable Sodium (mg/100g soil)	Gypsum (t/ha)	Sulphur (t/ha)
1	2.12	0.40
2	4.25	0.80
3	6.50	1.20
4	8.62	1.60
5	10.75	2.00
6	12.87	2.40
7	15.00	2.80
8	17.12	3.20
9	19.37	3.60
10	21.50	4.00

SOLVED EXAMPLES:

Example 1: A soil contains 12 me Na/100 g soil. The CEC of the soil is 20. Exchangeable Na percentage is to be reduced to 10. Workout the gypsum requirement.

ESP = Exch. Na / CEC x 100 = 12 / 20 x 100 = 60 %
Initial ESP – Final ESP = 60 – 10 = 50 % ESP to be reduced
Exch. Na = 12 x 50/60 = 10 me exch. Na/100 g to be replaced
GR = 1 me exch. Na/100 g = 86 mg gypsum/100 g soil
= 860 mg gypsum/1000 g soil = 860 ppm gypsum
= 860 x 2.24 = 1926.4 kg/ha
10 me exch. Na = 10 x 1926.4 = 19264 kg/ha = 19.2 t/ha
If purity is 80 % then,
GR = 19.2 x 100/80 = 24 t/ha

The GR in this example is 19.2 tones/ha. To get the net value of weight of gypsum, the value has to be multiplied by purity percentage i.e. if the purity of the commercial gypsum is 80 %, then the exact weight in the above example would be 24 tones/ha.

Example 2: Calculate GR of alkali soils containing CEC 20 me/100 g[cmol(p^+)kg^{-1}] and 10 me exch. Na/100 g soil, ESP is reduced to 10.

CEC = 20 me/100 g
Exch. Na = 10 me/100 g
ESP reduced to = 10 %
ESP = [Exch. Na/CEC] x 100
= [10/20] x 100
= 50
Initial ESP – Final ESP = 50 – 10 = 40 ESP to be reduced
ESP 50 = Exch. Na 10
So ESP 40=10 x 40/50 = 8 Exch. Na me/100 g to be reduced
1 me Exch. Na/100 g = 86 mg Gypsum/100 g
= 860 mg Gypsum/1000 g
= 860 ppm Gypsum
= 860 x 2.24 = 1926 kg/ha Gypsum
= 1.926 t/ha Gypsum
So 8 me Exch. Na/100 g = 8 x 1.926 = 15.41 t/ha

Example 3: Soil having CEC 20 me/100 g soil. It has Ca 10 me/100 g, Mg 5 me/100 g, K 2 me/100 g, Na 1 me/100 g. Calculate Ca, Mg, K, Na kg/ha.

(1) 1 me Ca/100 g = 20 mg/100 g [Eq. wt. of Ca =40/2=20]
= 200 mg/1000 g
= 200 ppm
= 200 x 2.24 kg/ha
10 me Ca/100 g = 10 x 200 x 2.24 = 4480 kg/ha
(2) 1 me Mg/100 g = 12 mg/100 g [Eq. wt. of Mg =24/2=12]
= 120 mg/1000 g
= 120 ppm
= 120 x 2.24 kg/ha
5 me Mg/100 g = 5 x 120 x 2.24 = 1344 kg/ha
(3) 1 me K/100 g = 39 mg/100 g [Eq. wt. of K =39/1=39]
= 390 mg/1000 g
= 390 ppm
= 390 x 2.24 kg/ha

2 me K/100 g = 2 x 390 x 2.24 = 1747 kg/ha
(4) 1 me Na/100 g = 23 mg/100 g [Eq. wt. of Na =23/1=23]
= 230 mg/1000 g
= 230 ppm
= 230 x 2.24 kg/ha = 515 kg/ha

Example 4: Soil having CEC 40 me/100 g. It has Na 20 me/100 g in exch. form. Bring down exch. Na percentage to 10 %. Calculate % Na. How much Na to be replaced as to bring its saturation to 10 % and calculate GR in kg/ha. Gypsum purity is 80 %.

(1) ESP = (Exch. Na/CEC) x 100 = (20/40) x 100 = 50 ESP
Initial ESP – Final ESP = 50 – 10 = 40 ESP to be reduced
(2) Exch. Na = (ESP x CEC)/100 = (40 x 40)/100 = 16 me Na/100 g to be replaced
(3) GR = 1 me Na/100 g = 86 mg gypsum/100 g
= 860 ppm
= 860 x 2.24 kg/ha
16 me Na/100 g = 16 x 860 x 2.24 = 30822 kg/ha
(4) 80 % purity = 30822 x 100/80 = 38528 kg/ha

Example 5: Soil containing 12 me exch. Na/100 g soil and CEC 40. It is desire to reduce the ESP to 10 %. Calculate the GR to amending the plough layer ($CaSO_4.2H_2O$ = 86 eq. wt.)
(1) ESP = (Exch. Na/CEC) x 100 = (12/40) x 100 = 30 %
Initial ESP – Final ESP = 30 – 10 = 20 % ESP to be reduced
Exch. Na = (12 x 20)/30 = 8 me exch. Na/100 g to be replaced
(2) GR = 1 me exch. Na/100 g = 86 mg gypsum/100 g soil
= 860 mg/1000 g
= 860 ppm
= 860 x 2.24 kg/ha
8 me exch. Na/100 g = 8 x 860 x 2.24 = 15411 kg/ha = 15.411 t/ha

Example 6: A soil have CEC = 25 me/100 g soil which possesses 5, 8 and 3 me/100 g of Ca, Mg and K, respectively. Calculate quantity of Na in me/100g and kg/ha and K_2O kg/ha.
(1) Na me/100 g = CEC – (Ca + Mg + K)
= 25 – (5 + 8 + 3) = 9 me/100 g
= 9 x 23 mg/100 g = 207 mg/100 g
= 2070 mg/1000 g = 2070 ppm
(2) Na (kg/ha) = 2070 x 2.24 = 4636.8 kg/ha
K = 3 me/100 g
= 3 x 39 mg/100 g = 117 mg/100 g
= 1170 mg/1000 g = 1170 ppm
= 1170 x 2.24 = 2620.8 kg/ha
(3) K_2O (kg/ha) = 2620.8 x 1.20 = 3144.96 kg/ha

Example 7: Workout the GR from following observations
(1) Weight of alkali soil = 5 g
(2) Sat. gypsum soln. = 100 ml
(3) Aliquate taken = 5 ml
(4) Difference of 0.02 N EDTA reading between blank and sample = 0.4

GR t/ha = Z x (1.72/1000) x (100/5) x (100/5) x 10,000 x 2.24/1000
= 0.4 x 15.411 = 6.16 t/ha

Example 8: Workout GR from following observations

(1) Weight of alkali soil = 5 g

(2) Sat. gypsum soln. = 100 ml

(3) Aliquate taken = 10 ml

(4) Difference of 0.02 N EDTA reading between blank and sample = 0.8

GR t/ha = Z x (1.72/1000) x (100/5) x (100/10) x 10,000 x 2.24/1000

= 0.8 x 7.7056 = 6.16448 t/ha

Example 9: If a sandy soil having cation exchange capacity (CEC) 20 cmol(p^+)kg^{-1} and 30 per cent base saturation at pH 4.5. Calculate the theoretical amount of lime ($CaCO_3$) required per hectare of land (0-15 cm depth) for raising base saturation to 60 per cent [weight of soil per hectare furrow slice (0-15 cm depth) = (2.24×10^6 kg).

$$\text{Per cent base saturation (BS)} = \frac{\text{me of basic cations (S)}}{\text{Total exchangeable cations (CEC)}} \times 100$$

Base saturation of the soil before lime application (initial) = 30 %

Base saturation to be raised through liming (final) = 60 %

$$\text{me of base cations initially present in the soil (S)} = \frac{\text{T x BS (percentage)}}{100}$$

= 20 x 30/100 = 6

$$\text{Again, me of basic cations at 60 \% base saturation (S)} = \frac{\text{T x BS}}{100}$$

= 20 x 60/100 = 12

Some of basic cations will be required to raise the base saturation at 60 %

= (12 – 6) = 6

1 me H/100 g = 50 mg/100 g lime [1 me $CaCO_3$/100g =50 mg lime/100 g]

= 500 mg/1000 g lime

= 500 ppm

= 500 x 2.24 kg/ha

= 1120 kg/ha

6 me H = 1120 x 6 kg/ha

= 6720 kg/ha = 67 quintals of lime will be required.

Example 10: A soil having CEC 25 me/100 g soil and various cations are present in following proportion :

Ca : 10 me/100 g K : 1 me/100 g

Mg : 5 me/100 g Na :3 me/100 g

by using these data calculate the following values :

i) % base saturation, ii) % base unsaturation, iii) Ca, Mg, Na and K kg/ha, iv) Workout lime requirement to neutralize the soil acidity.

% base saturation = me of basic cations/CEC x 100

= 10 + 1 + 5 + 3/25 x 100 = 19/25 x 100 = 76 %

% base unsaturation = 100 - % base saturation = 100 – 76 = 24 %

Ca = 10 me/100 g = 10 x 20 mg/100 g = 200 mg/100 g

= 2000 mg/1000g = 2000 ppm

= 2000 x 2.24 = 4480 kg/ha

Mg = 5 me/100 g = 5 x 12 = 60 mg/100 g

= 600 mg/1000 g = 600 ppm

= 600 x 2.24 = 1344 kg/ha

Na = 3 me/100 g = 3 x 23 = 69 mg/100 g
= 690 mg/1000 g = 690 ppm
= 690 x 2.24 = 1545.6 kg/ha
K = 1 me/100 g = 1 x 39 = 39 mg/100 g
= 390 mg/1000 g = 390 ppm
= 390 x 2.24 = 873.6 kg/ha
H = CEC – total cations = 25 – 19 = 6 me H/100 g
1 me H/100 g = 50 mg lime/100 g
= 500 mg/1000 g = 500 ppm
= 500 x 2.24 = 1120 kg/ha
6 me H/100g = 6 x 1120 = 6720 kg/ha lime

Problem 11

Calculate the leaching requirement (LR) of irrigation water having electrical conductivity of 3.0 dSm^{-1}. When electrical conductivity of drainage water is 8.0 dSm^{-1}.

Solution:

$$LR = \frac{EC_{iw}}{EC_{dw}} \times 100 = \frac{3}{8} \times 100 = 37.5 \text{ Per cent}$$

Problem 12

Assume irrigation water has a conductivity of 1.08 dSm^{-1}. The field crop planted has a 50 per cent yield reduction at a soil saturation extract conductivity of 7 dSm^{-1} (drainage water). Calculate the additional amount of water required to apply if the water needed to wet the profile is 6.35 cm (2.5 inches).

Solution:

$$LR = \frac{EC_{iw}}{EC_{dw}} = \frac{1.08\ dSm^{-1}}{7\ dSm^{-1}} = 0.154$$

So this fraction of water will be required additionally to wet the soil i.e. 0.154 x 6.35 = 0.98 cm.

So the total amount of water will be required
= 6.35 cm + 0.98 cm
= 7.33 cm (2.92 inches)

Chapter 4

Acid and Acid Sulphate Soils

Introduction

India acid soils occur in the high rainfall areas covering about 25 million hectares of land with a pH below 5.5 and 23 million hectares of land with a pH between 5.6 and 6.5. In India, acid soils occur in Assam, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, NEFA, Manipur, Tripura, West Bengal, Bihar, Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir, MP, Maharashtra, Kerala, Karnataka, Tamil Nadu and Andhra Pradesh. Punjab, Haryana, Rajasthan and Gujarat are the only states in India where acid soils do not occur.

Soil acidity is a limiting factor affecting the growth and yield of many crops all over the world. The basic problems concerning chemical properties of more acid soils are, besides acidity itself, the presence of toxic compounds and elements, such as soluble forms of Al, Fe and Mn, nitrites and various toxic organic acids. Aluminium (Al) toxicity is one of the major constraints on crop productivity on acid soils, which occur on up to 40% of the arable lands of the world. Al is the third most abundant element in the earth's crust and is toxic to plants when solubilised into soil solution at acidic pH values.

Very few plants can grow well in strong acid soils. Soil acidity below pH value 5.5 is generally injurious to plants. Plant roots are badly affected if the pH value exceeds limits of tolerance for particular crops. High degree of soil acidity (pH 5.0 to 6.5) decreases the availability of plant nutrients particularly phosphorus, calcium, magnesium, molybdenum, iron, manganese, potassium sulphur nitrogen, boron, copper and zinc. It also affects adversely the important microbiological processes, such as nitrogen fixation by *Azotobacter*, *Clostridium* and nodule inhabiting bacteria (*Rhizobia*) of leguminous plants.

Definition of Soil Acidity

An acid is a substance that tends to give up protons (hydrogen ions) to some other substance. Conversely, a base in any substance that tends to accept protons (hydrogen ions).

Soil acidity may be defined as the soil system's proton (H^+ ions) donating capacity during its transition from a given state to a reference state.

Soil acidity involves intensity and quantity aspects. The intensity aspect is universally characterized by the measurements of ion activity, expressed as pH. The quantity aspect is characterized, directly or indirectly, by the quantity of alkali required to titrate soil to some arbitrarily established endpoint. Soil acidity is a major problem in relation to plant growth and therefore, acid soils are called a problem soil.

Characteristics of Acid Soils

1. Acid soils have low pH and high proportion of exchangeable H^+ and Al^{3+}.
2. Kaolinite and illite types of clay minerals are dominant in these soils.
3. These soils have low CEC and low base saturation.
4. These soils have high toxic concentration of Al, Fe and Mn and deficiency of Ca and Mg.
5. These soils have nutrients and microbial imbalances.
6. These soils are generally low in available phosphorus and high P_2O_5 fixation capacity.
7. Soil acidity inhibits biological N-fixation.

Source of Soil Acidity

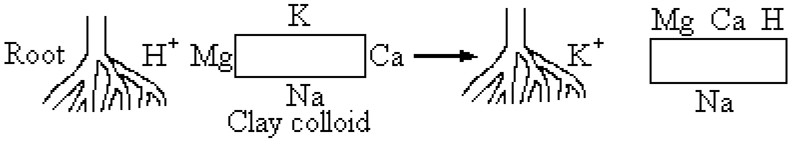
Several factors are responsible for the acid soils. Generally climate, hydrologic cycle vegetation, parent rocks, human interference and other factors play important roles in the origin and development of acid soils. Acid soils occur generally in humid regions where the rainfall is regular and very heavy. Dry regions are devoid of acid soils. The following factors are responsible for the development of acid soils. Acid soils is a base unsaturated soil which has got enough of adsorbed exchangeable H^+ ions so that to give soils a pH of lower than 7.0

1. Excessive rainfall: In soils of dry region, a large supply of bases is usually present because little water passes through the soil. With an increase in rainfall, the content of soluble salts is reduced to a low level and gypsum and $CaCO_3$ are removed in the order named. With further increase in rainfall, a point is reached at which the rate of removal of bases exceeds the rate of liberation from non-exchangeable forms. The considerable loss of bases due to intensive rainfall and leaching reduces the pH of the soil as well as increase the concentration of H^+ on exchange complex.

2. Ionization of water: The water may ionize and contribute H^+ on exchange complex as follows:

$$H_2O \rightarrow HOH \rightarrow H^+ \ OH^- \rightarrow H^+[\mathbf{X}] + \text{Bases} + OH^-$$

3. Contact exchange: The contact exchange between exchangeable H on root surface and the bases in exchangeable form on soil particle may take as follows:



4. Soluble acid production: The decomposition of organic matter in the soil produces many organic as well as inorganic acids. These acids may contribute H on exchange complex.

5. Use of nitrogenous fertilizers: Continuous use of nitrogenous fertilizers containing NH_4-N or giving NH_4-N on hydrolysis (i.e. urea) produce various acids in soils e.g. 1 mole of NH_4 in NH_4NO_3 gives 2 moles of HNO_3; 1 mole of $(NH_4)_2SO_4$ gives 2 moles of HNO_3 + 1 mole of H_2SO_4; 1 mole of NH_4OH gives 1 mole of HNO_3.Thus, continuous use of such fertilizers will produce acidity in soil.

6. Oxidation of FeS: FeS or iron poly sulphide accumulates under anaerobic conditions as a result of reduction of Fe^{3+} and SO_4. Under aerobic conditions, they will be oxidized and will produce H_2SO_4 as follows:

$$4FeS_2 + 15O_2 + 2H_2O \rightarrow 2Fe_2(SO_4)_3 + 2H_2SO_4$$

Under such conditions, soil pH values of 2 to 4 are frequently observed.

7. Hydrolysis of Fe^{3+} and Al^{3+}: The Fe^{3+} and Al^{3+} ions may combine with water and release H^+ as follows:

$$Al + H_2O \rightarrow Al(OH)^{2+} + H^+$$
$$Al(OH)^{2+} + H_2O \rightarrow Al(OH)_2^+ + H^+$$
$$Al(OH)_2^+ + H_2O \rightarrow Al(OH)_3^+ + H^+$$

The hydrogen produced may enter on exchange complex.

8. Acidic parent material: Some soils have developed from parent materials which are acid, such as granite and that may contribute to some extent soil acidity.

9. Acidification from the air : Industrial exhausts, if contain appreciable amount of SO_2 may cause acidity in soil in course of time due to dissolution of SO_2 in water (rain) as follows :

$$\underset{\text{(Rain water)}}{SO_2 + H_2O} \rightarrow \underset{\text{(Sulphuric acid)}}{H_2SO_3}$$

The phenomenon gives acid rain. In soil, the reaction may be as follows:

$$2H_2SO_3 + O_2 \rightarrow 2H_2SO_4$$

KINDS OF SOIL ACIDITY

Broadly soil acidity may be of two kind's *viz.*, (i) Active acidity (ii) Potential reserve/exchange acidity. The nature of soil can be illustrated as follows:

Adsorbed H (and Al) ions on soil colloids ↔ Soil solution H (and Al) ions
(Potential/exchange/reserve) (active acidity)

(i) Active acidity: Active acidity may be defined as the acidity develops due to hydrogen (H^+) and aluminium (Al^{3+}) ions concentrations of the soil solution. The magnitude of this acidity is limited. The acidity in soil solution is known as active acidity and is measured by pH meter.

(ii) Exchange acidity: Exchange acidity may be defined as the acidity develops due to adsorbed hydrogen (H^+) and aluminium (Al^{3+}) ions on the soil colloids. The magnitude of this acidity is very high.

However, residual acidity may be included to the total acidity. Residual acidity may be defined as the acidity which remains in the after active and exchange acidity has been neutralized. It is associated with aluminium hydroxyl ions and with H and Al atoms that are bound in non exchangeable forms by organic matter and silicate clay.

Passive Acidity or Reserve Acidity and is measured by determining the exchangeable H by $BaCl_2$ + Triethanol amine reagents. The total acidity or the titratable acidity is summation of H ion concentration present in solution as well as on exchange complex which can be measured by titration. All the forms of acidity are in equilibrium.

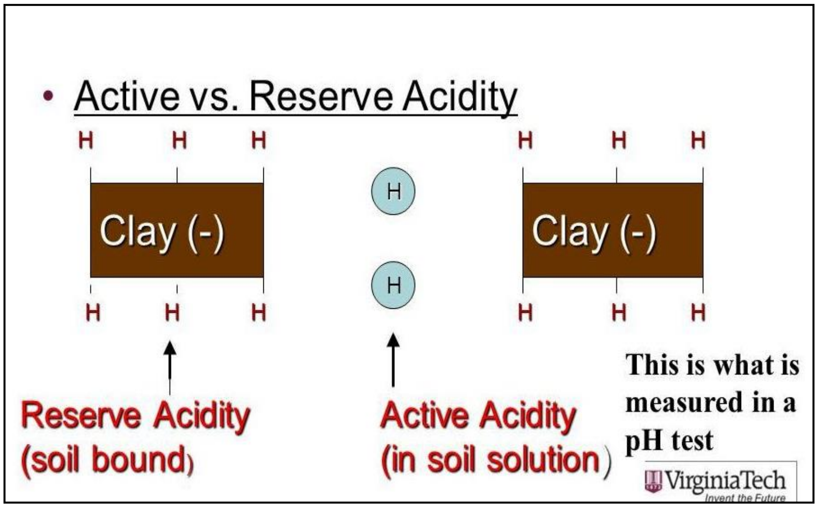
Total acidity: The total acidity is summation of active, exchange and residual acidity. It can be written as,

Total acidity = Active acidity + Exchange acidity + Residual acidity

Therefore, total soil acidity depends on the active, exchange and residual acidity of the soil.

Active acidity – soluble acidity, in the solution

Reserve acidity – adsorbed acidity, on the surface of particles



- Active vs. Reserve Acidity

This is what is measured in a pH test

DISTRIBUTION

Out of 157 million hectares of cultivable land in India, 49 m ha of land are acidic, of which 26 m ha of land having soil pH value less than 5.6 and the rest 23 m ha of land having soil pH range 5.6 to 6.5.

Soil groups	pH range	Area (m ha)	States
Laterites soils	4.8-7.0	12.65	Mysore, MP, Eastern *ghat* region of Orissa, WB, South Maharashtra, Kerala, Malabar Coast, Assam, parts of Santhal Parganas and Singhbhum in Bihar
Laterite and lateritic red soils	5.0-7.0	11.80	Kerala, Orissa, WB and Assam, parts of Santhal Parganas and Singhbhum in Bihar, Mysore, Bihar, MP, UP
Mixed red and black/yellow soils	5.5-6.5	23.66	Mysore, Bihar, MP, UP

The soils having low pH values have been observed in Assam and parts of UP, HP, WB, Bihar, Orissa and TN states. In Gujarat, part of Dangs arises due to one or more reasons as follows:

Classification of acid soils based on magnitude of acidity

According the intensity of acidity, the acid soils are of the following five steps

1. Slight acidic (pH range 6.6 to 6.1)
2. Medium acidic (pH range 6.0 to 5.5)
3. Strong acidic (pH range 5.5 to 5.1)
4. Very strong acidic (pH range 5.0 to 4.6)
5. Extremely strong acidic (pH range 4.5 or lower)

According to the amount of organic matter, acid organic soils can be classified in to the following two types:

i. **Peat soils:** Peat soils are characterized by presence of poorly degraded organic matter in India, peaty soils occur in Kashmir, Himachal Pradesh, Asam and other hill states.

ii. **Muck soils:** Such soils contain highly degraded organic matter. They have relatively higher pH values then the peaty soils. Thus they are less acidic. Muck soils are also found in Kashmir, Himachal Pradesh, Asam and other hill states

PROBLEMS OF SOIL ACIDITY

Problems of soil acidity may be divided into three groups which are as follows:

1. Toxic effects

(a) Acid toxicity
(b) Toxicity of different nutrient elements

2. Nutrient availability

a) Non-specific effects
b) Specific effects
    i. Exchangeable bases
    ii. Nutrient imbalances

3. Microbial activity

Toxic effects

Acid toxicity

The higher hydrogen ion concentration is toxic to plant under strong acid conditions of soil. The acid toxicity includes possible toxicities of acid anions as well as H^+ ions.

Toxicity of Different Nutrient Elements

Iron and Manganese: The concentration of these two ions (Fe^{2+} and Mn^{2+}) in soil solution depends upon the soil reaction or pH, organic matter and intensity of soil reduction. Due to increase in organic matter content in the soil the population of soil microbes increases and very rapidly used up the soil oxygen and results reduction of soil. As a result of soil reduction, the nutrient elements like Mn^{4+} and Fe^{3+} reduce to Mn^{2+} (manganous manganese) and Fe^{2+} (ferrous iron) respectively and increases their concentration to a very high and toxicity of those elements develops. Due to such toxic effects, a physiological disease of rice is found in submerged soils which are popularly known as *browning disease*.

Toxicity of Aluminium (Al)

The toxicity of Al may be greatly influenced by the accompanying cations. The toxicity of Al tends to decrease with increases in the concentration of other cations such as calcium. Al toxicity is a problem in both upland and lowlands soils. Aluminium toxicity in soils affects plant growth in various ways:

1. It restricts the root growth.
2. It affects various plant physiological processes like division orecils, formation of DNA and respiration etc.
3. It restricts the absorption and translocation of some important nutrient elements from soil to the plant like phosphorus, calcium, iron, manganese etc.
4. It causes wilting of plants.
5. It also inhibits the microbial activity in the soil.

Nutrient Availability

Non-specific effects

It is associated with the inhibition effect of root growth and thereby affects the nutrient availability.

Specific Effects

Exchangeable bases

There are two aspects of availability of exchangeable bases *i.e.* ion uptake process and the release of bases from the exchangeable form may be adversely affected due to soil acidity. Due to complementary ion effects exchangeable bases are released preferentially in a fractional exchange. Deficiency of bases like Ca^{2+} and Mg^{2+} are found in acid soils.

Nutrient imbalances

It is evident that soluble iron, aluminium and manganese are usually present in their higher concentrations under moderate to strong acid soils. Phosphorus reacts with these ions and produces insoluble phosphatic compounds rendering phosphorus unavailable to plants. Besides these, fixation of phosphorus by hydrous oxides of iron and aluminium or by adsorption, the availability of phosphorus is decreased. In acid soils, iron, manganese, copper and zinc are abundant, but molybdenum is very limited and unavailable to plants. In acid soils having very low pH, the availability of boron may also be decreased due to adsorption on sesquioxides, iron and aluminium hydroxy compounds. Nitrogen, potassium and sulphur become less available in an acid soil having pH less than 5.5.

Microbial Activity

It is well-known that soil organisms are influenced by fluctuations in the soil reaction. Bacteria and actinomycetes function better in soils having moderate to high pH values. They cannot show their activity when the soil pH drops below 5.5. Nitrogen fixation in acid soils is greatly affected by lowering the activity of *Azotobacter* sp. Besides these, soil acidity also inhibits the symbiotic nitrogen fixation by affecting the activity of *Rhozobium* sp. Fungi can grow well under very acid soils and caused various diseases various like root rot of tobacco, blights of potato etc.

AMELIORATION OF SOIL ACIDITY

In general the fertility status of acid soils is very poor and under strongly to moderately acidic soils the plant growth and development affect to a great extent. The crops grown on such problematic soil do not give remunerative return rather it lowers down the yield to a great extent. Because of the limited land resource it needs judicious management practices so that the yield of different crops can be increased. So, one of the most important and practically feasible management practices are the use of lime and liming materials to ameliorate the soil acidity. The addition of lime raises the soil pH, thereby eliminating most major problems of acids soils which has mentioned earlier.

Lime requirement of an acid soil may be defined as the amount of liming material that must be added to raise the pH to some prescribed value. This value is usually in the range of pH 6.0 to 7.0. Since this is an easily attainable value within the optimum range of most crop plants.

Principles of Liming Reactions

The reclamation of acidic soils is done by addition of liming material which may be calcitic limestone ($CaCO_3$) or dolomitic limestone [$CaMg(CO_3)_2$]. The rate of lime requirement is determined in the laboratory by method of Shoemaker (1961). The particle size of liming material affects the rate of neutralization reaction. Both these limestones are sparingly soluble in pure water but do become soluble in water containing CO_2. The greater the partial pressure of CO_2 in the system, the more soluble the limestone becomes. Dolomite is somewhat less soluble than calcite. The reaction of limestone ($CaCO_3$) can be written as:

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

$$Ca(HCO_3)_2 \rightarrow Ca^{2+}\downarrow \; + 2HCO_3^-$$

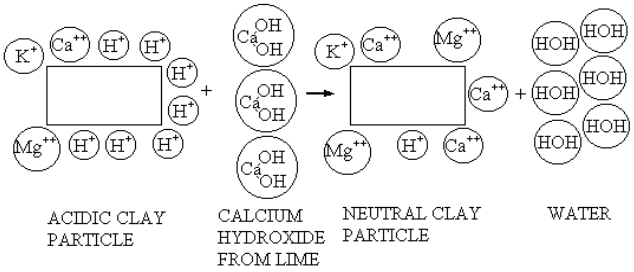
(Takes part in cation exchange reactions)

$$H^+ \quad + \quad CO_3^- \rightarrow H_2CO_3 \leftrightarrow H_2O + CO_2$$

(From soil (from lime) solution)

In this way hydrogen ions (H^+) in the soil solution react to form weakly dissociated water, and the calcium (Ca^{2+}) ion from limestones is left to undergo cation exchange reactions. The acidity of the soil is, therefore, neutralized and the per cent base saturation of the colloidal material is increased.

The process of changing pH by the addition of lime [$Ca(OH)_2$] is illustrated in the following Fig.



Liming Materials

Liming material may be defined as materials that are necessary for the neutralization of soil liming hydrogen (H^+) ions. The materials commonly used for the liming of soils are the oxides, hydroxides, carbonates and silicates of calcium or calcium and magnesium. The presence of only these elements does not consider a material as a liming compound. In addition to these compounds, the accompanying anion must be one that will reduce the activity of hydrogen (H^+) ions and hence aluminium in the soil solution. These are called "Agricultural Liming Material".

Why Gypsum is not considered as a Liming Material?

Gypsum is not considered as liming materials because on its application to an acid it dissociates into (Ca^{2+}) and sulphate (SO_4^{2-}) ions:

$$CaSO_4 \rightarrow Ca^{2+} + SO_4^{2-}$$

The accompanying anion is sulphate and it reacts with soil moisture produces mineral acid (H_2SO_4) which also increases soil acidity instead of reducing soil acidity.

$$SO_4^{2-} + H_2O \longrightarrow \underset{\text{(Strong mineral acid)}}{H_2SO_4}$$

Besides this, calcium (Ca^{2+}) in the gypsum after dissociation will result in replacement of adsorbed aluminium ($A1^{3+}$) in a localized soil zone (when gypsum applied as band placement) with a significant lowering of soi1 pH. Therefore, gypsum does not qualify as liming materials.

Kinds of Liming Materials

There are various kinds of liming materials that are used for the correction of soil acidity.

(i) Oxides of lime: It is normally called burned lime or quick lime. Oxide of lime is more caustic than limestone. Burned lime is produced by heating limestone and dolomite as follow:

$$CaCO_3 + \underset{\text{(Limestone)}}{Heat} \longrightarrow CaO + CO_2$$

$$CaMg(CO_3)_2 + Heat \longrightarrow CaO + MgO + 2CO_2$$

(ii) Hydroxides of lime: It can be produced by adding water to burned lime and is called slaked lime.

$$\underset{\text{(Burned lime)}}{CaO} + H2O \longrightarrow \underset{\text{(Slaked lime)}}{Ca(OH)2}$$

It is more caustic than burned lime (CaO). If it is kept open in the moist air, then combination of calcium hydroxide occurs as follows:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

In case of $Mg(OH)_2$

$$Mg(OH)_2 + CO_2 \longrightarrow MgCO_3 + H_2O$$

(iii) Carbonates of lime: These are by products of certain industries and so the content of calcium and magnesium varies. The two important minerals are found in this group Calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$].

(iv) Slags: These are generally three types of slags that are found important:

a. Blast furnace slag. It is a by-product of the manufacture of pig iron. As a liming material, this slag behaves essentially as calcium silicate. The neutralizing value of blast furnace slags ranges from shout 75-90%.

b. Basic slag. It is a by-product of the basic open-hearth method of making steel from pig iron, which in turn is produced from high phosphorus iron ores. The impurities in the iron, including silica and phosphorus are fluxed with lime and the basic slags are produced. Its neutralizing value ranges from 60 to70%.

c. Electric furnace slag. This is produced from the electric furnace reduction of phosphate rock during preparation of elemental phosphorus. This product is largely calcium silicate and is used as a liming material.

(v) Other liming materials: Coral shell, chalk, wood ash, press mud, byproduct material of paper mills, sugar factories, fly ash sludge etc. are considered as liming materials and also used for the amelioration of soil acidity.

Others factors

(1) Growing acid tolerant crops: In acid soils tolerant crops should be grown. Choice of crops may be done according to soil pH.
  a) High acid tolerant crops: Rice, potato, sweet potato, oat, castor, etc.
  b) Moderate acid tolerant crops: Barley, wheat, maize, turnip, brinjal, etc.
  c) Slightly acid tolerant crops: Tomato, carrot, red clover.

(2) Use of basic fertilizers: $NaNO_3$ and basic slag, etc.

(3) Soil and water management: Proper soil and water management checks leaching of bases and enhances decomposition of organic matter.

(4) Crop choice: Selection of crops tolerant to acidity is an effective tool to counter this soil problem and breeding of such varieties is of specific importance for attaining higher productivity, particularly in areas where liming is not an economic proposition. The crops can be grouped on the basis of their performance in different soil pH range.

***Relative tolerance of crops to soil acidity* Crops**	**Optimum pH range**
Cereals	
Maize, sorghum, wheat, barley	6.0-7.5
Millets	5.0-6.5
Rice	4.0-6.0
Oats	5.0-7.7
Legumes	
Field beans, soybean, pea, lentil etc.	5.5-7.0
Groundnut	5.3-6.6
Others	
Sugarcane	6.0-7.5
Cotton	5.0-6.5
Potato	5.0-5.5
Tea	4.0-6.0

Lime Requirement of Acid Soils

For reasonable crop production on acid soils, pH range from 6.0 to 7.0 is considered good. The amount of lime required to be added to acidic soil to raise the pH to a desired value is known as lime requirement.

The lime requirement of the soil is not only related to the soil pH but also to its buffer or CEC. Some soils are highly buffered than others and therefore, the lime requirement of soils having the same pH may differ considerably. The buffering capacity or CEC depends upon the amount and type of clay and organic matter present in the soil. The larger these amounts, the greater will be the buffering capacity. Therefore, soils containing clay, peat, muck will be highly buffered and need less lime requirement than that required by coarse textured soils which have low clay and organic matter content.

Beneficial effect of lime

1. Lime makes P_2O_5 more available.
2. Lime increase availability of N, increase nitrification and nitrogen fixation.
3. Organic matter decomposition is increased.
4. Lime makes K more available.
5. Bacterial growth more beneficial.
6. Harmful Al, Fe and Mn are rendered insoluble.
7. Ca and Mg make available.
8. Improve physical condition of soils.
9. Checks soil erosion.
10. Fertilizers effectiveness increase.

ACID SULPHATE SOIL

During the submerged period sulphate (SO_4^-) in the water are reduced to sulphides in which form they are stabilized generally as Ironsulphide (FeS).When these areas are drained the sulphides or elemental S are oxidized forming sulphuric acid .The soil pH of these may drop to level as low as 1or 2. Obviously plant growth cannot occur under this condition. Areas of these kinds of soils called “cat clays “are found in South East Asia.

Most soil will retain sulphate (this is the form taken up by plants). The mechanism of adsorbing sulphate is simple. sulphate or acid sulphate ions replace hydroxyl (OH) held by Aluminium (Al).

Characteristics of acid sulphate soil:-

- Acid sulphate soil is usually clay.
- The organic carbon content varies from 1.5 to 18%.
- The cation exchange capacity is 10 -25 meq/100g.
- Available N and P are low.
- There are many toxic elements like Iron, Aluminium. H_2S.
- These soils when submerged are nearly neutral in reaction but when drained out become extremely acidic and lethal to crop plants.

Acid sulphate soils are extremely acid soils. They have a pH less than H in some layer of the profile .The acidity is due to presence of sulphuric acid and Iron and aluminium sulphate. They are derived from marine sediments high in pyrites and poor in bases. Sulphur oxidation is an acidifying process. The reactions are:-

$$\underset{\text{Elemental sulphur}}{2S} + 3O_2 + 2H_2O \quad \underline{\text{oxidation}} \quad H_2SO_4$$

$$\underset{\text{Hydrogen sulphide}}{H_2S} + 2O_2 \quad \underline{\text{oxidation}} \quad H_2SO_4$$

Types of acid sulphate soils

Potential acid sulphate soils

Potential acid sulphate soils which have not been oxidised by exposure to air are known as potential acid sulfate soils (PASS). They are neutral in pH (6.5–7.5) , contain unoxidised iron sulfides, are usually soft, sticky and saturated with water and are usually gel-like muds but, can include wet sands and gravels have the potential to produce acid if exposed to oxygen.

Actual acid sulphate soils

When PASS is exposed to oxygen, the iron sulfides are oxidised to produce sulfuric acid and the soil becomes strongly acidic (usually below pH 4). These soils are then called actual acid sulfate soils (AASS). They have a pH of less than 4, contain oxidised iron sulfides, vary in texture and often contain jarosite (a yellow mottle produced as a by-product of the oxidation process).

Occurrence in India

Soil with sufficient sulphides (FeS_2 and others) to become strongly acidic when drained are termed acid sulphate soils or as the Dutch refer to those soils *cat clays*. When allowed to develop acidity, these soils are usually more acidic than pH 4.0. Before drainage, such soils may have normal soil pH and are only *potential acid sulphate soils.* Generally acid sulphate soils are found in coastal areas where the land is inundated by salt water. In India, acid sulphate soil is, mostly found in Kerala, Orissa, Andhra Pradesh, Tamil Nadu and West Bengal.

Formation of Acid Sulphate Soils

Land inundated with waters that contain sulphates, particularly salt waters, accumulate sulphur compounds, which in poorly aerated soils are bacterially reduced to sulphates. Such soils are not usually very acidic when first drained in water.

When the soil is drained and then aerated, the sulphide (S^{2-}) is oxidized to sulphate (SO_4^{2-}) by a combination of chemical and bacterial actions, forming sulphuric acid (H_2SO_4). The magnitude of acid development depends on the amount of sulphide present in the soil and the conditions and time of oxidation. If iron pyrite (FeS_2) is present, the oxidized iron accentuates the acidity but not as much as aluminium in normal acid soils because the iron oxides are less soluble than aluminium oxides and so hydrolyze less.

Management of Acid Sulphate Soils

Management techniques are extremely variable and depend on many specific factors *viz*, the extent of acid formation, the thickness of the sulphide layer, possibilities of leaching or draining the land etc. The general approaches for reclamation are suggested bellow:

Keeping the area flooded. Maintaining the reduced (anaerobic). Soil inhibits acid development, the use of the area to rice growing. Unfortunately, droughts occur and can in short time periods cause acidification of these soils. The water used to flood the potential acid sulphate soils often develop acidity and injure crops. If a non-acidifying layer covers the sulphuric horizon, drainage to keep only the sulphuric layer under water (anaerobic) is possible. Liming and leaching. Liming is the primary way to reclaim any type of acid soil. If these soils are leached during early years of acidification, lime requirements are lowered. Leaching, however, is difficult because of the high water table commonly found in this type of soil and low permeability of the clay. Sea water is sometimes available for preliminary leaching.

Chapter 5

Eroded Soil, Water logged Soil and Compacted Soils and Management

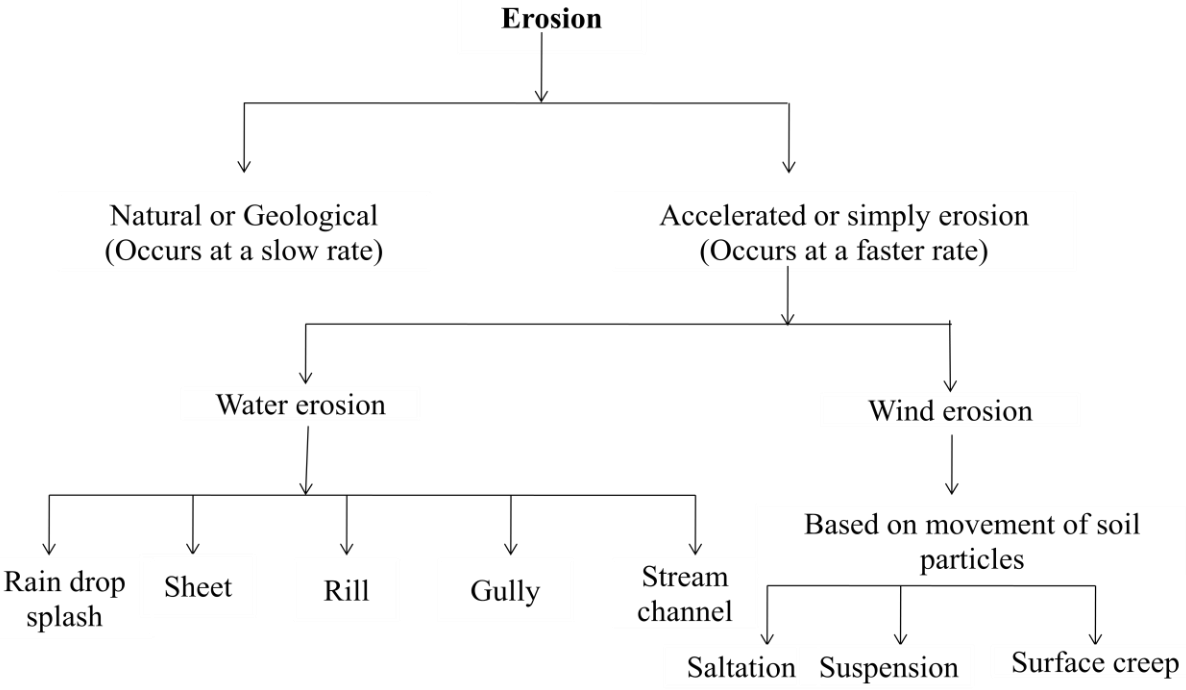
Soil erosion generally refers to detachment and transport of soil and soil material by water, wind, ice or gravity water and wind being the major factors. Large flood plains and coastal plains are formed due to wearing of mountains. However, this steady and slow process of nature is non-destructive, and is, therefore, known as 'natural erosion" or 'geological erosion'. Geological erosion is not detrimental to man's well being and is wholly beyond his control.

Soil erosion is defined as the detachment and transportation of soil mass from one place to another through the action of wind, water in motion or by the beating action of rain drops. Erosion extensively occurs in poorly aggregated soils (low humus) and in a higher percentage of silt and very fine sand. Erosion increases when soil remains bare or without vegetation. In India about 86.9% soil erosion is caused by water and 17.7% soil erosion is caused by wind. Out of the total 173.6 Mha of total degraded land in India, soil erosion by wind and water accounts for 144.1 Mha (Govt. of India, 1990). The surface soil is taken away by the runoff causing loss of valuable topsoil along with nutrients, both native and applied. In India about 5334 million tones (16.35 tonnes/ha/year) of soil is being eroded annually due to agriculture and associated activities and 29% of the eroded materials are permanently lost into the sea.

The process of soil erosion is made up of three parts:

(i) Detachment: This is when the topsoil is actually "detached" from the rest of the ground.
(ii) Movement: This is when the topsoil is relocated to another area.
(iii) Deposition: Where the topsoil ends up after this process.

Type of Soil Erosion



1. Natural or geologic erosion:

Such erosion is said to be in equilibrium with the soil forming process, It occurs under protective cover of natural vegetation, completely undisturbed by biotic interference, This long time, slow eroding process has developed the present topographic features like stream channels, valleys, canyons, through tile effect of water, wind, temperature changes and living organisms-

This is a normal feature of any landscape, Geologic erosion takes place steadily but so slowly that ages are required for it to make any marked alteration in the major features of the earth's surface. There is always equilibrium between the removal and formation of soil, so that unless the equilibrium is disturbed by some outside agency, the mature soil preserves more or less, a constant depth and character indefinitely,

2. Accelerated soil erosion:

When there is a disturbance in the existing equilibrium condition in nature then accelerated erosion takes place. The agencies responsible for such disturbance are man or animals, Man or animals interfere with natural equilibrium through activities like wrong land management, over exploitation of forests and natural vegetation, over grazing etc. The removal of the surface soil from areas denuded (uncover, bare, remove) of their natural protective cover as a result of human and animal interference takes place at a much faster rate than that at which it is built up by the soil forming process. This accelerated detachment rapidly ravages (damage, destruction, ruin, depredation) the land and it is with this type of soil erosion that vie are so seriously concerned, Nature requires, on an average, about 1000 years to build up 2.5 cm of top soil, but wrong farming methods may take only a few years to erode it from lands of average slope. Erosion consists of: {i) detachment of soil particles from the surface; and (ii) their transportation, that requires a source to carry the detached particles away.

Wind erosion

Wind erosion is the erosion of soil by the action of wind which dislodges the soil particles, transports from one place to another and deposits them there.

Erosion by wind, although most common in arid and semi-arid regions. It occurs to some extent in humid regions also. It is essentially a dry weather phenomenon and is accelerated wherever: (1) the soil is loose, dry and reasonably finely divided; (2) the soil surface is relatively smooth and vegetative cover is either absent or sparse; (3) the field is sufficiently large; and (4) the wind is sufficiently strong to initiate soil movement. Wind takes up soil from one place and deposits at another. If unprotected, the wind would slowly remove organic matter, fine silt and clay tractions leaving sand and gravel behind. This sorting action leads to more erodible and less productive soil. Based on movement of soil particles wind erosion are three types: - (i) saltation (ii) suspension (iii) surface creep.

i. **Saltation: -** This is activated by bouncing or jumping of the particles over the surface. The wind force lifts up the particles almost vertically into air, rotating several hundred revolutions per second and travels 10 to 15 times their height of rise. When the velocity is retarded, they fallout at an angle of 6-12° on the surface. The size of particles for saltation range from 0.1 to 0.5 mm. Saltation is the main process which is responsible for continued movement of soil particles into the air till it is finally deposited. Therefore saltation not only initiates movement but also breaks clods to erodible size. The larger the area, the greater is the number of times individual particle strike the surface. Consequently more number of particles is set in motion. This process is known as saltation-(sudden large amount).

ii. **Suspension**: Particles smaller than 0.1 mm may be moved by suspension. The movement of such particles is also initiated by saltation and once they enter the turbulent air, they may be lifted high into the air and may be carried many miles away from where the movement is initiated.

iii. **Surface creep**: - It is rolling or sliding of the soil particles along the surface. They are too heavy to be lifted by the wind and are therefore, rolled by the impact of smaller particles in. saltation. The particle size limit in this process varies from 0.5 to 2.0 mm. The rate of soil movement in surface creep in saltation is proportional to the cube of wind velocity.

Water erosion

Removal of soil from land surface by water including runoff from melted snow and ice is termed as water erosion. Water erosion occurs in stages which have been identified as

1. Rain drop erosion or splash erosion,
2. Sheet erosion,
3. Rill erosion,
4. Gully erosion
5. Stream bank erosion

1. Splash erosion

When raindrops strike the ground surface, the soil particles become loose and splashed due to its impact force. Momentary build up of the pressure gradients towards the edges of the drop disintegrates the soil and shoot some particles out. The falling raindrop at an average speed of 75 cm/sec is capable of creating a force of almost 14 times its own weight.

To produce significant erosion, the splashing must throw soil particles into a place where there is a water stream for transportation. The forces that influence splashing are: (i) the rain drop mass and velocity; and (ii) the soil characteristics (such as roughness, surface slope and aspect), hydraulic conductivity, moisture content, particle size, elasticity, and associated mass of the surface.

In cohesive soils, smaller particles are difficult to detach. On the other hand, to throw out large aggregates, more energy must be transferred from the rain drop. Coarse grained, dry soil will reduce the momentary build up of pressure in the rain drop because of surface roughness and faster energy dissipation caused by flow into the soil. The saturation of soil will weaken the cohesive forces, reduce seepage and enable stronger splashing. However, a thick enough water layer will protect the soil. Raindrop action can be cumulative, initially breaking aggregates and later throwing them out. We know from the laws of kinetic energy that a falling body has Kinetic energy = 1/2 x mass x velocity2:: 1/2 mv^2. The mass of rain drop depends on its size.

It is now established that collision of rain drops on bare soil and resulting splash is the major cause of soil erosion by water. About 95% of soil is splashed by falling rain drops and runoff water erodes less than 5% of the soil.

2. Sheet Erosion

It is the uniform removal of soil in thin layers from sloping land caused by sheet or overland flow of water. The breaking action of rain drop combined with surface flow is the major cause of sheet erosion. Areas where loose, shallow top soil overlies compact soil are most susceptible to sheet erosion. The eroding and transporting power of sheet flow are functions of depth and velocity of runoff for a given size, shape and quantity of soil particles or aggregates. In the initial stages of soil erosion, rain drops churn (mix, roil, agitate, shake, stir, toss) the top soil and along with runoff (excess, overflow) the muddy water moves away from the field. It is uniform removal of top soil in thin layer from the field. It is least conspicuous (apparent, obvious, noticeable, evident) and is the first stage of erosion.

Sheet erosion is a most serious problem in red soils covering 72 million ha in India. The depths of soils vary from 20 to 100 cm and rainfall intensity is very high though the total annual rainfall may not be high. Similarly, the laterite soils, suffer from severe rill erosion because of fairly high rainfall. The black soils, occupying nearly 88 million ha, when fallow during the monsoon, are subject to severe sheet erosion hazards. The annual loss of top soil may range from 11 to 43 tonnes/ha along with 10 to 30% of runoff loss.

3. Rill erosion

Rill erosion is the removal of soil by runoff water with the formation of shallow channels that can be smoothed out completely by normal cultivation. Rills develop as a result of concentration of runoff water where the silt laden runoff water starts flowing along the slopes through small finger-like channels. The soil eroded from upland areas comes from these small channels, called rills, and from inter-rill areas between them. The primary mechanism for soil detachment and transport from inter-rill areas is the energy resulting from raindrop impact while the primary mechanism for soil detachment and transport for rill erosion is the distributed shear force on the rill channel boundary due to concentrated flow of runoff water.

During a rainfall event flow is quickly concentrated in micro-rills, which in turn flows into larger rills and eventually discharge to an existing channel sys- tem. The concentration of flow in rills increases the erosive power of the flow resulting in increased soil detachment from the rill channel boundary. In general, rill erosion is incipient gully erosion. If rill erosion continues only for a short while, tillage operations may smoothen out the surface completely, so that the resulting soil profile is identical to one that is damaged by sheet erosion.

4. Gully erosion

As the volume of concentrated water increases and attains more velocity on slopes, it enlarges the rills into gullies. Here rills become so deep that the ground cannot be smoothed out by ordinary tillage tools. Gully can also originate from any depression such as cart tracks and cattle trails and indicates neglect of land over a long period of time. An advanced stage of gully results into ravine which is sometimes more than 16 to 33 m deep.

The rate of gully erosion depends primarily on the runoff producing characteristics of the watershed, soil characteristics, alignment, size and shape of the gully and the slope in the channel. Loose, open, well drained sloping soils gully rather easily when water is concentrated on them. A heavy or compacted soil often checks the rate at which gullying takes place. Gullies are sometimes as deep as 6 to 12 m. Gully erosion is most spectacular in 4 m ha land in India.

Four stages of gully development are recognised.

a. **Stage 1**: **Formation stage** -In this stage, the rill erosion Scour of the top soil in the direction of general slope as the runoff water concentrates. This stage normally proceeds slowly where the top soil is fairly resistant to erosion.
b. **Stage 2: Development stage** -In this stage, there occurs up stream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the C-horizon and the parent material is also removed rapidly as water flows.
c. **Stage 3**: **Healing stage** -In this stage, vegetation starts growing in the gully.
d. **Stage 4**: **Stabilisation stage** -In this stage, gully reaches a stable gradient, gully walls attain a stable slope, sufficient vegetation cover develops over the gully surface to anchor the soil and permit development of new top soil.

5. Stream erosion

Stream erosion is the scouring of soil material from the stream bed and cutting of the stream banks by the force of running water. Stream bank erosion is often increased by the removal of vegetation, overgrazing or tillage near the banks. Scouring is influenced by the velocity and direction of the flow, depth and width of the stream, soil texture and alignment of the stream. Rivers and streams often meander and change their course by cutting one bank and depositing sand and silt loads on the other. The damage is manifolds during flash floods.

EFFECTS OF SOIL EROSION

Some of the greatest effects of soil erosion include

- **Loss of top fertile soil.** The surface soil lost as runoff consists of fertile soils and fresh or active organic matter.
- **Accumulation of sand or other unproductive coarse soil materials on other productive lands.** In the plains, fertile lands have been made unproductive by the deposition or accumulation of soil material brought down from the hills by streams and rivers.
- **Silting of lakes and reservoirs.** Soil erosion from the catchment areas of reservoirs results in the deposition of soil, thus reducing their storage capacity
- **Silting of drainage and water channels.** Deposition of silt in drainage ditches in natural streams and rivers reduces their depth and capacity and overflows and flooding of downstream areas increase with damage to agricultural crops and also man-made structures.
- **Decreases water table.** With the increase in runoff, the amount of water available for entering the soil is decreased. This reduces the supply of water to replenish the ground water in wells, the yield of well is reduced.
- **Fragmentation of land.** Water erosion especially gully erosion may divide the land into several valleys and ridges and thus fields become smaller and more numerous. Crop rows are shortened, movement from field to field is obstructed and a result the value of land is decreased.

SOLUTIONS FOR SOIL EROSION

Best management practices are used to control erosion factors of both wind and water are

1) **Crop rotation-** improves the overall efficiency of nitrogen uptake and utilization in the soil. If certain cover crops are planted in the winter, erosion and runoff is prevented when the ground thaws, and nutrients are trapped in the soil and released to the spring crops.
2) **Contour cultivation-** On gently sloping land, a special tillage practice carried out on the contour of the field can reduce the velocity of overland flow. Contour cultivation should not be carried out on steep slopes because it will merely make the erosion situation worse.
3) **Strip cropping-** It is a technique in which alternate strips of different crops are planted in the same field. There are three main types: contour strip cropping, field strip cropping, and buffer strip cropping. If the strips are planted along the contour, water damage can be minimized; in dry regions, if the strips are planted crosswise to the contour, wind damage is also minimized.
4) **Terraces-** Constructing bench-like channels is otherwise known as terraces, enables water to be stored temporarily on slopes to allow sediment deposition and water infiltration. There are three types of terraces: bench terraces, contour terraces and parallel terraces. It will control erosion in wetter areas by reducing the length of the slope.
5) **Grassed Waterways -** They force storm runoff water to flow down the center of an established grass strip and can carry very large quantities of storm water across a field without erosion. Grass waterways are also used as filters to remove sediment, but may sometimes lose their effectiveness when too much sediment builds up in the waterways. To prevent this, it is important that crop residues, buffer strips, and other erosion control practices and structures be used along with grass waterways for maximum effectiveness.

6) **Diversion structures-** These are channels that are constructed across slopes that cause water to flow to a desired outlet. They are similar to grass waterways and are used most often for gully control.
7) **Drop structures -** Are small dams used to stabilize steep waterways and other channels. They can handle large amounts of runoff water and are effective where falls are less than 2.5 meters
8) **Riparian strips -** These are merely buffer strips of grass, shrubbery, plants, and other vegetation that grow on the banks of rivers and streams and areas with water conservation problems. The strips slow runoff and catch sediment. In shallow water flow, they can reduce sediment and the nutrients and herbicides attached to it by 30% to 50%.
9) **No-till planting-** This planting system prepares a seedbed 2 inches wide or less, leaving most of the surface undisturbed and still covered with crop residues. The result is a wetter, colder environment that protects the seed and soil with its insulating effect of the surface residue.
10) **Strip Rotary-** Tillage a strip four to eight inches wide and two to four inches deep is prepared by a rotary tiller, while the rest of the soil is left undisturbed. The soil is conserved because of the crop residues between the tillage strips
11) **Till Planting -**This plowing technique sweeps the crop residues into the area between the rows of crops. Soil density between these rows remains relatively high because of the absence of tillage. This soil is difficult for raindrops to detach and runoff to move.
12) **Annual Ridges -** Also known as permanent ridges or ridge tillage, the annual ridges are formed by using a rolling disk bedder, and planting is done after only minor spring seedbed preparation. The extent of soil conservation depends on the amount of residue left and the row direction. Planting on the contour plus increased surface residues greatly reduce soil loss.
13) **Chiseling**- This system does not turn the soil over, but rather leaves it rough and cloddy with plenty of crop residue remaining. The soil density and amount of covering depends on the depth, size, shape, spacing, and so on of the chisel blades. The residue and rough, cloddy surface of the soil reduces raindrops impact and reduces runoff velocities thus reducing erosion.
14) **Disking-** This system pulverizes the soil and gives great soil density The effect is similar to that of chiseling with results also depending on the depth, size, spacing, and so on of the disk blades. The deeper the disking, the fewer the residues that remain on the surface.

FACTORS AFFECTING SOIL EROSION

The major variables affecting soil erosion, *viz.*, climate, soil properties, topography, vegetation and other related factors, are briefly described below.

1. Climate

Climatic variables affecting erosion are precipitation, wind velocity, temperature, humidity and radiation receipts. The effect of climate on natural vegetation and on soil development shows that soil and vegetation boundaries coincide in a general way with climatic boundaries. Consequently, climate affects the erosion conditions of an area directly as well as through the vegetation that occurs. In arid climates, wind erosion is mote severe than in humid ones. Lack of organic matter in soils of arid and semi-arid regions makes them more susceptible to erosion by water as well as by wind.

2. Soil Properties

Soil erodibility is largely dependent upon texture, structure, organic matter, nature of clay and the amounts and kinds of salts present. Generally, fine textured and alkali soils are more erodible. On the other hand, soils with low silica/sesquioxide ratio, common in humid tropics, *e.g.,* latosals and other lateritic soils, are reported to be less erodible. Soils with greater absorptive and retentive capacities reduce runoff and are, therefore, less erodible.

Coarser textured soils containing a greater proportion of sand are more susceptible to wind erosion. This applies to all sand fractions less than about 1 mm in diameter. In addition, low silt, clay and organic matter content in such soils deters clod formation, and even if some clods are formed they are far less stable. In general, any process which reduces consolidation usually increases erodibility.

3. Topography

Slope accelerates erosion as it increases the velocity of the flowing water. The four-time increase in the degree of slope doubles the velocity of flowing water which can increase its erosive power four times and the silt-carrying capacity 32 times. Unidirectional general slope of the field results into sheet erosion while an undulating field with local slopes in more than one direction results into rill or gully erosion in addition to imperceptible sheet erosion. Lateritic soils, associated with rolling topography in high rainfall areas, also suffer from sheet and rill erosion. Different characteristics of slope such as steepness of slope, length of slope, configuration, variation in steepness, micro-topography and aspect of slope, all affect the soil erosion.

4. Biological Factors

Biological factors attributing to soil erosion include vegetation, residue mulch, animals and shifting cultivation practiced by tribal in hilly areas. Heavy destruction of natural protective cover like trees and grasses accelerates erosion in hilly areas. Shifting cultivation, particularly on steep slopes without any protective measures and animal traffic destroys natural vegetation and exposes soil surface to direct action of raindrops and runoff water.

The presence of vegetation acts as an erosion-retarding factor. Forests and grasses provide better cover than the cultivated crops. Vegetation intercepts the beating action of falling raindrops, retards the amount and velocity of surface runoff, permits more water flow into the soil, and checks the abrasive power of wind. It also reduces runoff as part of the intercepted rainfall is evaporated directly from the plant surface. Lack of vegetation creates erosion-permitting conditions. Plant roots and other residues of vegetation help to improve soil aggregation and porosity and hereby enhance infiltration and reduce runoff.

FLOODED SOILS/ WATER LOGGED SOILS:-

Water logged or flooded soil can be defined as soil whose development and properties are strongly influenced by temporary or permanent saturation in the upper part of the soil. The water logging of the surface horizons bring about reducing condition for temporary chemical and physical changes to take place.

Types of Water Logging

1. **Riverine Flood Water Logging: -** In the rainy season flood may come to the nearby land from the river having excess flood water.
2. **Oceanic Flood Water Logging**:-Ocean water spreads in the nearby land and causes water logging.

3. **Sub Soil Water Logging: -** High water table in the rainy seasons is normally unsuitable for root growth.
4. **Seasonal Water Logging:** - Runoff water accumulates in the low land and depressions in the rainy seasons.
5. **Perennial Water Logging: -** Deep water, swamp etc. get rain water, runoff water and seepage water from canal causing perennial water logging.

Factors affecting formation of water logged soils:-

1. **Climatological factors**: - Due to the high rain fall water accumulate on the soil surface.
2. **Flood:** - flood water is usually causing water logged situation in the field.
3. **Seepage from canal: -** Ground water levels are closer to the surface due to the seepage from canal.
4. **Land shape:** - Saucer shaped land get water from high lands which results into water logging.
5. **Uncontrolled and unwanted irrigation:** - excess irrigation may cause accumulation of water on the soil surface.
6. **Drainage: -** Poor drainage system is responsible for water logging in the field.

Detrimental effect of water logging is:-

1. **Water Depth**: - low land areas are usually flooded to depths of about 50 cm. and the limitation to crop production associated with extensively low reduction potential and partly because of low P availability. In the deep water (flooding to depth of 50to 100cm.) and very deep water or floating (water depth more than 100 cm.) areas the principles problem of rice production is the tendency for the rice crop to be submerged for periods of up to 10 days or more .
2. **Poor aeration: -** Inadequate supply of oxygen either retards or ceases plant growth as the accumulated CO_2 hampers the growth of the plants roots. Poor aeration results in the development of toxin and other injurious substances, only rice plants can survive under poor aeration.
3. **Soil structure**: - Continuous water stagnation destroys the soil structure and makes the soil compact.
4. **Soil temperature:-** It lower down the soil temperature moist soil have a higher specific heat than dry soil .Consequently a moist soil has lower temperature than dry soil. Low temperature affects the microorganism activity which consequently lowers the rates of nitrogen fixation.
5. **Soil pH**: **-** There is reversible pH change of the flooded soils. pH tends to increase in acid soil and decrease in alkaline soil ,undoubtedly pH is after towards normal.

Availability of nutrient:-

1. Nitrogen: - N deficiency is extremely common in water logged conditions due to lower temperature and reduced conditions; mineralization of organic N is affected.
2. Phosphorus: - The inorganic forms of P are usually present at higher levels in flooded soil than upland soils.

3. Potassium: - K response is apparent in many low lands soils. Flooding and pluddling of the soil during low land preparation may considerably increase the soil solution concentration of K because displacement of exchangeable K by the large amount of Fe and Mn in the soil solution.
4. Sulphur: - Sulphur deficiency has been reported from many low land areas.
5. Zinc: - Widespread deficiency of Zn to rice crop in wet land conditions is reported.
6. Fe &Mn: - Fe and Mn are available in excess causing toxicity to the plant.
7. Salinity: - Salinity is an important constraint to rice production in many coastal low lands as well as in some poorly drained in land areas.
8. Effect on crops: - under water logged condition all field crops cannot survive due to poor aeration and unavailability of nutrient, only rice is an exception.

COMPACTED SOILS

Soil compaction can be a serious and unnecessary form of soil degradation that can result in increased soil erosion and decreased crop production. Compaction of soil is the compression of soil particles into a smaller volume, which reduces the size of pore space available for air and water. Most soils are composed of about 50 per cent solids (sand, silt, clay and organic matter) and about 50 per cent pore spaces. *"Soil compaction can be a serious form of soil degradation".*

Effects of soil compaction on soil properties

The various forces of soil compression by agricultural equipment can cause soil particles to become compacted closer together into a smaller volume. As particles are compressed together, the space between particles (pore space) is reduced, thereby reducing the space available in the soil for air and water. Soil compaction can have a number of negative effects on soil quality and crop production including the following:

1. causes soil pore spaces to become smaller
2. reduces water infiltration rate into soil
3. decreases the rate that water will penetrate into the soil root zone and subsoil
4. increases the potential for surface water ponding, water runoff, surface soil waterlogging and soil erosion
5. reduces the ability of a soil to hold water and air, which are necessary for plant root growth and function
6. reduces crop emergence as a result of soil crusting
7. impedes root growth and limits the volume of soil explored by roots
8. limits soil exploration by roots and decreases the ability of crops to take up nutrients and water efficiently from soil
9. reduces crop yield potential

Importance of Soil Porosity

Soils consist of organic matter, various-sized soil particles referred to as soil texture (proportion of solid particles including sand, silt and clay) and pore spaces that contain air and water. The connectivity of soil pores coupled with the size and number of pores is very important for water infiltration, water and nutrient movement within soil and the ability of the soil to hold water. Large, inter-connected soil pore spaces enhance several actions:

1. water infiltration into soil
2. water percolation into the root zone and subsoil
3. air exchange with the atmosphere

Identifying Types of Soil Compaction

Soil compaction can occur at the soil surface in the form of soil crusting, or it can occur in the subsoil. Soil compaction is sometimes blamed for reduced crop productivity, but it is important to correctly diagnose the cause or causes of reduced crop production. Poor plant growth can be caused by a number of factors, including soil compaction.

The first step is to correctly diagnosis if a soil compaction problem exists and then, develops short and long-term management practices to prevent further damage.

Soil compaction can occur at different times of the year through different mechanisms. Careful observations can help diagnose the problem:

1. Is there poor crop growth in all years, with all crop types in the same area of the field?
2. Is there a spatial pattern to the crop growth (associated with wheel tracks, windrows, equipment widths, haul trails)?
3. Does the soil surface appear smooth and crusted?
4. Has there been a change in equipment size, weight or operations?
5. Are there soil types in the field with naturally dense horizons such as eroded knolls?
6. If you scrape away the surface soil with a shovel or trowel, can you see dense layers and/or horizontal root growth?

Be aware that compaction of agricultural soils can be caused by various farming practices:

1. Soil tillage that removes the protective residue from the soil surface, leaving the soil prone to natural environmental forces or excessive soil tillage that causes surface soil aggregates to break down or degrade, can lead to soil crusting, causing the surface soil layer to become hard and compacted.
2. Soil tillage implements can induce soil compaction just below the depth of tillage, particularly when soils are wet.
3. The weight of large farm equipment (tractors, seed carts, combines, trucks, manure spreaders) can cause wheel traffic compaction to a considerable depth within the root zone. As soil moisture content increases, so too does the depth of soil compaction.

Chapter 6

Polluted Soils, Problems and Management

DEFINITION

Soil pollution is defined as the build-up in soils of persistent toxic compounds, chemicals, salts, radioactive materials, or disease causing agents, which have adverse effects on plant growth and animal health.

Soil is the thin layer of organic and inorganic materials that covers the Earth's rocky surface. The organic portion, which is derived from the decayed remains of plants and animals, is concentrated in the dark uppermost topsoil. The inorganic portion made up of rock fragments, was formed over thousands of years by physical and chemical weathering of bedrock. Productive soils are necessary for agriculture to supply the world with sufficient food.

Soil pollution adversely affects the quality and the fertility of soil from human-born sources or natural sources. If the fundamental properties of soil fall, then its production capacity decreases. The growth of crops and vegetation is reduced and the land is convened to barren and rugged land. What is produced is not eatable due to pollution. Whether the pollution is in air or water, its impact is felt on the soil. In recognition of the promotion of soil science and soil resource conservation made by King Bhumibol Adulyadej of Thailand, the King's birthday, **December 5** is celebrated as **'World Soil Day'**. The United Nations Food and Agriculture Organization (FAO), through this day, acknowledge soil's significance as a critical component of the natural system and as a crucial contributor to the wellbeing of human, animal and plant life.

Today, there is a crying need to take a resolution for "**Going Green",** as it is necessary to take control over the growing soil pollution. Soil is the **farmer's gold**. If its quality decreases, then the economy of India and our food plate too will feel the same adverse impact. Agriculture without healthy soil cannot be the basis of the country's economy. It implies that if we think about doing anything - increasing food production - first of all, farmer’s will get any benefit or not. It is also necessary to do the management and disposal of liquid and solid residues from the factories.

There are many different ways that soil can become polluted, such as

- Seepage from a landfill
- Discharge of industrial waste into the soil
- Percolation of contaminated water into the soil
- Rupture of underground storage tanks
- Excess application of pesticides, herbicides or fertilizer
- Solid waste seepage

The most common chemicals involved in causing soil pollution are:

- Petroleum hydrocarbons
- Heavy metals
- Pesticides
- Solvents

Types of Soil Pollution

A. Agricultural Soil Pollution

(i) Pollution of surface soil
(ii) Pollution of underground soil

B. Soil pollution by industrial effluents and solid wastes

(i) Pollution of surface soil
(ii) Disturbances in soil profile

C. Pollution due to urban activities

(i) Pollution of surface soil
(ii) Pollution of underground soil

What is Soil Pollution?

With the rise of concrete buildings and roads, one part of the Earth that we rarely see is the soil. It has many different names, such as dirt, mud and ground. However, it is definitely very important to us. The plants that feed us grow in soil and keeping it healthy is essential to maintaining a beautiful planet. However, like all other forms of nature, soil also suffers from pollution. The pollution of soil is a common thing these days, and it happens due to the presence of manmade elements. The main reason why the soil becomes contaminated is due to the presence of manmade waste. The waste produced from nature itself such as dead plants, carcasses of animals and rotten fruits and vegetables only adds to the fertility of the soil

Main causes of Soil Pollution

The soil may be degraded either by toxic materials or contamination with heavy metals or by poor management that exhaust its fertility, depletes its organic matter and changes its soil structure to crusts and clods that restrict air and water movement.

A. Agrochemicals

- ✶ Pesticides
- ✶ Insecticides
- ✶ Herbicides
- ✶ Fungicides
- ✶ Fertilizers

B. Industrial wastes

- ✶ Effluents
- ✶ Dust and other wastes
- ✶ Radioactive wastes
- ✶ Heavy metals
- ✶ Acid precipitation

C. Urban wastes

- ✶ Municipal solid waste
- ✶ Municipal sewage
- ✶ Vehicular exhaust

D. Rural wastes

- Home wastes
- Litter
- Livestock wastes
- Plant residues
- Sediments

Effects of Soil Pollution

1. **Effect on Health of Humans:** Considering how soil is the reason we are able to sustain ourselves, the contamination of it has major consequences on our health. Crops and plants grown on polluted soil absorb much of the pollution and then pass these on to us. This could explain the sudden surge in small and terminal illnesses. Long term exposure to such soil can affect the genetic make-up of the body, causing congenital illnesses and chronic health problems that cannot be cured easily. In fact, it can sicken the livestock to a considerable extent and cause food poisoning over a long period of time. The soil pollution can even lead to widespread famines if the plants are unable to grow in it.
2. **Effect on Growth of Plants:** The ecological balance of any system gets affected due to the widespread contamination of the soil. Most plants are unable to adapt when the chemistry of the soil changes so radically in a short period of time. Fungi and bacteria found in the soil that bind it together begin to decline, which creates an additional problem of soil erosion. The fertility slowly diminishes, making land unsuitable for agriculture and any local vegetation to survive. The soil pollution causes large tracts of land to become hazardous to health. Unlike deserts, which are suitable for its native vegetation, such land cannot support most forms of life.
3. **Decreased Soil Fertility:** The toxic chemicals present in the soil can decrease soil fertility and therefore decrease in the soil yield. The contaminated soil is then used to produce fruits and vegetables which lacks quality nutrients and may contain some poisonous substance to cause serious health problems in people consuming them.
4. **Toxic Dust:** The emission of toxic and foul gases from landfills pollutes the environment and causes serious effects on health of some people. The unpleasant smell causes inconvenience to other people.
5. **Changes in Soil Structure:** The death of many soil organisms (e.g. earthworms) in the soil can lead to alteration in soil structure. Apart from that it could also force other predators to move to other places in search of food.

METHODS AND TOOLS FOR CONTROL SOIL POLLUTION:

To help the various players involved in the management of polluted soil are given below:

- Greater care in the use of pesticides
- Better land practices to reduce soil erosion and sedimentation
- Improvement of wastes from feedlots
- Disposal of waste accumulation of plant and animal waste without affecting the quality of the air or water
- Percolation is reduced by vigorously growing crop
- Erosion can be greatly reduced by a dense vegetative cover

- The rotation of crops to include meadows in the cropping sequence may reduce soil losses by as much 75 per cent
- Soil losses are reduced by mulching, strip cropping and contour cultivation
- Convening cropland to good grassland is recognized as most effective eliminating erosion and consequent sedimentation
- By replacing persistent pesticides with readily degradable ones as they are developed and become available
- Reduce nuisance conditions and improved sanitation
- The persistent pesticides are replaced by alternative methods of pest control
- Less persistent pesticides are used or more specific chemicals are used
- The rates of pesticides could be reduced sufficiently
- The greatest hazardous chemicals are not used
- To eliminate or reduce drastically the soil application of the toxic metals
- Animal excreta are used in biogas production
- Salts are removed by improved drainage systems
- Soil amendments are used
- Acid rain pollution is reduced by elimination S and N oxides drastically.

Chapter 7
Quality of Irrigation Water

All natural waters used for irrigation contains inorganic salts in solutions which are derived originally from the rocks or solid phase material through which water percolates. The most common dissolved constituents are chlorides, sulphates and bicarbonates of Ca, Mg and Na. The concentration and proportion of these salts determine the suitability of water for irrigation. Other constituent such as B, Li, F or other ions, which have a toxic effect on plants, may occur in lesser amounts in irrigation water. If water used for irrigation contains excessive quantities of the constituents noted above, it might affect the growth of plants in three ways *viz.*

a. As a result of adverse changes in the physical characteristics of the soil,
b. The increased osmotic pressure of the soil solution may decrease the physiological availability of moisture to plants,
c. Accumulation of certain ions in the soil solution that may have a specific toxic effect upon the physiological processes of the plant.

Therefore, the question arises "What should be the ideal quality of water to be used for irrigation?" Different workers for judging the quality of waters have proposed various standards. The five generally recognized criteria for judging the quality of irrigation water are as under:

QUALITY OF IRRIGATION WATER

1. Salinity hazard: Continuous use of water having high salt content will convert a normal soil into a saline soil. On the basis of electrical conductivity (EC) measurements, the waters were divided into four classes by USSSL as follows:

Conductivity (dS/m)	**Class**	**Symbol**	**Inference**
0.00 – 0.25	Low salinity	C_1	✶ Can be used for most soil for most crops ✶ Little likelihood of salinity
0.25 – 0.75	Medium salinity	C_2	✶ Can be used with moderate leaching ✶ Moderate salt tolerant crops should be grown
0.75 – 2.25	High salinity	C_3	✶ Cannot be used where drainage is restricted ✶ Salt tolerant plant and additional management practices should be followed
2.25 – 5.00	Very high salinity	C_4	✶ Not suitable for irrigation ✶ Can be used occasionally with leaching ✶ Salt tolerant crop should be grown with additional management practices

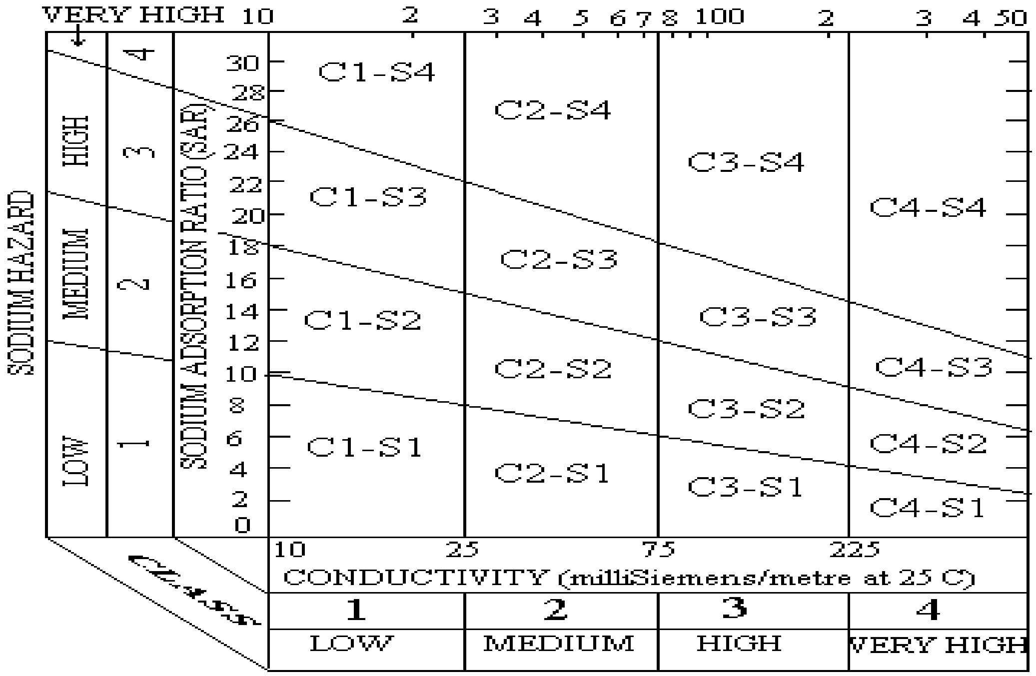
According to USSSL, the water having more than 5000 micromhos/cm EC value cannot be used for purposes of irrigation.

2. Alkali hazard: The continuous use of water having high concentration of Na will convert a normal soil into an alkali soil. The sodium adsorption ratio (SAR) developed by USSSL expresses the relative activity of Na ions in cation exchange reactions with the soil. The exchangeable Na percentage (ESP), which the soil will attain when the soil and water are in equilibrium, can be predicted approximately from the value of SAR of water. Accordingly, the waters are divided into four classes with respect to the Na hazards as follows:

SAR value	Class	Symbol	Inference
0 – 10	Low Na water	S_1	(i) Can be used for all soils with little danger of harmful Na level development (ii) The Na sensitive crops are affected
10 – 18	Medium Na water	S_2	(i) Sodium hazard likely in fine textured soil (ii) Can be used on soils having high permeability
18– 26	High Na water	S_3	(i) May produce harmful level of exchangeable Na in most soils except gypsiferous soils (ii) Requires special management practice like good drainage, high leaching and addition of organic matter and gypsum
> 26	Very high Na water	S_4	(i) Unsatisfactory for irrigation except at low and perhaps medium salinity of irrigation water, special management as above should be made

$$\text{SAR} \quad : \frac{\text{Na}}{\sqrt{\dfrac{\text{Ca + Mg}}{2}}}$$

The USSSL has prepared the diagram for use of water having different values of EC as well as SAR.



3. **Bicarbonate hazard:** The bicarbonate ions are primarily important because their tendency to precipitate Ca and to some extent Mg, in the soil solution as their normal carbonates e.g.

$$Ca + 2HCO_3 \rightarrow CaCO_3 + CO_2 + H_2O$$

The CO_3^{-2} ions are seldom present in water but HCO_3^- ions may be present in appreciable proportion of the total anions present in irrigation waters. Based on the theory of precipitation of Ca and Mg, Eaton (1950) suggested the concept of "Residual Sodium Carbonate" commonly known as RSC. The RSC can be found out by following equation:

$$RSC = (CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

Where; concentrations of all ions are expressed in meq/lit.

It is obvious from above equation that as the Ca and Mg are lost from the soil solution by precipitation, the relative proportion of Na remaining in water is increased. Thus, the alkali hazard as defined by the SAR is increased. The standard for RSC as given by USSSL as follows:

RSC (meq / lit)	**Quality of irrigation water**
Less than 1.25	Probably safe for most purpose
1.25 – 2.50	Marginal can be used on light textured soil with adequate leaching and application of gypsum
More than 2.50	Not suitable for irrigation purposes

4. **Boron hazard:** Boron is very toxic to plants at low concentration in the soil solution. Because boron tends to accumulate in the soil from even low concentration in the irrigation waters, it is necessary to consider this constituent in assessing the quality of irrigation waters. The USDA has suggested the type of crops to be grown with respect to boron content in irrigation water. The limits are as under:

Boron content of irrigation water (ppm)	**Boron tolerance of crops**	**Crops to be grown**
0.3 – 1.0	Sensitive	Citrus, Apricot, Peach, Apple, Pear, Plum, walnut
1.0 – 2.0	Semi-tolerant	Sweet potato, Oats, Sorghum, Maize, Wheat, Barley, Radish, Peas, Tomato, Cotton, Potato, Sunflower
2.0 – 4.0	Tolerant	Carrot, Cabbage, Onion, Beans, Sugar beet, Alfalfa, Date

5. **Chlorides:** The grading of irrigation waters based on chloride content as proposed by Schofield is as under:

Chloride (meq/lit)	**Class**
0 – 4	Excellent
4 – 7	Good
7 – 12	Permissible
12- 20	Doubtful
More than 20	Unsafe

6. Other elements: The safe limit for other elements present in irrigation water is as follows:

Element	For waters used continuously on all soil (ppm)	For used up to 20 years on fine textured soil at pH 6.0 to 8.5 (ppm)
Al	5.00	20.00
Arsenic	0.10	2.00
Cu	0.20	5.00
Fluorine	1.00	15.00
Lead	5.00	10.00
Lithium	2.50	2.60
Mn	0.20	10.00
Mo	0.01	0.05
Se	0.02	0.02
Zn	2.00	10.00
Fe	5.00	20.00

SUITABILITY OF IRRIGATION WATER

It is said that "probably too much emphasis has been placed on an attempt to answer the question. How good is the water?" rather than "What can be done with this water?" The suitability of irrigation water (SI) will be determined by following five factors (f): SI = f (QSPCM).

1. **Quality of irrigation water:** Amount, nature and proportion of various cations and anions present in the water.
2. **Nature of the soil to be irrigated:** Texture, structure, drainage, permeability, depth of water table, chemical composition of the soil, pH, and $CaCO_3$ content will determine the effect of irrigation water on the soil.
3. **Nature of the crop plants to be grown:** water, which may not be suitable for very sensitive crop, may be excellent for tolerant crops.
4. **Climatic conditions:** High temperature and less humidity will require more number of irrigation.

USE OF SALINE WATER

Even the waters containing high amount of dissolved salts has been used successfully in highly permeable sandy soils. Similarly, the waters showing considerable alkali hazards have also been used successfully on permeable soils or by addition of gypsum and FYM on semi-permeable soils. The high RSC content can be corrected by addition of gypsum and the water can be used for the purpose of irrigation. Attempts have also been made for using saline waters by diluting it with good quality water or by giving alternate irrigation with good and bad quality water.

Besides the salinity and alkalinity hazard of water, some industrial effluents and sewage water are also problem water that can be reused by proper treatment. The complex growth of industries and urbanization (Urban development) leads to massive increase in waste water in the form of sewage and effluent. Waste water supplies not only nutrient but also some toxic elements such as total solids of chloride, carbonate, bicarbonate, sulphate, sodium chromium, calcium magnesium, *etc.*, in high concentration. Besides this the effluent or waste water creates

BOD (Bio-chemical Oxygen Demand). These waste water when used for irrigation leads to surface and sub surface source of pollution due to horizontal and vertical seepage.

Much of the ground water (32-84%) surveyed in different Indian States is rated either saline or alkali. Because of the continental monsoonal climate, the basic principles of saline water management need some adaptation, e.g. providing for a leaching requirement is not appropriate when the growing season for post-monsoon winter crops starts with a surface-leached soil profile, because it would increase the salt load. High salinities during the initial stages of growth are particularly harmful. Further, if benefits are to be gained from frequent saline irrigation, the amount of water applied per irrigation needs to be reduced. This is not possible with most widely surface irrigation methods; hut can be achieved with sprinkler and drip methods. However, in India the large-scale use of such systems is not yet technically or economically feasible.

RISKS INVOLVED IN USING SALINE WATER FOR IRRIGATION

Irrigating with saline water on duplex or clayey soils can result in dangerous levels of salinity building up in the root zones of crops.

In such cases, after two years of irrigation with water with conductivities of 0.7-1.4 dS/m, the water ponding above the clayey B horizon has been found to have salinity values ranging from 3.0 to 5.0 dS/m. These levels reduce yields significantly and if the soil dries out, will kill crops.

The observations indicate that the depth of this "perched water" varies between about 20 and 30 cm and therefore is at least 10 cm thick. A layer of perched water like this represents about 1000-2500 kg/ha (1-2.5 t/ha) of salt in the upper soil profile, the root zone of all crops.

Common problems are creates using for saline water

The following are the most common problems that result from using poor quality water.

1. **Salinity:** If the total quantity of salts in the irrigation water is high, the salts will accumulate in the crop root zone and affect the crop growth and yield. Excess salt condition reduce uptake of ware due to high concentration of soil solution.
2. **Permeability:** Some specific salts reduce the rate of infiltration in to the soil profile.
3. **Toxicity:** When certain constituents of water are taken up by plants which accumulates in large quantities and results in plant toxicity and reduces yield.
4. **Miscellaneous:** Excessive nitrogen in irrigation water causes excessive vegetative growth and leads to lodging and delayed crop maturity. White deposits on fruits or leaves may occur due to sprinkler irrigation with high bicarbonate water

What can you do?

If you are in an area where there may be a soil salinity risk, or where your irrigation water may be saline, there are six critical actions you should take:

- **i.** Determine if there is salinity hazard from salt stored already in the soil or regolith or if a saline water table is already present. This can be done by a consultant experienced in a salinity assessment.
- **ii.** Determine if your water source contains significant salinity and measure your water salinity regularly. A chemical analysis of the water will also be needed. These tests

will tell you if you are at risk from inducing salinity from your applied irrigation water.

- **iii.** Measure your soil salinity before and during your irrigation year. Measure at the surface and in the zone just above the clayey B horizon. If you are adding salt, the levels at these two locations can increase rapidly.
- **iv.** Improve your drainage. This may mean subsurface drainage to be effective.
- **v.** Ensure you leach out any salt build-up by using additional irrigations, and rainfall. Check that leaching has occurred before you plant again.
- **vi.** Maintain your calcium and sodium balance using gypsum or lime as appropriate.
- **vii.** Application of greater amounts of organic matter such as FYM, compost *etc.*, to the soil to improve permeability and structure
- **viii.** Mixing of good quality water with poor water in proper proportions so the both the sources of water are effectively used to maximum advantage.
- **ix.** Periodical application of organic matter and rising as well as incorporation of green manure crops in the soil.
- **x.** Raising of salt tolerant crops such as cotton, ragi, sugar beet, paddy, groundnut, sorghum, corn, sunflower, chilies, tobacco, onion, tomato, garden beans, amaranthus and lucerne.

NITRATE TOXICITY

All the N present in fertilizer and organic matter are ultimately converted to nitrates, the form in which N is absorbed by most of the plants. The nitrates are readily soluble and are leached down the soil profile and reach the ground water, soil erosion and runoff also can NO_3 to water bodies.

Drinking water-contaminated by NO_3^{--} can cause major health problems in human and animals. Such as, ‘methemoglobinemia’ (blue baby syndrome) or possible carcinogenic effects due to nitrosamines. When NO_3^{--} is reduced to NO_2^- by bacteria in the digestive tract, NO_2^- oxides iron in the hemoglobin (Fe^{2+} to Fe^{3+}) forming methemoglobin. This results in bluish colouration on the skin. It can be a serious problem in infants since after the age of 6 months. The bacteria are suppressed, because of the increased acidity in the digestive tract. According to EPA, 10 mg N/l (45 mg NO_3^-/l) is the prescribed limit for drinking water for human consumption though it is four times more for livestock.

Out of the fertilizer N applied to the soil hardly 40% is utilized by the crops and the rest are subjected to various losses or retention in soil. The NO_3^- loss can be minimized if the following N management principles are followed:

1. Avoid excess use of N fertilizers.
2. Use of neem coated urea increases nitrogen use efficiency (NUE).
3. Granular urea, sulphur coated urea etc. are desirable.
4. Integrated nutrient management involving fertilizers and organics helps in increasing CEC and thereby retention of NH_4^+ ions and moisture.
5. Excess frequent irrigations to be avoided. Sprinkler and drip methods are advantageous.
6. Cropping pattern should be such that the fertilizer residues are fully utilized, e.g. Potato leaves a considerable residue. When pearl millet is taken without fertilizers in summer, the residues are fully utilized.

Nitrate toxicity can be serious when the purchased input fertilizer is carelessly used without ensuring maximum NUE or not following soil and water conservation measures and allowing excess soil erosion or runoff.

EUTROPHICATION

Pollutants do not have to be toxic themselves to result in the death of a species, destruction of an ecosystem, or general degradation of water quality. In some cases their presence is sufficient to set into play a chain of events that can have the same effect. In fact, sometimes a substance in limited quantities is important, necessary, and a natural part of the evolution of a given ecosystem. However, these same sub- stances will receive the label "pollutant" when the effect they cause is undesirable.

The addition of nutrients to an ecosystem, such as a lake, is an example of some- thing that is good in the right amounts but detrimental when in excess. This addition can be seen as an enrichment of the lake that leads to other slow processes, collectively referred to as the natural aging of a lake. The enrichment process is generally an irreversible one that all lakes experience and is known as eutrophication. The word is derived from the Greeks whereas "eu" means "well" and "trophe" means "nourishment". A simple definition of eutrophication is therefore the naturally occurring biological process of the enrichment of water with nutrients.

Lakes are generally categorized by limnologists according to the degree of nutrient enrichment. A young lake formed during the retreat of the glaciers is a cold, sandy-bottomed, transparent lake with little plant life. It has a low nutrient input or loading and is referred to as an "oligotrophic" lake, from the Greek word "oligo" for poor or few. As a lake becomes older, it gradually receives nutrients and sediments from the surrounding drainage basin. It then experiences an increase in productivity with increased plant growth and some production of gamefish. The lake will eventually become nutrient rich or eutrophic, and plant growth, in the form of microscopic phytoplankton and rooted aquatic plants, can occur to a level in which the water becomes undesirable for various uses. Following are the general steps in the lake aging process:

1. Streams from the drainage basin bring in soil and nutrients to a collective low point that becomes a fertile lake.
2. The increased fertility gives rise to an accumulating growth of both plants and animals.
3. As the lake's biomass increases, organic deposits build up on the bottom and it becomes shallower, richer, and warmer.

Given sunlight and nutrients, plant life abounds and is fed on by primary consumers. The food chain/food web becomes established. If cultural Eutrophication comes into play, abundant nutrients become available. The imbalance can result in algae blooms; the explosive growth of one or more types or species to the detriment or exclusion of others. Blooms can occur for long periods of time and extend over large areas having significant impact on the ecology of the ecosystem and even human activities.

In agricultural soils, soil and water conservation measures should be followed to minimize runoff and soil sediments added to the water bodies. Watershed management should be effectively implemented to check runoff and soil erosion from non-agricultural lands such as wastelands, grass lands, etc.

ACID RAINS

We have seen that the oxides of sulphur and nitrogen are important gaseous pollutants of air. These oxides are produced mainly by combustion of fossil fuels, smelters, power plants, automobile exhausts, domestic fires etc. These oxides are swept up into the atmosphere and can travel thousands of kilometers. The longer they stay in the atmosphere, the more likely they are to be oxidised into acids. Sulphuric acids and nitric acid are the two main acids, which then dissolve in the water in the atmosphere and fall to the ground as acid rain or may remain in atmosphere in clouds and fogs.

Acidification of environment is a man-made phenomenon. The acid rain is infect a cocktail of H_2SO_4 and HNO_3 and the ratio of the two may vary depending on the relative quantities of oxides of sulphur and nitrogen emitted. On an average 60-70% of the acidity is ascribed to H_2SO_4 and 30-40% to HNO_3. The acid rain problem has dramatically increased due to industrialization. Burning of fossil fuels for power generation contributes to almost 60-70% of total SO_2 emitted globally. Emission of NO_3^{--} from anthropogenic sources ranges between 20-90 million tons annually over the globe. Acid rains have assumed global ecological problem, because oxides travel a long distance and during their journey in atmosphere they may undergo physical and chemical transformations to produce more hazardous products.

Acid rains create complex problems and their impacts are far reaching. They increase soil acidity, thus affecting land flora and fauna; cause acidification of lakes and streams thus affecting aquatic life, affects crop productivity and human health. Besides these they also corrode buildings, monuments, statues, bridges, fences, railings etc. Due to acidity, levels of heavy metals as aluminium, manganese, zinc, cadmium, lead and copper in soil and water increases beyond the safe limits. Many bacteria and blue green algae are killed due to acidification, thus disrupting the ecological balance.

The acid rain problems are acute in developed Western countries. In India, industrial belt emits lot of gases which have potential to cause acid rain. Proper planning is needful to ensure unit for development of industries, environment and ecosystems are not threatened due to acid rain.

SOLVED PROBLEMS

Example 1: An irrigation water having EC value of 0.45 dS/m contains calcium (Ca^{2+}) and magnesium (Mg^{2+}) 2.0 and 1.0 me/l, respectively. Calculate (i) the concentration of sodium (Na^+) in me/l and (ii) SAR of the irrigation water. Give comments on the irrigation water.

$$\text{(i) Na (me/l)} = \text{EC (dS/m)} \times 10 - Ca^{2+} + Mg^{2+} \text{ (me/l)}$$

$$= 0.45 \times 10 - (2+1) = 4.5 - 3 = 1.5$$

$$\text{(ii)} \quad \text{SAR} \quad : \quad \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

$$\frac{1.5}{\sqrt{\frac{(2+1)}{2}}} = 1.225$$

The irrigation water has no sodium hazard and it can be safely used for the irrigation purposes.

Example 2: An irrigation water sample on analysis gives the following results: EC x 10^6 = 1200 µmhos/cm or 1.2 mmhos/cm or dS/m, Ca + Mg= 8 me/l Calculate the followings:
(1) Total salts in ppm and % (2) Na me/l and SAR (3) Salt added in kg/ha per irrigation (Depth of irrigation = 5 cm)

(i) ppm = 640 x EC x 10^3
= 640 x 1.2 = 7680 =768 ppm

(ii) % salt = 768/10,000 = 0.0768 % or
= EC x 10^3 x 0.064 = 1.2 x 0.064 = 0.0768 %

(iii) SAR first Na me/l = ECe x 10 - Ca + Mg = 1.2 x 10 – 8 = 12 – 8 = 4 me/l

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} = \frac{4}{\sqrt{\frac{8}{2}}} = \frac{4}{\sqrt{4}} = \frac{4}{2} = 2$$

(iv) Salt kg/ha
(i) ppm = mg/l = 768 mg/l
(ii) gram/l = 0.768
(iii) kg/l = 0.768/1000
100 x 100 x 0.05 = 500 cu.m. water/ha= 500 x 1000 litre

$$\frac{500x1000}{1} \times \frac{0.768}{1000} = 500 \times \frac{768}{1000} = \frac{3840}{10} = 384 \text{ kg/ha salt added}$$

Example 3: An analysis of irrigation water as under:

(1) EC : 2.6 dS/m
(2) Ca + Mg : 18 meq/l
(3) CO_3 : 3.5 me/l
(4) HCO_3 : 21.5 me/l

Calculate : (1) % salt, (2) Total cation concentration, (3) ppm salt, (4) Na concentration me/l, (5) SAR, (6) RSC, (7) Amount of salt added in soil kg/ha and GR of kg/ha per irrigation. (Note : Depth of irrigation water = 6 cm.)

(1) ppm salt = 640 x EC x 10^3
= 640 x 2.6
= 1664 ppm salt = 1.424 g/l salt

(2) % salt = ppm/10,000 <u>OR</u> 0.0640 x EC x 10^3
= 0.1664

(3) Cation concentration = EC (dS/m) x 10 = Ca + Mg + Na
= 2.6 x 10 = 18 + Na
= 26 – 18 = Na
= 8 = Na me/l

(4) SAR $= Na/\sqrt{\frac{Ca+Mg}{2}}$ $= 8/\sqrt{3}$ = 8/3 = 2.67

(5) RSC = (CO_3 + HCO_3) – (Ca + Mg)
= (3.5 + 21.5) – (18)
= 25 – 18
= 7 me/l

(6) Amount of salt added per irrigation per hectare

$$6 \text{ cm/ha} = \frac{6 \times 100 \times 100}{100} = 600 \text{ cu.m. water/ha}$$

1 cu.m. = 1000 litres
600 cu.m = 6,00,000 liters/irrigation
1664 mg/l = 1.664/1000 g/l
6,00,000 x 1.664/1000 = 998.4 kg/ha/irrigation
<1.25, 1.25-2.5, >2.5 7 RSC – 2.5 = 4.5 RSC to be reduced by gypsum
RSC Z me/l = Z x 86 mg/l GR
= Z x 0.086 g/l GR
= Z x 8.6 g/100 l GR
= 4.5 x 8.6 = Y g/100 l GR

lit	g
100	
6,00,000	Y

$$Y = \frac{Y \times 6{,}00{,}000}{100 \times 1000} = 6Y = 4.5 \times 8.6 \times 6$$

= 232.2 kg/ ha GR

Example 4: Work out the LR for water having 2000 µmhos/cm EC value. The crop has capacity to withstand salinity to the extent of 8 mmhos/cm. Five cm of water is applied for irrigation.

$$LR = \frac{EC_{iw} \times 100}{EC_{dw}} = 2 \times 100/8 = 25\ \%$$

(2000 µmhos/cm = 2 mmhos/cm)

25 % water should be given extra for irrigation or 6.25 cm of water (5 cm+1.25cm which is 25 % of 5 cm) must be given to leach down the excess of salts. Generally the LR values should be kept below 25 % as excess value will induce wasteful use of water and reduce the irrigation efficiency. It will also raise the underground water table depth or will increase the drainage requirement. Thus, for reducing the value of LR, salt tolerant crops should be chosen.

Example 5: An irrigation water having EC value of 0.45 dS/m contains calcium (Ca^{2+}) and magnesium (Mg^{2+}) 2.0 and 1.0 me/l, respectively. Calculate (i) the concentration of sodium (Na^{+}) in me/l and (ii) SAR of the irrigation water. Give comments on the irrigation water.

(i) Na (me/l) = (EC in dS/m x 10) - ($Ca^{2+} + Mg^{2+}$)
= (0.45 x 10) – (2 +1) = 4.5 – 3 = 1.5

$$\text{(ii) SAR} = \frac{Na^{+}}{\sqrt{\dfrac{Ca^{2+} + Mg^{2+}}{2}}}$$

$= 1.5/\sqrt{[(2+1)/2]}$

$= 1.5/\sqrt{(3/2)}$

$= 1.5/1.224$

$= 1.225$

The irrigation water has no sodium hazard and it can be safely used for the irrigation purposes.

***Example 6:** Irrigation water containing 414, 120 and 24 mg/l of Na, Ca and Mg, respectively. Calculate (1) Total cation concentration me/l) (2) SAR (3) EC value (mSm^{-1}) (4) OP (5) Total dissolve salt (mg/l).*

Na = 414 mg/l = 414/23 = 18 me/l
Ca = 120 mg/l = 120/20 = 6 me/l
Mg = 24 mg/l = 24/12 = 2 me/l
Total cation concentration = Ca + Mg + Na = 6 + 2 + 18 = 26 me/l
SAR = Na/√Ca+Mg/2 = 18/√6 + 2/2 = 18/√4 = 18/2= 9
EC x 10^3 = Total cation(me/l) /10 = 26/10 = 2.6 mmhos/ cm or dS/m
OP = EC x 10^3 x 0.36 = 2.6 x 0.36 = 0.936 bars
Total dissolved salts = Ca + Mg + Na = 414 + 120 + 24 = 558 mg/l

Example 7: An analysis of irrigation water is as under:
(i) EC 250 mS/m, (ii) Ca + Mg = 9 me/l (iii) CO_3 + HCO_3 15.0 me/l (iv) Depth of irrigation water 5 cm/ha (10 irrigations were given) Calculate :(i) Na me/l, (ii) SAR, (iii) ppm and % salt, (iv) Amount of salt added through irrigation water (kg/ha), (v) RSC and necessary to workout GR of irrigation water and give your comment.

EC = 250 mS/m = 2.5 dS/m
Total cation me/l = EC x 10^3 x 10 = 2.5 x 10 = 25 me/l
Na me/l = Total cation – (Ca + Mg) = 25 – 9 = 16 me/l
SAR = Na/√Ca+Mg/2 = 16/√9/2 = 16/√4.5 = 16/2.12 = 7.55
% salt = EC x 10^3 x 0.064 = 2.5 x 0.064 = 0.16 %
ppm salt = % salt x 10,000 = 0.16 x 10,000 = 1600 ppm
5 cm/ha irrigation = 100 x 100 x 0.5 = 500 cu.m/irrigation
10 irrigations = 500 x 10 = 5000 cu.m
1 cu.m = 1000 l water hence 5000 cu.m = 5000 x 1000 = 50,00,000 l
0.16 % salt means 0.16 kg/100 l water so 50,00,000 x 0.16/100 = 8000 kg/ha
or 1600 ppm = 1600 mg/l = 1.6 g/l = 50,00,000 x 1.6/1000 = 8000 kg/ha
RSC = (CO_3 + HCO_3) – (Ca + Mg) = 15 – 9 = 6 me/l
Initial RSC – Final RSC = 6 – 2.5 = 3.5 me/l to be reduced
1 me RSC = 86 mg gypsum/l
= 0.086 g/l
3.5 me RSC = 3.5 x 0.086 = 0.301 g/l
so for 1 litre = 0.301 g gypsum
hence 50,00,000 l = 0.301 x 50,00,000/1000 = 1505 kg gypsum/ha
Comment : EC = 2.5 mmhos/cm = 2500 micromhos/cm = C_4 =Salinity hazard
SAR= 7.55 = S_1 = Low Na water = can be used
RSC = 6 = not suitable for irrigation

Chapter 8

Remote Sensing and GIS techniques

Remote sensing is the science and art of acquiring information about objects fro, made at a distance without any physical contact. Infect, when we see an object and understand what it is, our eye is sensing that object, remotely. Similarly, the term remote sensing is generally used form observing out earth surface from space using satellites or from the air using aircraft after suitable modification.

Remote Sensing (RS), also called tele-detection or earth observation, refers in a general sense to the instrumentation, techniques and methods used to observe (Sense) the surface of the earth usually by the formation of an image (portrait) in a position stationary or mobile at a distance remote from that surface.

Use and potentialities of remote sensing in agriculture and forestry:

1. Identification and area measurements of various major agricultural crop types.
2. Mapping of soil and water temperatures.
3. Mapping of surface water, including snow-pack.
4. Mapping of disease and insect invasion.
5. Mapping of gross forest types.
6. Mapping of forest-lire boundaries.
7. Assessment of crop and timber-stand vigour.
8. Determination of soil characteristics and soil moisture condition.
9. Delineation of rangeland productivity.
10. Mapping of areas of potential forest-fire hazard.
11. Mapping of major soil boundaries.

In the field of soil studies, the remote sensing techniques have been employed in obtaining land-use inventories, soil surveys, detection of salinity, and detection of moisture stress, soil mapping and measuring thermal properties of soils.

Table 8.1: Possible Use of Remote Sensing Techniques in Assessment and Monitoring of Land, Water and Crop Resources

A. Soil and Land resources	• Soil characteristics, soil survey and land use planning, • Watershed characterization and management. • Waste land mapping and monitoring.
B. Soil salinity & water logging	• Extent of saline and effect of reclamation measures, • Seasonal water logging, extent of wetland areas.
C. Soil erosion & Soil conservation	• Fluvial erosion, extent and depth of gullies. • Eolian erosion, sand dune movement, shilling cultivation,
D. Agricultural disasters	• Desertification arid hind forms and change in vegetative cover. • Agricultural draught management. • Extent and damage due to floods.
E. Water resources	• Surface water bodies, ground water targeting, • Soil moisture status and soil moisture mapping. • irrigation scheduling, evapotranspiration estimation,

F. Crop resource estimation	• Crop identification, discrimination & acreage estimation. • Crop yield modeling and crop production forecasting. • Crop condition assessment, crop stress detection (water, nutrient and diseases).

Remote sensing in soil survey

Use of remote sensing techniques for soil survey has been advanced to a great extent from aerial photo-interpretation to visual interpretation of aerospace multispectral data and digital analysis. Introduction of microwave remote sensing for soil moisture studies has been of high value for soil mapping.

Aerial photographs have been used since sixties and often soil scientists have found it very useful tool for preparation of small and medium scale soil maps. Large scale aerial photographs have been used for detailed soil survey with intensive and judicious field checks.

Aerial photography in soil survey

Aerial photographs are the pictures taken by an aerial camera fitted into a plane flying under certain specific conditions of flight. Aerial photographs are of two types (1) oblique and (2) vertical.

Importance

Aerial photographs are only pictures of earth's surface, but not of the soil which is a three dimensional piece of land shape having specific morphological, physical, chemical and biological characteristics. This information of soil profile is required for soil classification and mapping.

In normal soil survey about 80 per cent of the observations are made in the field are needed for locating the soil boundaries and the other 20 per cent are used to describe the soils. So aerial photographs reduce the time spent for locating the soil boundaries.

Methods of image interpretation

Visual Interpretation

For visual interpretation, imagery of visible and infrared bands i.e., standard False Color Composites (FCCs) are used in identifying the various elements for soil survey. The steps involved are summarized below:

1. Procurement of satellite imagery and toposheet of scale 1: 250,000 or 1: 50,000.
2. Construction of tentative legends.
3. Monoscopic visual interpretation of the imagery for physiography, based on differences in- tone and texture or a combination of these two elements to prepare pre field physiographic map.
4. Transfer of physiographic delineation into a topo-base of scale of satellite imagery.
5. Selection of sample areas/sample strips for detailed study.
6. Procurement of aerial photographs of the sample areas.
7. Transfer of broad land types from satellite imagery to aerial photograph.
8. Detailed photo-interpretation of the aerial photographs.

9. Selection of sample area on aerial photographs.
10. Ground observations in sample areas of photo/imagery to correlate land type (physiographic unit) and soil relation-ship.
11. A minimum of five to seven soil observations are done within each physiographic delineation
12. Compilation of the legend from sample strips and construction of final legend.
13. The soil map of the sample area is prepared.

The above information is transferred over a base map. Once the soil composition of each land unit is established, the interpretation of the imagery can be done for the entire area by extrapolation. Thus a physiographic-soil map is prepared.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

With the advancement of computer technology digital image processing techniques are also being used for soil mapping. Wherever there is close relationship between physiographic and land use, digital analysis proves to be useful. Thus digital soil mapping requires incorporation of landforms, topography (slope/aspect) and vegetation (land use/land cover) information to improve the accuracy while classifying remotely sensed data. GIS has been emerged as a powerful tool to integrate this information's to improve the classification. Ancillary data are of any type of spatial and non-spatial information that may be value in the image classification process: including elevation, slope aspect, geology, and hydrology and vegetation maps.

What is GIS?

A geographic information system (GIS) is a computer-based tool for mapping and analyzing things that exist and events that happen on Earth. The system which provides for the entry, storing, manipulation, analysis, retrieval and display of spatially orients data, through digital techniques. The major components are:

- Data input
- Data encoding (topology creation)
- Editing and manipulation
- Data conversion
- Data analysis
- Data base management
- Output generation and presentation

Fundamental concepts of GIS

Any data that can be mapped has both location and possess an attribute, attribute can be both qualitative (*e.g.* land use, geology, etc.) or quantitative (*e.g.* elevation, dip, population, *etc.*) and it may sometime very with time (*e.g.* temperature, land use, population *etc.*) These three components *viz.*, location, attributed and time represent the content of most GIS. The real value of any information, derived from any source, depends on whether or not it can be interrelated 1 with other spatially distributed (cartographic) information. This is possible only when the varied information is stored in GIS format.

Potential areas of GIS for Agriculture

GIS is a useful tool for database management analysis and presenting of all types of spatial data with the textual information. By integrating the crop simulation models with the research information generated at various location across variable natural resources environment, optimum by plans at farm, regional and national level can be derived. GIS could be of immense use in the following areas of agriculture.

- Land suitability assessment
- Agriculture production marketing
- Irrigation scheduling
- Crop condition monitoring
- Farm management
- Soil and water management
- Fisheries management
- Wet land management
- Wasteland development
- Disaster management

Chapter 9
Land Capability Soil Classification

LAND CAPABILITY CLASSIFICATION

Evaluation of land for land use planning is a consequent step following the soil survey and mapping process. In the recent years, it has been popularized in almost every land development programme. The system of land capability classification requires that every acre of land be used in accordance with its capability and limitations. The land capability classification is a broad grouping of soils bases on their limitations and also serves as a guide to assess suitability of the land for cultivation, grazing and forest plantation. The use of land without paying regard to its capability is like drawing on bank account without knowing the balance. As a result, crop yields progressively decline and it requires extra-efforts for obtaining sustain crop production.

Land Capability Groupings

The grouping of soils into capability classes and sub-classes is done on the basis of their, capability to produce crops and pasture plants without deterioration over a long period of time. The criteria used in assessing a land unit are the physical land properties and the degree of limitation as a function of the severity with which crop growth is inhibited. It is mainly 1 based on:

(i) the inherent soil properties,
(ii) the external land features and
(iii) the environmental factor that limit land use. The first two information are provided by standard soil survey report and the third information is provided by other agencies.

The following different factors that determine the capability of a soil are

a) Depth of soil
b) Drainage condition of soil
c) Texture and Structure of soil
d) Relief (slope)
e) Intensity of soil erosion
f) Susceptibility to overflow and flooding and degree of saturation
g) Problematic soils with particular reference to salts, alkali, acidity and other unfavorable chemical properties
h) Climatic variation etc.

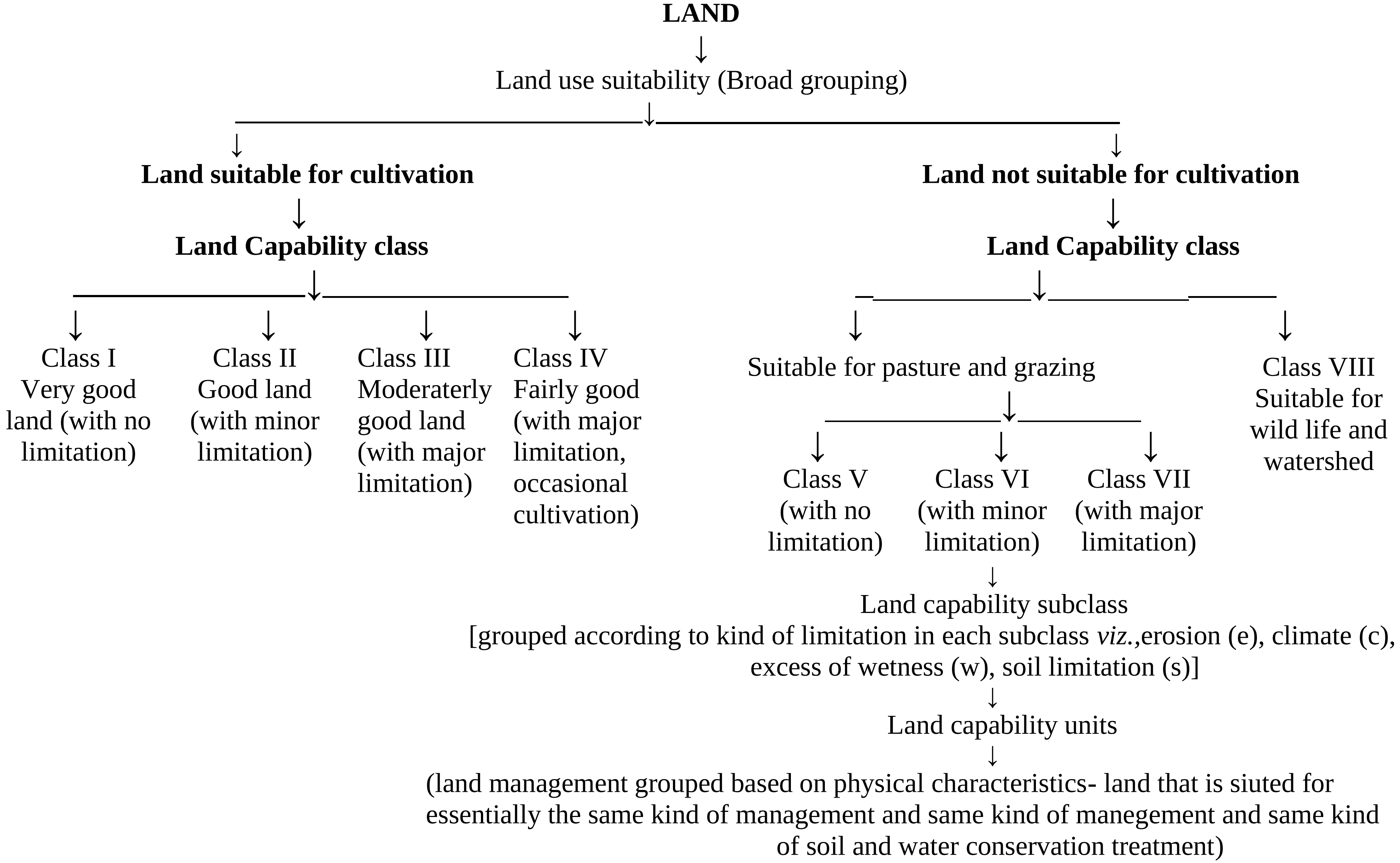
The land capability classification scheme developed by soil conservation service, United States Department of Agriculture (USDA) is appended in Table 9.1. The classification scheme has four categories namely land suitability class, land capability classes (comprising eight classes). Land capability sub-class and capability units.

(i) **Land suitability class.** It is a broad grouping of lands and it can be grouped into (a) land suitable for cultivation and (b) land not suitable for cultivation because of various constraints like excessive wetness or dryness, extreme variation in slopes etc.

(ii) **Land capability classes.** It consists of eight classes viz. Class I to Class VIII. Classes I through IV can be used for cultivation and classes V through VIII cannot be cultivated in their present state under normal management.

Table 9.1: Land Capability Classification System

Land Capability Classification System



LAND

↓

Land use suitability (Broad grouping)

↓

Land suitable for cultivation

↓

Land Capability class

↓

Class I
Very good land (with no limitation)

Class II
Good land (with minor limitation)

Class III
Moderaterly good land (with major limitation)

Class IV
Fairly good (with major limitation, occasional cultivation)

Land not suitable for cultivation

↓

Land Capability class

↓

Suitable for pasture and grazing

↓

Class V
(with no limitation)

Class VI
(with minor limitation)

Class VII
(with major limitation)

Class VIII
Suitable for wild life and watershed

↓

Land capability subclass
[grouped according to kind of limitation in each subclass *viz.*,erosion (e), climate (c), excess of wetness (w), soil limitation (s)]

↓

Land capability units

↓

(land management grouped based on physical characteristics- land that is siuted for essentially the same kind of management and same kind of manegement and same kind of soil and water conservation treatment)

Examples: IIe, IIc, IIw mean good land with problem of erosion, climate condition, wetness and soil limitations, respectively.

Class –I	—Very good land	Land suitable for cultivation
Class –II	—good land	
Class –III	—moderate] good land	
Class –IV	—fairly good land	
Class-V, VI and VII	—Land suitable for pastures and grazing	Land not suitable for cultivation
Class-VIII	—Land suitable for wild life and watershed	

(iii) Land capability sub-class. It is a sub-group of land capability class, indicates the kind of limitations encountered in the management and use of the land. The soil capability sub-classes recognized are :

e—erosion hazard is the main limitation
w—wetness
s—shallow, droughty or stony
c—climate, too cold or too dry

These are indicated on the land capability maps by the above mentioned symbols. In class I land, there is no limitation. In othe classes like Class II, if there is problem of wetness, this is indicated by llw.

(iii) **Land capability units.** It is the further sub-divisions of the land capability sub-classes. Soils in one Unit are enough alike to be suited to the same crops and pasture plants, to require similar management and to have similar productivity and other responses to management.

Soils in a land capability unit are characteristically similar having similar potentialities and hazards. A given land capability unit can be used by farmers directly for farm planning and other uses. If the existing limitations can be permanently removed or reduced by following appropriate measurs like provisions of irrigation, drainage, control of gullies and construction of flood controlling structure etc., then the land capability class can be changed toward a better class. A further deterioration of the existing conditions will shift the capability to a worse class.

As an output from soil survey, classification provides a framework for making local generalisation about soil, based on the properties of the soil series identified. Recently, for making soil survey data a more precise and useful, geographic information system (GIS) and soil information system (SIS) techniques are being used to give physical distribution of soil classes, to assess full range of soil variability, to relate individual data with the spatial variability of social properties, to interpret individual components of map units and other current information about land use practices through a comprehensive electronic database. However, of late, these techniques have been widely used to increase efficiency and speed of the soil survey and land use planning programme. These modern systems were developed mainly because it was not possible for humans to handle in an orderly way the huge amounts of data derived from soil and land surveys until and unless advanced computer hardware and software technology is used for the purpose.

Chapter 10

Multipurpose Trees: Their Selection and Role in Land-Use Systems

How Do We Define 'Multipurpose' Trees-Mpts?

We have already noted in the introduction that the term 'multipurpose trees', as used in this source book, covers all woody perennials used in agroforestry. From many attempts to arrive at an agreed definition, we have selected the following as most appropriate for understanding the multiple functions of woody perennials in an agroforestry technology:

Multipurpose trees are defined as all woody perennials that are purposefully grown to provide more than one significant contribution to the production and/or service functions of a land-use system. They are so classified according to the attributes of the plant species as well as to the plant's functional role in the agroforestry technology under consideration (after Burley and von Carlowitz, 1984).

“Any woody perennial species can be 'multipurpose' in one situation and 'singlepurpose' in another.”

At What Scale Do We Use Multipurpose Trees In The Landscape?

Agroforestry can be applied at different scales in a landscape. The smallest scale is the individual farm, where trees might be grown around the homestead or as boundary markers. At the macro scale, agroforestry practices may be applied to whole watersheds or to large expanses of open cereal farms, where the trees may be used to control water or wind erosion, as contour barriers or shelterbelts.

The fundamental roles of the woody perennials can vary greatly in relation to the needs of the system, as indicated in Table 1.1. Many examples are described in ICRAF's Agroforestry Systems Inventory (see Nair, 1989). Supplement One is a checklist of MPT characteristics, their possible productive and service roles, and also some important management characteristics. In the context of experiments on agroforestry, the smallest unit can be regarded as the zone of interaction between the multipurpose tree and the individual crop plant —the 'tree-crop interface' (Huxley, 1983a).

The production roles of woody perennials in land-use systems

A. Forestry Applications

1. Protection forestry, land reclamation and rehabilitation
2. Management of natural vegetation
3. Industrial plantations
4. Community woodlots
5. Farm woodlots

B. Agroforestry Technologies

1. Trees in cropland, mixed intercropping
2. Hedgerow intercropping
3. Contour strips in farmland

4. Trees in home gardens
5. Live fences and hedges
6. Trees on borderlines and boundaries
7. Trees on terraces and earthworks
8. Trees on waterways, gullies and flood plains
9. Fodder lots
10. Windbreaks and shelterbelts
11. Improved fallows
12. Trees in pastures and rangelands

Agroforestry Systems and Fuelwood Resources

The use of agroforestry to meet the multifarious requirements of rural farmers has been practiced in this country since time immemorial. The need is now increasingly felt in view of the dwindling forest area, rising prices and uncertain availability of commercial energy resource in the near future. King and Chandler (1978) defined it as a sustainable land management system which increases the overall yield of land, combines the production of crops (including tree crops) and forest plants and/or animals simultaneously or sequentially on the same unit of land and applies management practices that are compatible with cultural practices of local people. The system holds promise to the energy needs of small and marginal farmers who cannot afford to keep 10 per cent of the land for fuelwood plantations. Choice and selection of right species and site are the two most important factors determining its success or the failure. The tree species should not only be compatible with underlying crops but complementary also with due emphasis on fast growth and short rotation.

The species selected should offer the advantage of:

1) multipurpose plants,
2) wide adaptability and easy to establish,
3) little care and maintenance cost,
4) unpalatably: to goats and wild animals,
5) high survival under adverse edapho-climatic conditions,
6) rapid growth and ability to coppice,
7) increase soil fertility i.e., N-fixation,
8) least competitors and good nutrient pumps and
9) high calorific values and burning quality.

Before starting any such experiments, a, preliminary survey of overall requirement. of the local people, availability and suitability of the land, fodder and fibre requirement and oilier problems need to be studied in detail. The diagnostic and design technique of the ICRAF can be handy in this regard (ICRAF, 1983). The fuelwood requirement can also be substantiated by any of the following agroforestry systems:

1. **Agri-silviculture:** Agricultural crop (and fodder crop) + Fuel/fodder tree species
2. **Silvi-pastoral:** Rearing of animal + Fuel/fodder tree and grass/forage species
3. **Agri-silvipastoral:** Agricultural crop + Fuel/fodder tree and forage + rearing of animal
4. **Horti-silviculture:** Fruit vegetable crop + Fuel/fodder tree species

5. **Multipurpose production system:** Minor forest produce (and medicinal plants) +Fuel/fodder tree species.

Multipurpose Trees to People's Needs: The Importance of Socioeconomic Factors

The role of a woody perennial is not confined to its service and production functions; it must be acceptable in all respects to the farmer and to the local community. Tree characteristics that are particularly important to many local communities include smokiness of fuelwood, odours and flavours imparted by fuelwood or charcoal, and thorniness. However, the overriding factors for farmers *are perceived economic benefits* and *the reduction of risk.* A new species or technology will not be adopted by local farmers if it cannot be shown to be superior in these respects. For this reason, long-term research programmes must include the collection of appropriate economic data.

Other, 'social', factors have to be taken into account when planning research, although they are more difficult to quantify than economic benefits. These include personal and community preferences, tastes, and cultural and religious behaviour; there are many examples of species that grow well on a particular site but are not favoured by farmers for such reasons. Many of these factors can be identified during diagnostic surveys of rural areas (see Chapter Two for more details). A research programme must eventually investigate these preferences, attempt to put values on community preferences and provide factual information on growth characteristics and uses of trees to help local communities and development planners in decision making.

The Role of Indigenous Species

In many countries, an important point of discussion is whether MPT species used in agroforestry should be indigenous or exotic. The most important factor in all cases is to make the best choice for the farmer and for the site. As in modern farming and also in plantation forestry, there may have been an overemphasis on exotic tree species for agroforestry, mainly because they were thought to be easier to manage than indigenous species and their products more saleable.

However, indigenous MPT species also need to be evaluated—not only those that are common locally, but also those that are less well known or that have specialized uses. Many of these species can be identified during diagnostic exercises, ethnobotanical surveys or specialized marketing studies. Although the fact that local farmers currently utilize a particular species does not necessarily imply that it will be suitable for a specific agroforestry technology, such information at least suggests that the species should be examined since it is known to survive and to be acceptable under local conditions.

Diagnosing Land-Use Problems and Designing Agroforestry Technologies

The farmer or other land user makes the final decision on whether or not to adopt an agroforestry technology for use in a particular land-use system. Yet the enormous variety of potentially useful ways of using trees together with crops and/or animals makes it difficult to decide which agroforestry technologies to adopt in any given situation.

Similar problems confront the researcher who has to decide which of many possible agroforestry experiments should be conducted, especially when resources for research are scarce.

The priorities for research and extension should always be those technologies that have the greatest potential for solving problems, and not necessarily those that are easiest to carry out.

In order to help agroforestry researchers and extension workers to identify these priorities and arrive at sound agroforestry recommendations, ICRAF has developed a tool known as the diagnosis and design (D&D) methodology. This is simply a systematic approach for applying to agroforestry the common-sense medical principle that 'diagnosis should precede treatment'.

In any field of endeavour, the ability to solve a problem depends on being able to define exactly what that problem is. A clear statement of the problem is often all that is needed to suggest the nature of a possible solution. This is the core of the logic that the D&D methodology uses to identify relevant agroforestry technologies for a given set of land-use problems and potentials. This same logic is followed to ascertain the desirable attributes of MPT species to be used in a particular land-use system.

The Diagnosis of Problems and Potentials

Following this approach, the diagnosis of land-management problems and potentials leads to a set of specifications for agroforestry interventions, i.e. *what* an agroforestry technology is expected to do for the system and, to some extent, *how* it should do it. These system specifications suggest general agroforestry technologies from the list given in Table 1.1. To design an appropriate prototype technology, detailed specifications are required. These specifications must include the characteristics of suitable MPT species and other plant components, plus detailed plans for spatial arrangements and management practices.

This step requires knowledge of the component species, the ways in which they interact with each other and their responses to management, so that they can be combined into a workable system.

Because each *distinctive land-use system* has a different set of problems that call for different solutions, each system requires a separate D&D exercise. Thus, there is a need for a prediagnostic reconnaissance survey, during which the land-use systems that are to be the focus of a particular exercise are delineated and described. Detailed D&D field surveys then examine each distinct land-use system.

The ultimate objective of the D&D process is, of course, to encourage the use of selected agroforestry technologies by farmers and other land users. However, available knowledge on the precise ways in which species interact is still rudimentary. At the same time, many agroforestry technologies are still of a 'notional' character, while others, known to exist as traditional farmer practices, have yet to be subjected to systematic scientific scrutiny. For this reason, most D&D exercises point to requirements and priorities for further research.

Several tree species produce gums and resins that are easily collected, for instance Boswellia and Acacia. They provide valuable cash income for rural people.

MPT attributes in relation to production and service functions

Attributes	Effects
Breeding pattern, outcrossing or inbreeding, pollination method	Related to production and service functions; variation found in populations of seedling origin
Dioecious or monoecious	Distribution of sexes within and between individual plants: important for seed and fruit production and pollen flow
Tree height	Ease of harvesting leaf, fruit, seed, branch wood; shading effects
Stem form	Suitability for timber, posts, poles; shading effects
Crown size and form	Quantity of leaf, mulch and fruit production; shading effects
Multi-stemmed habit	Fuelwood production; shading effects
Rooting pattern (deep or shallow; spreading or geotrophic)	Competitiveness with other components, particularly resource sharing with crops; suitability for soil conservation
Leafiness; physical and chemical composition of leaves and pods	Fodder and mulch yield and quality; soil nutritional aspects
Thorniness	Suitability for live fencing or hedgerow intercropping
Wood quality	Acceptability for fuelwood and various wood products
Phenology: leaf flush, leaf fall, flowering and fruiting cycle; seasonality	Timing and labour demand for fruit, fodder, seed harvest; ability to withstand extreme conditions
Deciduousness	Seasonal or permanent leaf fodder availability; suitability for live fences, hedges and shelterbelts
Pest resistance; vigour	Major requirements, irrespective of function
Site adaptability and ecological range	Suitability for extreme sites or reclamation uses
Response to pruning and cutting	Use in hedgerow intercropping or for pollarding, lopping, coppicing
Possibility of nitrogen fixation	Use in hedgerow intercropping, planted fallows, rotational systems

Albedo: The ratio of reflected to incoming radiation, usually given in percent of vegetation or soil.

Allelopathy: The influence of plants, rather than microorganisms, upon each other, arising from the products of their metabolism.

Alley cropping: Also called 'alley farming' and 'hedgerow intercropping'; an agroforestry intercropping system in which species of shrubs or trees are planted at close in-row spacing, with wide spacing between rows to leave room for herbaceous crops.

Phenology: The study of the time of appearance of characteristic periodic phenomena in the life cycle of organisms in nature, for example flowering or leaf fall, especially as influenced by environmental factors.

Bio remediation

“Remediate" means to solve a problem and "Bio-remediation" means to use biological organisms to solve an environmental problem such as contaminated soil or groundwater. Agroforestry is the collective name for all land use systems in which woody perennials are deliberately grown with agriculture crops and/or animals either in some form of spatial or temporal sequence. In agroforestry system there must be ecological and economic interaction between the components. Agroforestry systems have the potential to make use of marginal and degraded lands through the soil improving effects of trees. Problematic soils are those soils which are not suitable for arable farming because of specific limitations.

Aspects of this new approach include:

1. find ways of making the use of marginal lands sustainable; reclaim and restore degraded land;
2. improve germplasm to produce plant varieties which are adapted to soil constraints;
3. maintain soil organic matter and biological activity, with benefits both for soil physical conditions and balanced nutrient supplies;
4. improve nutrient cycling and nutrient use efficiency in
5. agro ecosystems;
6. use fertilizers and other external inputs at moderate
7. levels, seeking strategic use to overcome deficiencies that cannot otherwise be remedied;
8. Improve water-use efficiency.

The capacity of trees to maintain or improve soils is shown by the high fertility status and closed nutrient cycling under natural forest, the restoration of fertility under forest fallow in shifting cultivation, and the experience of reclamation forestry and agroforestry. Soil transects frequently show higher organic matter and better soil physical properties under trees. Some species, most notably Faidherbia abide, regularly give higher crop yields beneath the tree canopy.

Trees improve soil fertility by processes which:

1. Increase additions to the soil;
2. Reduce losses from the soil;
3. Improve soil physical, chemical and biological conditions.

The most important sets of processes are those by which trees:

1. Check runoff and soil erosion;
2. Maintain soil organic matter and physical properties;
3. Increase nutrient inputs, through nitrogen fixation and uptake from deep soil horizons;
4. Promote more closed nutrient cycling.

Kinds of Problem Soils

There are two types of problems.

1. Physical problems
2. Chemical Problems
    1. Fluffy paddy soil
    2. Acidic soils
    3. Sandy soil
    4. Salt affected soils –Saline soils
    5. Subsoil hardening or hardpan -Sodic soils
    6. Surface crusting -Saline-sodic soils

7. Water logged soil
8. Peat and marshy soils

1) Fluffy Paddy soils – these are the low mechanical strength soil developed under continuous rice cultivation practice. Puddling break soil aggregates into a uniform structure less mass.
2) Sandy soil- Sandy soils are the result of the weathering and disintegration of a variety of rocks such as Granite, Limestone and Quartz. This soil is found in Haryana, U.P., Bihar states of India.
3) Hardpan soil- these occurs in red soils due to illuviation of clay in association with oxides of Fe, Al and calcium carbonate. It prevents root proliferation and limits nutrient uptake from surface soil.
4) Surface crusting – it refers to the crust formation at the surface of the soil.This is due to presence of colloidal oxides of iron and aluminium in Alfisols which binds the soil particles under wet regimes.
5) Peat and Marshy Soil- Occur in Humid region Formed by accumulation organic matter black in colour and High acidic. Areas: Kottayam and Alleppey in Kerala, Coastal Odisha, Sunderbans of W.B.
6) Waterlogged Soil- In any land where Excessive water content and inadequate aeration in the soil called waterlogged soil.

Bioremediation through agroforestry

1. Tree species: Eucalyptus robusta, Syzygium cumuni, Terminalia arjuna, Salix tetrasperma, Dalbergia latifolia, Eucalyptus camaldulensis, Eucalyptus grandis
2. Grasses: Brachiaria mutica, Dichanthium caricosum, Paspalum notatum, Brachiaria decumbens.

Chemical Problem

Acid soils – This soil having pH less than 7 is called Acidic Soil and extremely acidic soil has pH between 4- 4.75.These are formed due to leaching of bases in high rainfall zones and also due to development of soils from acidic parent materials like granite and sandstone and application of acid forming fertilizers. It is common in Pine forest. **Areas:** Karnataka, M.P., Odisha, West Bengal, Kerala, Assam, Bihar.

Adverse effect on plant growth

1. High solubility of elements like Al, Mn and Fe in toxic amounts due to high soil acidity.
2. Beneficial activities of soil micro- organisms are adversely affected.
3. Due to soil acidity, nutrients such as Ca and K may be deficient.

Mechanism for reclamation of saline soils

Halophytes are the native flora of saline soils. Few are suitable for reclamation. The basic principle of reclamation is the removal of excess salt to a desired level in root zone.

Providing proper drainage, use of salt free irrigation water, acidic fertilizers, organic manures etc. are some of the mechanisms adopted. The process of salinization is accelerated by rapid evaporation from the surface. Leaching with water of good quality and adequate drainage of excess water from the soil is carried out. The selection of salt tolerant species is done which include suitable tree species such as Prosopis juliflora, Tamarix articulate, Acacia nilotica etc. Agricultural crops include barley, sugarbeet, cotton wheat, rice beans etc.

1. The removal of excess salts to a desired level in root zone.
2. Leaching and adequate drainage.
3. Mulching to reduce salinity.
4. Organic matter addition keeps the salts in diluted form and increases water holding capacity of soil.
5. Green manuring, tree planting.

Bioremediation through Agroforestry

1. Promising woody species for saline soils are Salvadora spp., Prosopis juliflora, Acacia nilotica, Parkinsonia aculeata, Butea monosperma, Terminalia arjuna, Salix spp., D. sissoo and Casurina equisetifolia.
2. Highly salt tolerant and high biomass producing grass species include Aeluropus lagopoides, Sporobolus helvolus, Cynodon dactylon and Brachiaria ramosa.

Mechanism for reclamation of alkali soils

The reclamation practice include proper drainage of water to remove salts from the root zone use of salt free irrigation water, addition of organic matter, addition of molasses, alkali tolerant crops sush as paddy, cotton, mustard, wheat, tomato, onion etc. Green manuring of dhaincha has been found to be beneficial.

Bioremediation through Agroforestry

Prosopis juliflora and Karnal grass improves the soil condition to such an extent that after some time or years, less tolerant but more palatable fodder species such as- Berseem (Trifolium alexandricum) senji (Melilotus parviflora) and shaftal (Trifolium resupinatum) can be grown under trees.

Saline and Sodic Soil

Soil that is high in both salt and sodium is considered to be saline - sodic soil. Due to high pH and the dominance of sodium (Na+) ions in alkali soil, part of the soil organic matter dissolves and comes into the soil solution. Extracts of such soils have a characteristic dark brown or black colour. The dissolved organic matter in the soil solution becomes deposited as a thin film on the soil surface. The prevalence of such black stains in such soils are called “Black alkali”.

Areas: Parts of Gujarat, Rajasthan, Punjab, Haryana, Maharashtra.

Mechanism for reclamation

Such soils have the mixture of characteristics of both saline and alkali soils. Therefore soils showing high salinity should be reclaimed for both first for salinity and later for excessive exchangeable sodium. Growing of crops tolerant to high exchangeable sodium ensures reasonable returns during initial years of reclamation. Cropping practice including a green manure crop and/or legume is common. Low organic matter and high pH deters the biological activity and thus decreases the transformation of\and availability of nutrients, and causes significant volatilization of nitrogen from applied nitrogenous fertilizers. Tolerant crops such as rice, sugarbeet and dhaincha are used. Trees species include Prosopis juliflora, Acacia nilotica, Prosopis chinensis etc.

Bioremediation through Agroforestry

Acacia auriculiformis, Azadirachta indica, Casurina equisetifoia, Dalbergia sissoo, Alianthus excelsa, Prosopis cineraria, Acacia tortilis and A. nilotica tree species are used for bioremediation of the saline and sodic soils.