FUNDAMENTALS
OF SOIL SCIENCE

DR SUNIL KUMAR
DR MAHENDRA SINGH
DR RAJIV RAKSHIT
DR NINTU MANDAL

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SOIL SCIENCE- INTRODUCTION, BRANCHES, NEED IN AGRICULTURAL SCIENCE

INTRODUCTION:

Soil and land, though related, are two different entities. Land is two-dimensional entity representing geographical area and landscape, while soil is a three-dimensional body with length, breadth and depth and is hidden below the land surface. Soil is recognized by digging a pit and exposing its profile. The profile of a soil with well marked horizons called A, B and C tells the history of its formation and bears the imprint of many physical, chemical and biological processes which have led it to the present form.

Soils are formed by weathering process of rocks which in the words of Hans Jenny can be depicted by the equation:

$S = (cl, r, p, o, t, \ldots)$

Where; S= soil,
cl= climate (rainfall, temperature, snow, etc.)
r= relief/topography
p= parent material (rocks, minerals and geographical information)
o= organisms (plants and animals), and
t= time or age

The soil serves not only as a medium for plant growth and for microbiological activity *per se* but also as a sink and recycling factory for numerous waste products which might otherwise accumulate to poison our environment. Moreover, the soil supports our buildings and provides material for the construction of earthen structures such as dams and road beds.

DEFINITION OF SOIL:

“Soil is a natural body composed of inorganic and organic constituents, having a definite genesis and a distinct nature of its own”-- **Dokuchaev (1900)**

“Soil is a natural occurring body that has been evolved owing to combined influence of climate and other organisms, acting on parent material, as conditioned by relief over a period of time” --**Jenny (1941)**

“Soil is the unconsolidated mineral matter on the immediate surface of the earth that serves as a natural medium for the growth of land plants”

“Soil is the unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate, macro and micro organisms and topography, all acting over a period of time and producing a product, that is soil, that differs from the material from which it is derived in many physical, chemical, biological and morphological properties and characteristics --**SSSA (1970)**

“Soil is a natural body synthesized in a profile form from a variable mixture of broken and weathered minerals and decaying organic matter, which covers the earth in a thin layer and which supplies, when containing proper amounts of air and water, mechanical support and in part sustenance to plants”

BRANCHES OF SOIL SCIENCE:

Pedology:- The Science dealing with the genesis ,survey and classification and the laws of geographical distribution of soils as a body in nature. Pedology is the study of soil as a natural body and does not focus primarily on the soil’s immediate practical use.

Edaphology:- The science that deals with the influence of soils on living things, particularly plants, including man’s use of land for plant growth. Edaphology is the study of soil from the stand point of higher plants.

Soil Fertility: - The quality of the soil that enables it to provide essential chemical elements in quantities and proportions for the growth of specified plants.

Soil Chemistry:- Deals with the chemical constituents , the chemical properties and the chemical reactions of soil in relation to crop needs.

Soil Physics:- Study of various physical processes that are taking place in and through the soils.

Soil Microbiology:- Deals with microscopic population of the soil, its role in various transformations and its importance in plant nutrition and crop production.

Soil Conservation:- Deals with the protection of soil against physical loss by erosion and against chemical deterioration.

Soil Genesis:- The study of the mode of origin of soils, with special reference to the processes responsible for the development of Solum or true soil from the unconsolidated parent material.

Soil Survey:- The systematic examination, description, classification and mapping of soils in an area.

Soil Technology:- It is an applied science and deals with the principles and practices of soil erosion and conservation, and management of problem soils, viz. saline, sodic (alkaline), acid, waterlogged and other degraded soils.

Need in agricultural science:

Soil provides anchorage to roots enabling plants to stand erect; it act as a store house of water and nutrients for plant growth; it act as an abode of flora and fauna which suitably transform nutrients for uptake by plants roots; it provides space for air and aeration which create a healthy environment for the biological activity of soil organisms.

PEDOLOGY, EDAPHOLOGY- CONCEPT, HISTORY

Modern Concepts of Soil

Knowledge about soils comes from two basic sources; farmer experience based on centuries of

trial and error, and scientific investigations of soils and their management 1 From the dawn of agriculture, cultivators recognized good soils being attracted to fertile soils of river valleys. 2 More than 42 centuries ago, Chinese used a schematic soil map as a basis for taxation. 3 Homer (about 1000 B.C.) referred the use of manure on the land. 4 Early Greek and Roman writers described farming systems that involved leguminous plants and the use of ashes and sulphur as soil supplements.

Early Scientific Investigations

French agriculturist **J.B. Boussingault** (1834) proved that air and water were the primary sources of C, H, and O in plant tissue.

German chemist – **Justus Von Leibig** (1840) - Crop yields were increased by adding minerals or

inorganic elements to the soil. He proposed that the mineral elements in soil and in added manures and fertilizers are essential for plant growth. He disproved the humus theory.

Leibig's research led to the concept that certain factors were essential for plant growth and that

if any one of these factors was limiting, plant production would be reduced accordingly – **Law of**

Minimum

R. Warrington – Nitrogen transformations are biological

S. Winogradski (1890) – Isolated two groups of bacteria responsible for nitrogen transformations. Nitrogen assimilating bacteria grow in nodules of leguminous plants

Research in USA

C G Hopkins (Illinois) : Developed effective soil management system based on lime stone, rock phosphate and legumes.

Milton Whitney of USDA emphasized field studies and initiated the first National Soil Survey

Systems.

F H King(Wisconsin) studied the movement and storage of water in soils in relation to root penetration and crop growth.

Concept of pedology and edaphology

Pedology:- The Science dealing with the genesis ,survey and classification and the laws of geographical distribution of soils as a body in nature. Pedology is the study of soil as a natural body and does not focus primarily on the soil's immediate practical use.

Edaphology:- The science that deals with the influence of soils on living things, particularly plants, including man's use of land for plant growth. Edaphology is the study of soil from the stand point of higher plants.

Origin of Earth, Earth crust, Composition

Evolution of Earth

The origin and evolution of earth is best explained by 'Planetesimal Hypothesis' put forth by T. C. Chamberlain and F.R. Moulton in 19t h century and Nebular hypothesis.

Planetesimal Hypothesis:

According to this when a big star comes closer to sun it creates certain gravitational pull because

of which tearing away of the outer matter took place. The teared matter got condensed and started to move around the sun in orbits. These are called planetary nucleoids.

According to 'Nebular Hypothesis':

1. Whole solar system at one time is a cloudy (nebula) mass of matter in form of vapor or gas.
2. It was intensely hot and incandescent. It was in perpetual motion.
3. On lapse of time nebula began to cool and the vapors in the outer layer are condensed and thrown out in the form of rings. Further condensation and disruption lead to formation of planets.
4. The central mass which is still incandescent and not yet condensed is 'SUN'

Spheres of Earth

Geographically EARTH constitutes of three spheres corresponding to three states of matter (Solid, Liquid & Gas)

The solid zone is Lithosphere. The incomplete covering of water forming seas and oceans (liquid
Spheres) is Hydrosphere. The gaseous envelop over the earth surface is Atmosphere.

Atmosphere:-

The atmosphere forms an envelope, 322 Km over the earth's surface. This envelops of air that covers both lithosphere and hydrosphere is called atmosphere. It contains water modules and dust, which act as nuclei for the condensation of water vapor to form cloud or fog.

N_2 - 78.054 % O_2 - 20.946 %

CO_2 - 0.033 % Argon - 0.934 %

In addition, inert gases such as helium, neon, krypton and xenon are present. The water vapor content in atmosphere varies from place to place and time to time. Air becomes less dense with height until it gets too thin to support life. Atmosphere contributes only 0.03 % weight to the earth.

Hydrosphere

1. Covers almost 3/4t h of earth crust.
2. The Hydrosphere is 10 Km deep and occupies 70 % of earth's surface.
3. Hydrosphere makes only 6.91 % of the earth mass but by volume 15 times than that of
   the visible land above the sea level.
4. It contains absorbed air and carries particles of rocks as sediments.
5. Most of it lies with in the ocean basins and also appears on surface of land in the form of rivers, ponds, lakes and as ground waters.
6. The quality of different waters, varies

Lithosphere

It is the solid sphere. It consists of continents, ocean basins, plains, plateaus and mountains, valleys, sand dunes, lava flows and fault scraps. The interior of earth consists of rocks and minerals. It is covered by gaseous and watery envelops. It amounts to 93.06 % of earth's mass.

Interior of the earth crust

The Earth-ball consists of 3 concentric rings; Crust, Mantle and Core.

Crust: It is 5-56 km thick; consist of rocks with density of 2.6-3. The soil scientists are interested in it, especially in its skin. It varies from 5 to 11 km in the oceans and 35 to 56 km in the continents.

Mantle: It's have 2,900 km thickness; comprises mixed metals and silicates and ultra basic rocks with density of 3.0-4.5.

Core: The innermost portion of the; it is 3,500 km in thickness; comprises metals, such as nickel and iron with average density of 3-12.

The density of earth as a whole is 5.5 Mg m^{-3}, whereas the density of the common rocks varies from 2.6 to 2.7 Mg m^{-3}, and the density of the haviest rock is 4.0 Mg m^{-3}. The density of the core is 9.0 Mg m^{-3}. From this it is evident that the density increase from the crust to the core.

Composition of Earth's Crust

Most of the hard, naturally formed substance of the earth is referred to as 'rock' out of 106 elements known eight are sufficiently abundant as to constitute 98.6 % (by weight) of the earth crust (up to 16m) Out of eight elements, two are in great abundance and comprise ¾ the total composition of the crust. The other six elements are metals.

Non metallic (%)	O^{2-} - 46.60	Titanium - 0.41
	Si^{4+} - 27.72	Hydrogen – 0.17
	Carbon - 0.12	
Metallic **- (%)**	Al^{3+} – 8.13	Phosphorus- 0.09
	Fe^{2+} – 5.00	Sulphur - 0.07
	Ca^{2+} - 3.63	Manganese- 0.07
	Na^{+} – 2.83	Barium - 0.05
	K^{+} – 2.59	Strontium - 0.02

Mg^{2+} – 2.09, *Chromium, Nickel, Lithium chlorine & Fluorine* – each 0.01

Others – 1.41

COMPONENTS OF SOIL, SOIL PHYSICAL PROPERTIES

Components of soil

Mineral soil consists of four major components i.e., inorganic or mineral materials, organic matter, water and air. In a representative loam surface soil, the solid mineral particles comprise about 45% of the soil volume and organic matter 5%. At optimum moisture for plant growth, the pore space is divided roughly in half, 25 %, of volume being water space and 25 % air. The proportions of air and water are subjected to rapid and great fluctuations. The four soil components occur in a thoroughly mixed condition in soil and this mixture encourages interactions with in and between the groups and permits marked variations in the environment for the growth of plants.

The proportion of different components in the diagram depicts the good soil condition for plant growth (Loam surface soil).The air and water are extremely variable and their proportions determine in large degree the soil's suitability for the plant growth. Mineral Matter: The Inorganic portion of soils is quite variable in size and composition. It is composed of small rock fragments and minerals of various kinds.

Rock Fragments

2.0 - 75.0 mm - gravel or pebbles
75.0 - 250.0 mm - cobbles (round) flags (flat)
> 250.0 mm - stones or boulders

Soil Particles

0.2 - 2.0mm - sand (gritty)
0.02 - 0.2mm - fine sand (gritty)
0.002 - 0.02mm - silt (powdery)
< 0.002mm - clay (sticky)

The proportion of different sized particles (texture) determines the nutrient supplying power of the soil, considerably. Primary minerals (original) are prominent in sand and slit fractions; where as the secondary minerals (formed) dominate in clay fraction and in some cases the silt fraction. The inorganic fraction of soil is the original source of most of the mineral elements that are essential for plant growth.

Organic Matter

It comprises an accumulation of partially disintegrated and decomposed plant and animal residues and other organic compounds synthesized by soil microbes as the decay occurs. It is a transitory soil constituent as it is continuously broken down by soil organisms and lasts from few hours to several hundred years. It requires maintenance by regular addition to the soil of plant and/ or animal residues .Organic matter content varies from 1.0 to 6.0 % by weight in top soil and very less in sub soil. In respect of soil productivity organic matter plays an indispensable role.

Soil Water

Soil water is held in soil pores with varying degrees of tenacity depending on the amount of water present and size of the pores. Soil water with its soluble constituents (nutrients) makes up soil solution, which is the critical medium for supplying nutrients to growing plants. Soil water plays significant role in controlling energy balance of the soil and regulates the gaseous exchange in the upper layer of the soil. The presence of water in different amounts in soil governs its thermal, mechanical, physical, chemical and biological properties.

Soil Air

The content and composition of soil air are determined largely by the water content of the soil, since the air occupies those soil pores not filled with water.

Soil air always differs from atmosphere air in composition because of moisture content, root and microbial activities.

1. Relative humidity may approach 100% at optimum soil moisture
2. CO2 content is often several hundred times higher than 0.033%
3. Oxygen content usually <20%. In extreme cases only 5-10%

In cases of low soil air, the diffusion rate of air in to and out of the soil would be slow and this leads to unsatisfactory conditions for optimum plant growth.

Soil physical properties

The properties related to the mechanical behavior of the soil mass are referred to as the physical properties of soil. The detail in brief is given below:

Soil texture

Soil texture may be defined as the relative proportion of the various soil separates namely sand, silt and clay in a given soil. The size of particles or separates in mineral soil is not easily changed. So the proportion of each size group in a given soil can not be altered easily. That is why soil texture is considered.

Soil textural classes:

The groups based on the relative proportions of the various soil particles are known as soil textural classes. Soil textural class names are used to give an idea of the soils of the textural make up of the soils and to indicate their physical properties. Soil textural classes may be broadly be grouped into:

1. **Sandy soil:** This group includes soils having at least 70% sand particle and 15% or less clay particles by weight. The basic soil textural class names of this group are sands and loamy sands which are coarse in texture. These soils have relatively low chemical activity for which they are resistant to weathering. As the soils this group have very low content of clay particles, they have low specific surface area and they are non sticky and plastic in nature. The water holding capacity and the amount of plant available water of these soils are low but drainage condition and aeration of them are high. They have low CEC for which their nutrient supplying ability and nutrient retention power is very low. The productivity of these soils is normally low.
2. **Loamy soils:** An ideal loam may be defined as a mixture of sand, silt and clay particle in about equal proportion. An ideal loam soils feels gritty and cohesive. It has good drainage, medium water retention capacity, medium plant water available content, low plasticity, low stickiness, medium CEC. The nutrient retention and nutrient supplying capacity is medium. This is an ideal soil for crop production.
3. **Clayey soils:** Clayey soils must contain at least 35% clay particles and in most cases not less than 40% of clay particles. These soils are fine in texture have very good water holding capacity, CEC, nutrients retention and availability to the plants.
4. **Silty soils:** Soil having at least 80% silt and 12% or less clay. These soils feel silky and buttery and possess some plasticity, cohesion and adsorptive capacity. The surface of this normally compact and crusty. This soil has medium plant available water and fair internal drainage condition or soil aeration.

Soil structure

Soil structure may be defined as the arrangement of primary soil particles such as sand, silt and clay in to a stable aggregate. In the broad sense Soil Structure denotes: a) the size, shape and arrangement of particles and aggregates; b) the size, shape and arrangement of the voids or spaces separating the particles and aggregates; and c) the combination of voids and aggregates in to various types of structures.

Peds – Natural aggregates which vary in their water stability.

Clod – It is used for a coherent mass of soil broken in to any shape by artificial means such as by tillage.

Fragment - It is a broken ped.

Concretion – It is a coherent mass formed with in the soil by the precipitation of certain chemicals dissolved in percolating waters. Concretions are usually small like shotgun lead pellets.

Classification of Structure: Classification of soil structure for field description is based on i) the **type** as determined by the shape and arrangement of peds ii) the **class,** as differentiated by the size of the peds and iii) the **grade**, as determined by distinctness and durability of peds.

TYPES: As per the geometric shape, the aggregates can be broadly divided in to two types.

1. Simple structure 2. Compound structure

1. Simple structure: In this the natural cleavage plains are absent or indistinct.

a. Single grain structure: Occur in sandy soils

b. Massive structure: Coherent mass with high bulk density occur in soil crusts, paddy soils

c. Vesicular or honeycomb structure: Massive or loose aggregates of nodular ferruginous mass seen in laterites.

2. Compound Structure: The natural cleavage plains are distinct. Described with relative length of horizontal and vertical axes and shape of peds.

Spheroid al: Small rounded peds with irregular faces and are usually separated from each other in a loosely packed arrangement. When spheroidal peds are porous, the structure is called as Crumb, while less porous peds are called granular**.** Usually granular peds are <1cm, while crumb

peds are<0.5 cm in diameter. The diameter typically ranged from 1.0 to 10.0 mm.

Granular and crumb structures: are characteristic of many surface soils (A horizon) particularly those high in organic matter. They are prominent in grassland soils and soils that have been worked by earth worms. This structure is invariably subjected to management practices.

Plate like: Relatively thin horizontal peds or plates characterize this structure. The thicker units are called **Platy** and thinner ones are called **Laminar**. The platy types are often inherited from parent materials, especially those laid down by water or ice. Sometimes, compaction of clayey soils with heavy machinery can create platy structure. Found in surface layers of some virgin soils**.**

Block Like: Blocky peds are irregular, roughly cube -like and range from 5 to 50 mm across. The individual block are not shaped independently but are molded by the shapes of the surrounding blocks. When the edges of the blocks are sharp and rectangular faces distinct, they are called **Angular blocky**, and when faces and edges are somewhat rounded they are referred as **subangular blocky**. These types are usually found in B horizons, where they promote good drainage, aeration and root penetration.

Prism – Like: These are vertically oriented pillar like peds with varying heights among different

soils and may have a diameter of 150 mm or more.

In **columnar** structure pillars have distinct rounded tops, and in invariably found in subsoils high in sodium (nitric horizon). If the tops of the pillars are relatively angular and flat horizontally, the structure is designated as **Prismatic**. These structures are associated with welling types of clay and commonly occur in sub surface horizons in arid and semi-arid regions.

Rocks

A rock is defined as mixture of two or more minerals.

Petrology

Is the science of rocks which form the units of earth crust.

Petrography

Deals with description of rocks and *Petrogenesis* are the study of origin of rocks.

Minerals

Minerals are naturally occurring inorganic solid homogenous substances composed of atoms having an orderly and regular arrangement with definite chemical composition and characteristic geometric form.

Eg. Quartz (SiO_2), Orthoclase ($KAlSi_3O_8$), Olivine [$(Mg,Fe)_2SiO_4$)

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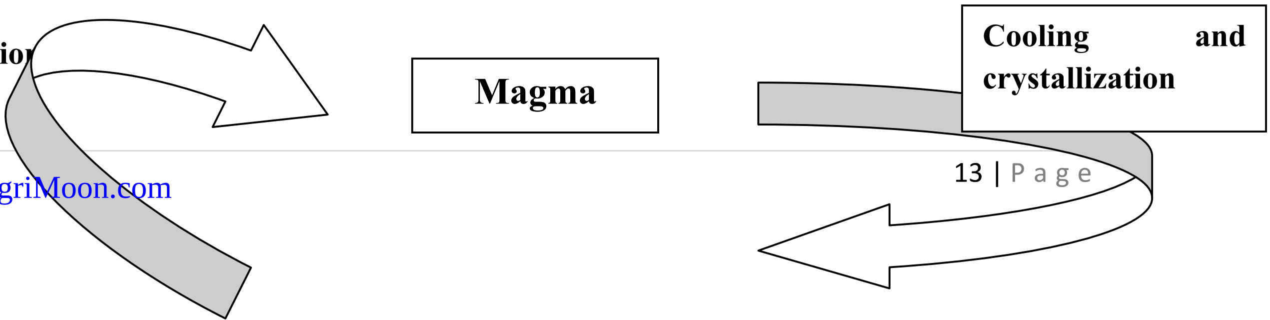
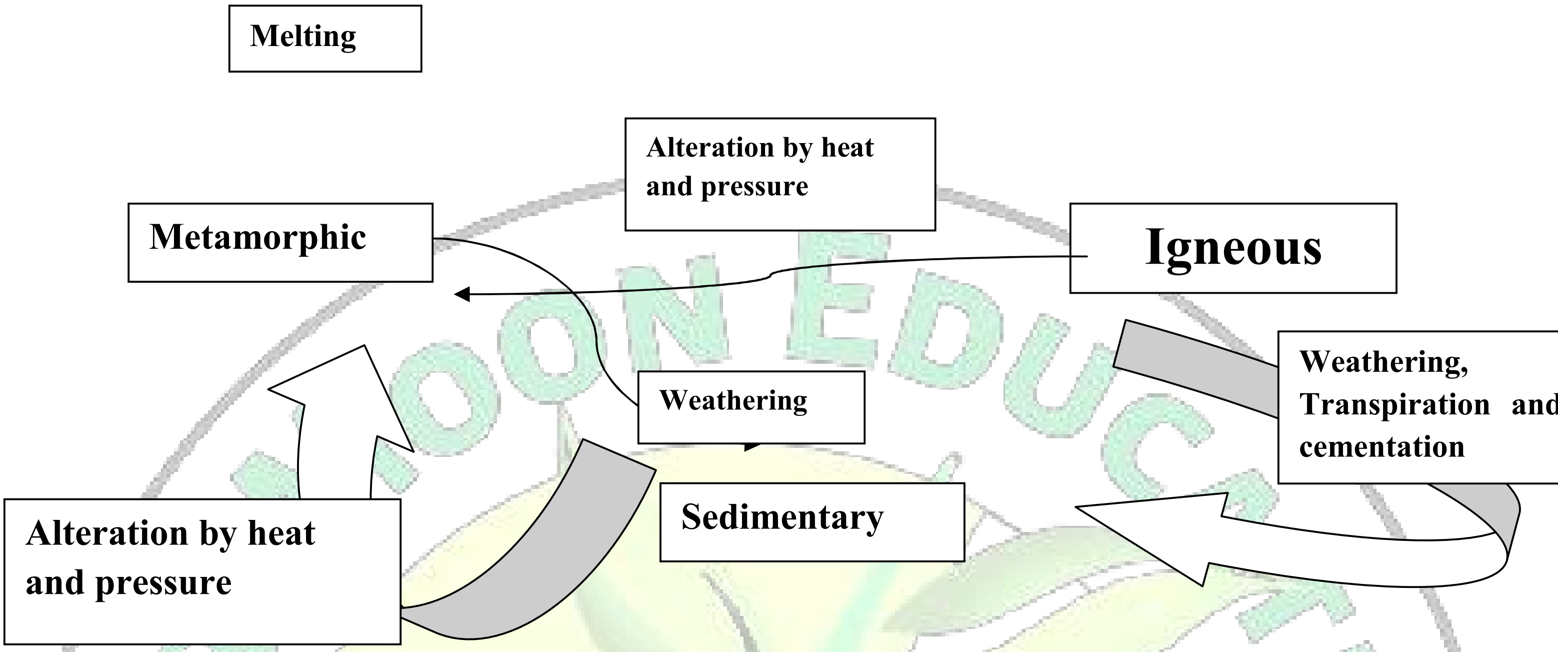




Rock Cycle

Classification of rocks

On the basis of their genesis and structure, rocks are generally grouped into three classes, namely, i. Igneous ii. Sedimentary iii.Metamorphic.

Composition of upper 5 Km of earth surface

Rock Type	**Examples**	**% composition**
Sedimentary	Shales	52
	Sandstone	15 } 72%
	Limestomes and Dolomites	7
Igneous	Granite	15
	Basalt	3
Other Rocks		8

Igneous rocks: L. ignis, meaning fire

Formed by solidification of molten magma on or beneath the surface of earth. They are characterized by ***nonlaminar massive structure*** and on whole make up 95% of earth crust.

Igneous rocks

Based on mode of origin **Based on chemical composition**

Intrusive or Plutonic **Extrusive or volcanic** **Acid** **Neutral** **Basic**

Solidification at Solidification takes place (65-75%) (55-65%) (40-55%)

Moderate depth of earthon surface of earth Silica SilicaSilica

Eg.GraniteEg.Bassalt eg. Granite Andesite Gabbro

Sandstone Deorite Basalt

Coarse grained crystals Fine grained crystals

Sedimentary rocks: (L. sedimentum, meaning settling) Formed from the consolidation of sediments derived from the breaking down of pre-existing rocks. The sediments are transported to new place through wind and water action and deposited in new arrangements and cemented to form sedimentary rocks. *Stratification is the most common features of these rocks so these are called stratified rocks.* They are formed through four stages **i. *Weathering ii. Transportation iii. Deposition and iv. Diageneis.*** Based on their origin, sedimentary rocks are grouped into two main classes.

Sedimentary Rocks

Based on the origin

Fragmental, Detrital or mechanically formed Chemically formed

(Formed by the deposition and cementation

of erosion products or fragments of preexisting rocks, varied in texture and structure eg. Sandstone Shale)	**Inorganically formed by** evaporation or precipitation *Evaporation:* halite and gypsum *Precipitation*: limestone and dolomite	**Organically or biochemicallyformed**

Metamorphic rocks

The word metamorphic means change in form and metamorphism is used as general term for all those changes that alter more or less completely the original characteristics of rocks.

Metamorphic rocks can be defined as those which have undergone some chemical or physical change from its original form. They are formed from the subsequent transformation of igneous and sedimentary rocks under the influence of chemically active liquids and gasses and internal heat and pressure. There are two broad classes of metamorphism i. **Thermal**: Changes bring about by heat as dominant factor ii. **Dynamothermal**: Changes brought about by combined effect of heat and pressure.

Pre-existing and their equivalent metamorphosed rocks

Pre-existing/Original rocks	**Metamorphosed rocks**
Conglomerate	Genisss
Limestone	Marble
Basalts	Schists
Coal	Graphite

Weathering

Weathering is defined as the process of disintegration and decomposition of rocks and minerals, brought about by physical, chemical and biological processes leading to the formation of regolith.

Regolith: Unconsolidated residues of the weathering or weathered rocks on the earth surface or above the solid rocks. The regolith or at least its upper part may therefore be termed as parent materials of soils.

Parent materials

Parent materials may be defined as the unconsolidated and more or less biochemically-weathered mineral materials from which soils are developed.

Rocks, being the original starting point in the weathering process, are first broken down into smaller fragments and eventually into the individual minerals of which they are composed off. Simultaneously the rocks disintegrate the minerals therein are attacked by weathering forces and are changed to new minerals either by alterations or by decomposition , resulting in the release of soluble constituents (most of which are lost through drainage waters). The minerals which are synthesized may be grouped as follows.

- The silicate clays
- The resistant end-products, including Fe and Al oxides.

Weathering Processes

Different weathering agents

Physical/Mechanical **(Disintegration)**	**Chemical** **(Decomposition)**	**Biological** **(Disintegration and decomposition)**
1. Physical condition of rocks	1.Hydration	1. Man and animal
2. Change in temperature	2.Hydrolysis	2. Higher plants and their roots
3. Action of water	3. Solution	3. Microorganisms.
Fragmentation, transportation &	4. Carbonation	
Decomposition	5. Oxidation and reduction	
Action of freezing		

Alternate wetting & drying

Action of glacier

4. Action of wind and sand blast

5. Atmospheric electric phenomenon

Physical weathering

In physical weathering, rocks are disintegrated, that is broken down into comparatively smaller pieces, without producing any new substances. The result of physical weathering can be compared with the hammering or crushing of rocks under a great force. The different agencies that take part in the process of physical weathering are:

Physical condition of rocks

The permeability of rocks is probably the most important single factor that determines the rate at which the rocks weather. Coarse-textured (porous) sandstone will weather more readily than fine textured (almost solid) basalt.

Changes in Temperature

Alternate expansion and contraction due to diurnal changes in temperature, is more common in hot and desert regions where the surface of rocks weaken and even crumbles since the rocks do not conduct heat easily.

The minerals within a rock also vary in their rate of expansion and contraction. The cubical expansion of quartz is twice that of feldspars. The dark coloured rocks are fast changes to temperature as compared with light coloued rocks. This differential expansion of minerals in a rock surface generates stresses between the heated surface and the cooled unexpanded parts, resulting in fragmentation of rocks. This process, with time, may cause the surface layer to peel-off from the parent masses and the rock may disintegrate. This phenomenon is called ***exfoliation***.

Eg. The peeling off the skin from parent rock (basalt) due to diffential expansion and contraction of minerals as a result of changes in temperature (popularly known as ***onion type of weathering***).

Action of water

Water acts as disintegrating, transporting and deposing agents. The rain water beats the surface of rocks as the rain falls and starts its journey towards the ocean. The moving water has a great cutting and carrying force. It forms gullies and ravines and carries with it suspended soil materials of varying size.

The materials deposited in the silted-bed are the ***alluvium*** and the change in course of river is called ***meander***.

Action of freezing

In the cold regions water in the cracks and crevices freezes into ice, increasing its volume by ***one-tenth***. As freezing starts from top there is no room or way for expansion of entrapped water. Further increase in volume due to freezing of subsurface water exerts an enormous outward or side-ward pressure which breaks apart the rocks.

Alternate wetting and drying

Some minerals expand or increase considerably in volume on wetting and shrink on drying. Smectitic clays in dry weather shrink considerably forming large number of wide cracks or in the ground. On subsequent wetting the minerals swells. The ultimate effect of alternate wetting and drying on smectitic clay-enriched rocks with platy structure, such as ***shale*** is to loosen and eventually disintegrating the rocks.

Action of wind and sand blast

Dust storms which itch rocks on their way and transports tones of materials from one place to another. This shifting of sand causes serous wind erosion problem and may render the cultivated land as wasteland with a thick mantle of sand cover, for instance sandy desert of Rajasthan and other places , not only itches rock on their way but also blocks roads and rail-lines with thick mantle of sand cover.

Chemical weathering

In physical weathering, wherein rocks are broken into smaller pieces, chemical weathering is more complex in nature and involves the transformation of rocks into some new products.

The chemical weathering of feldspars, for examples, produce clay minerals, which has different composition and physical properties.

Feldspars+ Water* → *Clay minerals + soluble cataion and anions

Chemical weathering becomes much more effective as surface area of rocks increases. Since, chemical reactions occurs on the surface of rocks, therefore smaller the fragments, the larger the surface area per unit volumes of soil available for reaction. ***Chemical weathering is most important factors so far soil formation is concerned.***

Effectiveness of chemical weathering depends on the composition of rocks. **Quartz (SiO_2)** respond slowly for chemical attack, like **olivine (Fe, Mg)$_2$ SiO_4 or pyroxene**.

a. Hydration

Is the chemical union of water with a substance leading to a change in structure of a substance. It is called chemical combination of water or addition of water of crystallization. Owing to hydration, there is swelling and increase in volume or bulk of substance. The minerals loose their structure and becomes soft. It is most common process in nature and works with sedimentary rocks. Such as aluminum oxide, iron oxide and gypsum , whereby these minerals absorbs water , expand and tend to fall apart.

$2Fe_2O_3+3H_2O \longrightarrow 2Fe_2O_3.3H_2O$

(Hematite) (Limonite)

$CaSO_4+2H_2O \longrightarrow CaSO_4.2\ H_2O$

(Anhydride) (Gypsum)

b. Hydrolysis

The property is due to dissociation of H_2O into H^+ and OH^-, these ions chemically combine with minerals and brings about changes, such as exchange, decomposition of crystalline structure and formation of new compounds.

Feldspars +Water → Clay minerals +soluble cataion and anions

$KAlSi_3O_8+8\ HOH \longrightarrow HAlSi_3O_8+\ KOH$

(Orthoclase) (acid silicate clay)

$2HAlSi_3O_8+\ 8\ HOH \longrightarrow Al_2O_3.3H_2O+6H_2SiO_3$

(recombination) (Silicic acid)

c. Solution: Direct solution of primary minerals without a chemical change is not a common phenomenon. However, some substances in a rock are soluble in water.

When the soluble substance are removed by the continuous action of flowing or percolating water , the rock no longer remains solid and develops holes, rill or rough surface and ultimately decomposes. The action is accelerated when the water is acidified by dissolution of organic and inorganic acids. Such waters may dissolve not only alkaline earths but also silica (as in tropical soils).

d. Carbonation

Carbonation is the combination of carbon dioxide with base. This process is quite effective in decomposing the minerals of rocks and soil. Decomposition of the material accelerates on the addition of organic matter to it. This is due to production of carbon dioxide and organic acids which have marked dissolving and decomposing effect on various rocks. The gas readily combines with base to produce carbonates and bicarbonates as

$CO_2 + 2KOH \longrightarrow K_2CO_3 + H_2O$

$K_2CO_3 + H_2O + CO_2 \longrightarrow 2KHCO_3$

The carbonated water has an itching effect on some rocks, especially limestone and those containing cementing substances , such as conglomerate . The removal of the cement that holds sand particles together in sandstones and conglomerates leads to disintegration. The process known as carbonation

$CO_2 + H_2O \longrightarrow H_2CO_3$

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

Oxidation and Reduction

Oxidation is the absorption (by the mineral) of oxygen ions usually from oxygen dissolved in water. Since the rocks are exposed to atmospheric air, there is every possibility for atmospheric oxygen to combine with minerals. The process of combination of oxygen is called oxidation. Water takes oxygen from atmosphere in solution form and carries it to or penetrates into every crevice and fissures of rocks and thus brings air into intimate contact with different minerals substances present.

$2FeO + O_2 \longrightarrow 2Fe_2O_3$

$4Fe_3O_4 + 3H_2O \longrightarrow 6Fe_2O_3$

(Magnetite) (Hematite)

The main product of chemical weathering are very small ($<2\mu$) which carry a significant negative charge on their surface and have mica like structure. Most common type is hydrous mica.

Biological weathering

Living agents are responsible both for decomposition and disintegration of rocks and minerals. The biological life is controlled largely by the prevailing environment. ***Fungi are active in warm and humid environment; bacteria are cool and humid environment.***

Man and animal, Higher plants and their roots, microorganisms are responsible for biological weathering.

Weathering of minerals

There are many factors which influence weathering of minerals, of which following are important

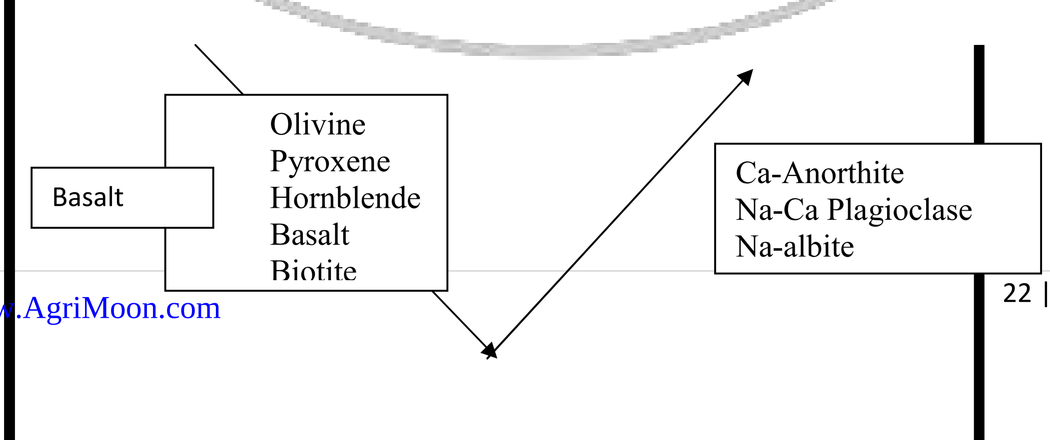
- .Climatic conditions
- Physical characteristics
- Chemical and structural characteristics

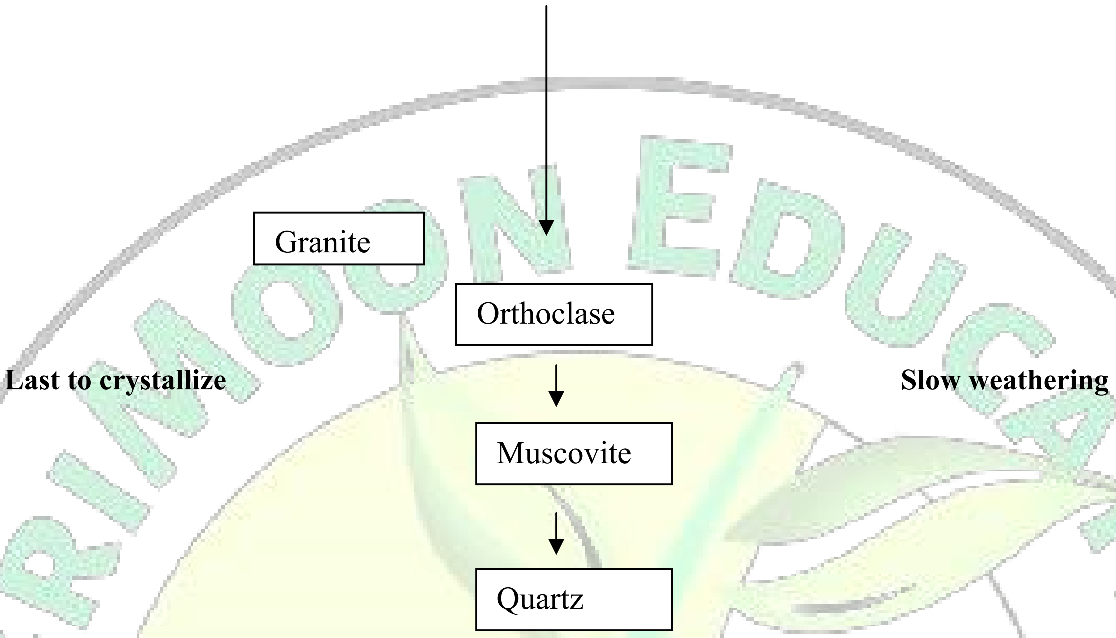
Weathering sequence

Weathering sequence of Goldich (1938)

Quartz (most resistance)> Muscovite, K-feldspars> Na and Ca-feldspars> Biotite, Hornblende and Augite> Olivine> dolomite and calcie> gymsum (least resistant)

First to Crystallize **Rapid weathering**





Relative rate of chemical weathering of common igneous rock-forming minerals. The weathering decreases from top to bottom. It follows Bowen reaction series. It shows that olivine is the first and quartz the last minerals to crystallize.

Soil Formation

The soil formation is a process of two consecutive but overlapping stages:

i. The weathering of rock (R) into regolith (C)
ii. Formation of true soil from the regolith

Factors of Soil Formation

Dokuchaiev (1900), the father of Soil Science, was the first person to show that soils usually form a pattern in the landscape and established that they develop as a result of the interplay of a various soil forming factors , viz. parent material, climate and organisms and time which he put forward in the form of an equation:

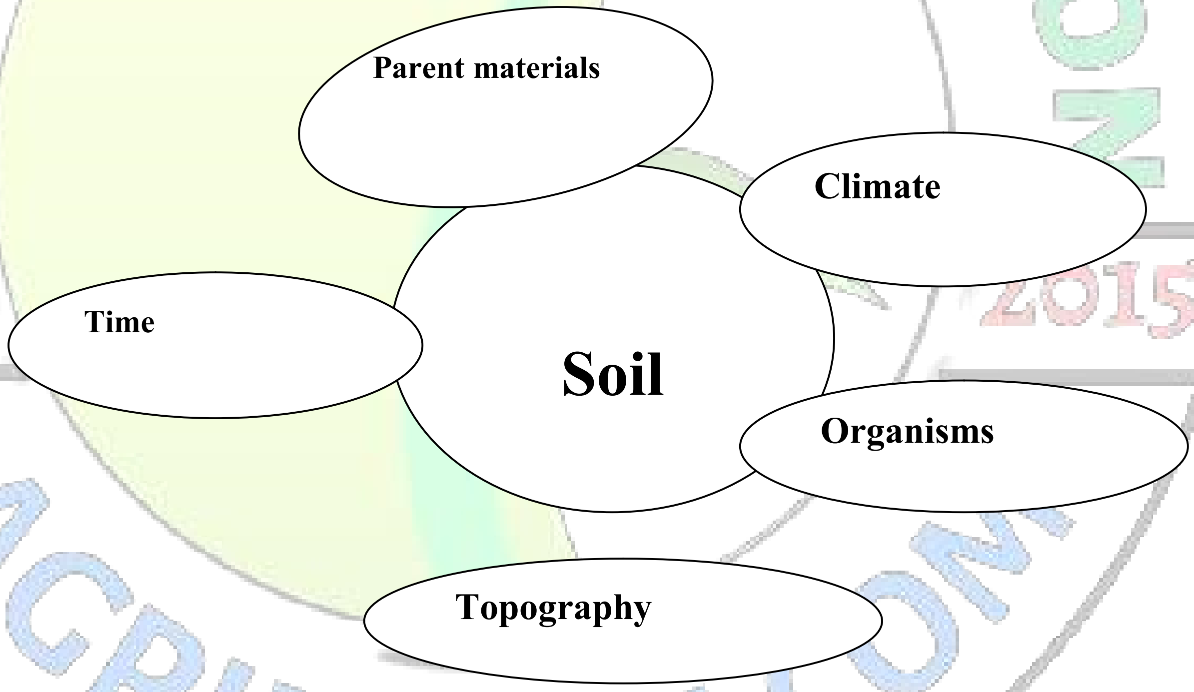
S=f (p, cl, o)

Where S denotes soils, p, parent soil, cl, climate and o, organism

Jenny (1941) formulated the following equation

S= f (cl, b, r, p, t…)

Where S, denotes soil property, such as pH,N and clay; cl, environmental climate; b, biosphere, *i.e.* vegetation and organisms; r, relief or topography; p, parent materials; t, time… denotes additional unspecified factors.



Soil-the end product of various soil forming factors

Soil forming factors

The five soil forming factors, acting simultaneously at any point on the surface of the earth , to produce soil.

Soil forming factors

Passive factors | **Active factors**

1. Parent material
2. Relief or topography
3. Time

4. Climate
5. Vegetation and organisms

Passive soil forming factors

Passive soil forming factors are those which represents the ***source of soil forming mass*** and conditions affecting it. These provide a base on which the active soil forming factors work or act and develop different soils. Such factors are :***Parent materials, relief or topography and time***.

Parent material

Parent material is that mass (consolidated rocks, such as igneous, metamorphic or sedimentary, to unconsolidated sediments such as alluvium, colluviums, Aeolian/losses, glacial till etc) from which soils are developed.

Jenny (1941) defined parent material as the initial stage of soil system. The role of parent materials in soil formation is passive . There is weak correlation between the parent materials and kind of soils developed. Different kind of parent materials may give rise to comparable soils if the climate and vegetation of an area are identical or the same kind of rocks , say , Bassalt can results in different soils if the other factors especially climate and vegetation, vary. Bassalt, an igneous rock , may give rise to highly weathered Red soils (Ultisols) in the humid tropics and Black cotton soils (Vertisols) in the semiarid or subhumid subtropics.

Soil texture is influenced by parent materials. Highly siliceous parent materials, such as sandstones may give rise to very sandy soils while basic rocks and fine grained sediments tend to develop fine-textured soils.

Acid igneous rocks (like granite, rhyolite) produced coarse textured Podzolic soils (Alfisols)

Basic igneous rocks basalts, alluvium or colluviums derived from limestone or basalt, produced fine textured cracking –clay soils (Vertisols).

Basic alluvium or Aeolian materials produce fine and coarse textured soils (Entisols and Inceptisol).

Relief or topography

Topography and relief are often used as synonymous. They denote ***configuration of land surface***. The relief units are geomorphologicallydistinct areas, such as an undulating plain, say alluvial plain. Relief may be described in terms of relative relief, drainage spacing, slope angle. The topography refers to the diffrences in elevation of the land surface on a broad scale. The prominent types of topographic designations , as given in FAO guidelines (1977) are

Land surface	***with slope off***
Flat to almost flat	<2%
Undulating	6-10%
Rolling	11-15%
Hilly	16-30%

Mountainous> 30% with great range of elevations

Toposequence

Soils that are formed from the same kind of parent materials but differ in their topographic positions, within a landscape, show diffential profile development, the sequence of such soils is termed as toposequence. These concepts differ from that of Catena.

Soil catena

In soils,**Milne (1935)** introduced the term ***Catena*** **(**a Latin word meaning a chain) for a sequence of topographically related soils which have comparable parent materials, climate and age, but show different characteristic owing to variation in relief and drainage. Although, the approach is an important part of soil geography, yet it has been widely-criticized and is no more in use.

Time

Soil formation is a very slow process requiring thousands of years to develop a mature profile with distinct horoizonation. The period taken by a given soil from the stage of weathered rocks (i.e. regolith) up to the stage of maturity is considered as time. By matured soils we mean that soils with fully developed horizons (A, B, C). In soil formation, nature works slowly. It has been reported that it takes thousands of years to develop one cm of soils. The time that nature devotes to the formation of soils is termed as ***pedogenic time***.

Mohr and Van Baren (1954) suggested five stage of weathering that are dependent on mineralogical features of soils

Stage	**Characteristics**
Initial	Unweathred parent material
Juvenile	Weathering started ; but most of the original material still weathered.
Virile	Easily weatherable minerals fairly decomposed , clay content increased ; slowly –weatherable minerals still appreciable
Senile	Decomposition reaches at final stage ; only most resistant minerals survive
Final	Soil development completed under prevailing environment

In India, soils in the alluvial regions were classified on the basis of age of alluvium as ***Khaddar (young) and Bhangar (old).***

Active soil forming factors

Active soil forming factors are those which ***supply energy*** that acts on mass *i.e.* the regolith or parent materials, for the purpose of soil formation. Such factors are climate and vegetation.

Climate

Parent materials provide bulk on which the climate acts and produce soil. Climate is the most significant factors for controlling the type and rate of soil formation. Rainfall and temperature are most important criteria in soil formation.

The conceptis based on **precipitation (water supply)** and**evapotranspiration (water need) (Trhonthwaite and Mather, 1955)**. When precipitation exceeds water-need, there is a surplus of water for storage and leaching. When water needs exceeds water supply there is potential deficit of water.

Climate affect soil formation directly and indirectly. Directly climate affects soil formation by supplying water and heat to react with parent materials. Indirectly , it determines the fauna and flora activities which furnish a source of energy in the form of organic matter. These energy in the form of acids act on rocks and minerals and release salts and secondary minerals.

Under comparable rainfalls, the depression may receive more rainfall than the sloping landforms. Such differences in the moisture regimes may lead to diffential profile development.

Precipitation and soil property relationship

Profile development and Horoizonation

Leaching and **percolation** of water through the soils are two outstanding processes in soil formation which determines the characteristics of profile. It is generally accepted that only 15-50% of total precipitation is available for percolation and the rest is lost by way of surface runoff and evapotranspiration. The percolation is dependent on the intensity of rainfall , texture of mineral materials , slope , temperature and vegetation.

There is no distinct horoizonation in the arid and hyper-arid regions because there is no water or acidic solution for percolation , with the result highly soluble salts , such as sodium chloride and or sulphate or concentrate in the solum. With the increasing precipitation, there is more percolation and consequently more profile development with distinct horoizonation.

Temperature

Effect of temperature on is in its rate of soil formation that can be related to the ***Vant Hoffs (1884) law which states that " for every 10^{O}C rise in temperature, the speed of chemical reaction increases by a factor of two or three".***

In the cold humid climates, low temperatures retard chemical reactionsin soils. But, leaching , just as tropics , is pronounced so much that it gives soil a distinct acid reaction. Under such condition, activity of fungi increases (as tolerant to acid environment) and that of bacteria decreases (as they prefer neutral to slightly alkaline reaction). Decomposition of organic matter is also slow under acid slow in cold humid region.

Clay content

The clay content of soils increases with increasing rainfall and annual temperature. Warm humid regions shows very high clay content (>50%) and is the least in hot, arid regions having very low clay content (<10%).

Silica (SiO_2): Sesquioxide ratio ($R_2O_3=Fe_2O_3+Al_2O_3$)

In regions of high moisture contents, the SiO_2: R_2O_3 ration decreases as the temperatureincreases. The ration in different regions varies as under:

Region	**SiO_2: R_2O_3**
Cold, humid eco-region	3 to 3.5 (or more)
Subhumid ecoregion	2 to 3
Tropical ecoregion	<2

Vegetation and organisms

Vegetation is an active soil forming factor which greatly influence soil evolution. This is evident for fact that desert soils are markedly different (in terms of their morphological features and physic-chemical properties) from the forest or grassland and/or tropical soils because of varying vegetation cover.

Production and addition of organic matter

The greatest contribution of vegetation is through the addition of organic matter or leaf litter to the soil surface. Grasses with fibrous root system decompose readily in-situ and favor the accumulation of organic matter upto 15% in the rooting zone.

Translocation and accumulation of mineral substances

The translocation of mineral substances is influenced by the type of vegetation and prevailing environment. Coniferous trees are poor feeders of bases , such as Ca, Mg, and K , these cataion tend to leach down by the percolating water , rendering the soil acidic. Grassland vegetation observed under low rainfall and neutral to alkaline soil conditions retains high amount of bases to soil surface and checks soil from becoming acidic.

Plant composition and profile development

Pine-forest litter having low bases (<50%) and low ash content (2-5%) and whose lechates are acidic (pH5) tend to make soil acidic. Organic matter of grass vegetation , rich in bases and ash content and leachates are neutral tend to develop normal soils. Soils under heath or pine forest vegetation develop into Podzols (Spodosols) and under grass vegetation into Mollisols as in tarai region.

Microorganisms and soil formation

Various micro-organisms that inhabit the soil form one of the important components of soil. They are grouped as :

Microflora : Bacteria, Actinomycetes, Fungi and algae

Macrofauna : Protozoa and nematodes

It has been estimated that a gram of soil may contain 1 to 100 million microorganism forming a very small fraction (<1%) of soil mass. Of which bacteria occupy about 90% of total polulation, actinomucetes (9%) and algae 1%. Among microfauna, protozoa are most abundant. Micro-oranisms play an important role in biochemical transformation. According **to Nobel Laureate Waskman*“without soil microbes, life on planet would come to a standstill*”**.Organic matter decomposition, humification, nitrogen fixation , ammonification , nitrification , denitrificatio , oxidation and reduction are various important processes mediated by microorganisms.

Pedogenic Process

Fundamental pedogenic process

The basic process involved in soil formation, according to Simonson (1959) include

1. **Gains or additions** of water, mostly as rainfall, organic and mineral matter to soil

2. **Losses** of the above materials from soil
3. **Transformation** of minerals and organic materials within soils
4. **Translocation** or movement of soil materials from one point to another within soil

It is usually divided into (i). Movement in solution (***leaching***) and (ii) movement in suspension (***eluviations***) of clay, organic matter and hydrous oxide.

Fundamental processes of soil formation, that include transformation and translocation, are :***humification, eluviation and illuviation***.

Humification

Humification is the process of transformation (*i.e.* decomposition) of raw organic matter into humus. It is an extremely complex process involving various organisms, such as bacteria, fungi, actinomycetes, earthworms and termites.

Eluviation (Analogus to Emigration)

Eluviations means "***washing out***".Eluviation is the process of removal of constituents in suspension or solution by the percolation water from upper to lower layers. The eluviations encompass mobilization and translocation of mobile constituents, resulting in textural differences. French Scientist, use an analogous term ***Lessivage*** to describe the mechanical movement of clay and iron oxides from the A horizons without undergoing chemical alteration.

Illuviation (Analogus to Immigration)

The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer (or horizon of gains) that have the property of stabilizing translocated clay minerals is termed as illuvial ***(B horizons, especially Bt***). The process leads to textural contrast between E and Bthorizons. And higher fine : total clay ratio in the Bt horizon.

Specific Pedogenic Process

The basic pedogenic process provide a framework for the specific processes to operate in due course.

Calcification

It is the process of precipitation and accumulation of calcium carbonate ($CaCO_3$) in some part of profile. The accumulation of $CaCO_3$ may result in the development of ***calcic horizon***. Calcium is readily soluble in acid soil water/or when CO_2 concentration is high in root zone as :

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 + Ca \longrightarrow Ca(HCO_3)_2 \text{ (Soluble)} \uparrow$$

$$Ca(HCO_3)_2\text{(Soluble)} \xrightarrow{Temp} CaCO_3 + H_2O + CO_2$$

$$CO_2\text{(Precipitates)} \downarrow$$

Here the main weathering process is hydrolysis is the presence of CO_2 from soil air.

The process of precipitation after mobilization is called calcification and the resulting illuviated layer of calcium carbonate is designated as ***Bk***.

Under arid and semiarid regions in India and Middle east countries, the surface soil horizons are neutral to slighty alkaline in reaction. The lime enriched soils were termed by ***Marbut as Pedocals.***

Decalcification:

It is the reverse of calcification that is the process of removal of $CaCO_3$ or calcium ions from the soil by leaching.

Two contrasting specific pedogenic process

Parameter	Podzolization	Laterization
Process	Process of soil formation resulting in the formation of Podzols (termed ***Spodosols*** , in soil taxonomy)	Is the process that removes silica, instead of sesquioxoide from upper layers and thereby leaving sesquioxoide to concentrate in solum. "Laterite" was derived from word "later" meaning brick or tile
Climate	Cold and humid climate	Warm and humid tropical climate
Parent materials	Siliceous or sandy parent material	Basic parent materials having sufficient iron-bearing ferro-magnesium minerals

		(Pyroxene. Amphiboles, Biotite and chlorite)
Vegetation	Coniferous , pine and hemlock	Rain forest of tropical areas
Condition	Leaching and translocation of sesquioxde. Reprecipitation of sesquioxoide and humification of organic materials	High temperature .Intense leaching and basic kind of parent material all favour the removal of silica (desilication) and accumulation of sesquioxide.
Distinct horizonation	Contrasting B-horizon with three distinct layers *i.e* a dark layered of precipitated humus , a reddish brown layer due to deposition of sesqioxide and yellowish brown layer	Bs horizon formation
Land use	Owing to intensive leaching they have poor reserve of bases, low in fertility. Suitable for oats, potatoes and clover.	Deeply weathered soil, lowin CEC and fertility. Phosphorus fixation is problem. Soil crusting is problem. Plantation crops such as cashew nuts, coconut, banana.

Gleization

The term “***glei***” is of Russian origin meaning blue, green or grey clay.The gleization is a process of soil formation resulting in the development of gley (or gley horizon) in the lower part of profile above the parent materials due to poor drainage condition (lack of oxygen) and where waterlogged conditions prevail. Such soils are called ***Hydromorphic*** soils .The process is not particularly dependent on climate but often on impeded drainage condition.

Reduction of iron to soluble ferrous iron occurs under such condition.

Intrazonal Processes

Salinization

Solonization/Alkalization

Solodization/Dealkalization

Salinization

Salinization is the process of accumulation of salts, such as sulphates, chlorides of calcium, magnesium, sodium, potassium in soils in the form of a salty (salic) horizon. As a result of accumulation of salts ,***Solonchaks or Saline*** soils are developed.

Formation

i. Arid or semiarid climatic condition
ii. Lower topographic positions or depression landforms
iii. Imperfect or poor drainage conditions
iv. Alluvial deposites along sea coasts
v. Saline irrigation water

Solonization

The process involves accumulation of sodium ions on exchange complex of the clay, resulting in formation of Sodic soil (Solonetz). All cataions in solutions are engaged in reversible reaction with the exchange sites on the clay and organic matter particles.

Pedoturbation

Is the process of mixing of soil. Mixing to certain extent occurs in all soils. The most common types of pedoturbation are

i. **Faunal pedoturbation: By** animals (ants, earthworms, moes, rodents)
ii. **Floral pedoturbation: By** tree tipping
iii. **Argillipedoturbation:** Mixing of materls in soil solum by churning process caused by swell-shinkclays , observed in deep black cotton soils of central India.

Soil Classification

Classification is the grouping of objects in some orderly and logical manner. It is based on the properties of object for the purpose of their identification and study.

Classification system

Dokuchaiev's Genetic System

Dokuchaiev, the founder of modern pedology, emphasize soil classification on genetic basis. The Russian System of soil classification, tended to emphasize on soil genesis and hence the term ***Genetic System of Soil Classification*** introduced.

Dokuchaiev's (1900) soil classification scheme

Zones		**Soil Type**
Class A	Normal soil (Zonal)	Tundra soil, chernozem , Laterite, Red soil
Class B	Transitional soil (Intrazonal)	Carboante containg soils, Secondary alkaline soils
Class C	Abnormal soil (Azonal soil)	Alluvial soil, Aeolian soil

Zonality concept :

The soils that have ***fully developed soil profiles*** and are ***in equilibrium*** with the environmental conditions, such as climate and vegetation, are termed as zonal soils. Eg. Podzol, Laterites, Chestnuts.

The soils where ***time*** has been a ***limiting factors*** to produce horoizonation are termed as ***Azonal soils*** . eg. Alluvial soils, sand dunes

Soils occurring ***within the zonal areas*** and having characteristics that are determined by the ***local conditions*** such as topography, specific parent materials are termed as ***intrazona***l soils. Eg. Calcimorphic and Hydromorphic soils.

Marbut's (Morpho genetic system)

Marbut (1927) was the first to advocate classification of soils on the basis of their ***intrinsic properties*** rather than soil forming factors, thus reducing emphasis on geology or parent rock.

At highest category level, he divided Zonal soils into two classes ***Pedalfers***and ***Pedocals***. The former showing the accumulation of iron and aluminum and later of calcium as calcium carbonates.

The pedalfers were presumed to occur in areas of **high rainfall** having real surplus of water for leaching . **Pedocals** occur in areas of low rainfall and high evaporative demand with deficit of water. He introduced the concept of ***Great Soil Groups***.

Soil Taxonomy: A comprehensive system

In**1960**, a comprehensive system of soil classification, popularly known as **7th Approximation** (Soil Survey Staff, 1960) was published.

Salient features

The comprehensive system is ***morphogenetic system***, in which ***morphology*** of soils, that is outcomes of soil genesis, serve as guide. The system is based on properties of soils that exist today.

- Unlike the genetic system, the comprehensive system, is based on ***measurable soil properties***. The soil classes have been defined in term of soil properties that exist today.
- It considers all such properties which affect soil genesis or the outcomes of soil genesis. Hence ***soil genesis from the backbone of the system***, but it does not appear in definitions of soil taxa.
- The common definitions of a class of taxonomic system are***type or orthotype***.
- The nomenclature, using coined words, is derived mainly from Greek and Latin words.
- Anew category ***Subgroup*** has been introduced to define the central concepts of great groups.

- Unlike genetic system, it is an ***orderly system*** without prejudices and facilitates easy remembering of the objects without undue taxing the human memory.

Diagnostic horizon

A diagnostic horizon is one, which is formed as a result of ***pedogenic processes*** and having ***distinct properties or features*** that can be described in terms of ***measurable soil properties***.

A number of diagnostic horizon has been identified in soil taxonomy. Based on their location in soil profiles, they have been divided into two categories

Surface and subsurface

Epipedons (Greek, "epi", from epidermis, meaning over, upon or skin and pedon, soil)

The "epipedon" are simply ***uppermost soil horizons*** and include the upper part of the soil ***darkened by organic matter*** or shows evidence of ***eluviations or both***. It may include all or parts of ***illuvial B horizons*** if the darkening by organic matter extends from the soil surface into or through B Horizon.

Nine epipedon has been recognized of which three *viz*., ***mollic,ochric and umbric*** are of importance in India.

Mollic epipedon

A thick, dark coloured, soft mineral horizon with **high (> 50%) base saturation** and strong structure. It contains **1 % or more organic matter** (when mixed to a depth of 17.5 cm) with colour values darker than 3.0 (moist) and 5.0 (dry) and chroma less than 3.5 (moist). Soil structure can not be massive and hard, very hard or extremely hard when dry. Base saturation is over 50% and the epipedon is not naturally dry in all parts for more than nine months in a year.

Umbric epipedon

A surface horizon like mollic but **is low (< 50%) in base saturation** (dominantly saturated with H^+) with high C:N ration and is not naturally dry for than three months in a year**.**

Ochric epipedon

A surface horizon that is light in colour. It contain less than 1 % organic matter and is hard, very hard or massive when dry or remains dry for more than three months in a year.

Endopedon (Greek“endo” means endodermis, meaning subsurface or deep seated, pedon, soil)

The diagnostic subsurface horizons are called endopedons. The endopedon includes lower part of the soil , where minerals accumulates.

Nineteen endopedon has been recognized, of which eight are commonly observed in India.

Hierarchy of Soil Taxonomy

Order
↓
Sub order

Great group

Sub group

Family

Series

Site factor

Order (12) : The highest category in the system. Based largely on **morphology**.

Sub order(63): Comparable to great soilgroupof genetic system. Emphases ***moisture and temperature regime***

Great group (240+): A basic category based on diagnostic sub surface horizon. Based on ***diagnostic horizon***

Sub group (1000+): A new category designated to ***define the central concept*** of great groups.

Family: A practical category for making predictions for land use plans. **Soil temperature** regimes used as criteria.

Series: The lowest and specific category

Formative elements of soil orders and their derivation

Name of soil order	Formative elements in name order	Derivation of formative element	Mnemonicon or Memory device	Soils equivalent in other system
Entisol	ent	Nonsense syllable	Recent	Azonal, some low humic gley soils
Vertisol	ert	L,verto, turn	invert	Gruosols, black cotton soils (regur)
Inceptisol	ept	L. inceptum, begining	inception	Ando, Sol Brun Acide
Aridisol	id	L. aridus,dry	Arid	Desert soil, Sierozems,Solonchok
Mollisol	oll	L. mollis , soft	Mollify	Chestnut, chernozem, brunizem, rendzinas
Spodosol	od	Gk. Spodos,wood ash	Podzol: odd	podzols
Alfisol	alf	Nonsense syllable	Pedalfer	Grey-brown podzolic
Ultisol	ult	L, Ultimus,last	Ultimate	Red yellow podzolic
Oxisol	ox	French,oxiode,oxide	oxide	Laterites, latosols
Histosol	ist	Gk. Histos, tissue	Histology	Bog soils
Andisol	and	Jap. and	Ando	Volcanic ash soils
Gelisol	el	Gk. Gel, ice	Frost churnig	Frozen tundra soils showing cryoturbation

A flow diagram giving simplified key for classifying soils in different orders of soil taxonomy

Concept	**Order**
Soils that have permafrost within 100 cm or gelic material with	**Gelisols**

permanent frost within 2 m of the surface.

Soils that have > 30% organic matter to a depth of 40 cm.**Histosols**

Soils that have spodic horizon within 2 m but have no plaggen **Spodosols**

epipedon or an argillic or a kandic horizon above the spodic

horizon

Soils that have andic soil properties in 60% or more of thickness **Andisols**

between soil surface and 60 cm or lithic or paralithic contact

Highly weatherd soils with an oxic horizons within 1.5 m but

have no kandic horizon or

contain 40% clay in the surface 18 cm and have a kandic horizon **Oxisols**

within 100 cm of the surface overlying the oxic horizon

Soils with swell-shrink types of clays , having 30% or more clay **Vertisols**

upto 50 cm depth or to lithic or paralithic contact , deep cracks

when dry , at 50 cm and have slickensides or wedge shaped aggregates **Aridisols**

Dry soils that have Ochric or anthropic horizons and either have a salic

calcic, gypsic or cambic

have an argillic or natric horizon and an aridic soil moisture regimes

and an epipedon that is not hard and massive when dry

Low base saturated soils that have an argillic or kandic horizons but with**Ultisols**

base saturation (at pH 8.2) of < 35% at 2 m depth below the soil surface

Dark coloured base rich (> 50%) soils of grassland vegetataion with **Mollisols**

a mollic epipedons that is hard and massive when dry

High base status (>35%) soils of humid or subhumid regions with **Alfisols**

an ochric epipedons and argillic/natric or kandic horizons	
Soils that have no spodic, agrillic, natric, oxic, petrocalcic, but have an altered or cambic- B horizon.	**Inseptisols**
Recent soils with no diagnostic horizons other than an ochric or anthropic epipedon	**Entisols**

Soil Texture, Particle size and Textural Classes

Soil texture is the relative proportion of various soils separates in a soil. It is usually expressed on percentage basis. Soil separates are group of soil particles of given size range i.e. different size of particles which together make up a given soil.

Each soil separate represents a distinct physical size group. Mineral particles less than 2 millimetres in equivalent diameter and ranging between specified size limits. The names and sizes of the 7 soil separates recognized in the United States are as follows:

Very Coarse Sand	2.0 - 1.0 mm
Coarse Sand	1.0 - 0.5 mm
Medium Sand	0.5 - 0.25 mm
Fine Sand	0.25 - 0.10 mm
Very Fine Sand	0.10 - 0.05 mm
Silt	0.05 - 0.002 mm
Clay	0.002 mm

We will be using these separates

Sand ………	2.0- 0.05 mm
Silt …………….	0.05 – 0.002 mm
Clay …………..	<0.002 mm

Think of this relationship for the three main groups:

1. Sand = basketball (sand may be seen with the naked eye)
2. Silt = golf ball (silt particles may be seen with a good microscope)

3. Clay = pin (clay can only be seen with an electron microscope)

Modifiers that are used for coarse materials those are greater than 2mm.

Gravels …………….. 2 mm – 3 in
Cobbles ………….. 3 in - 10 in
Stones …………… 10 in - 24 in
Boulders ………….. 24 in

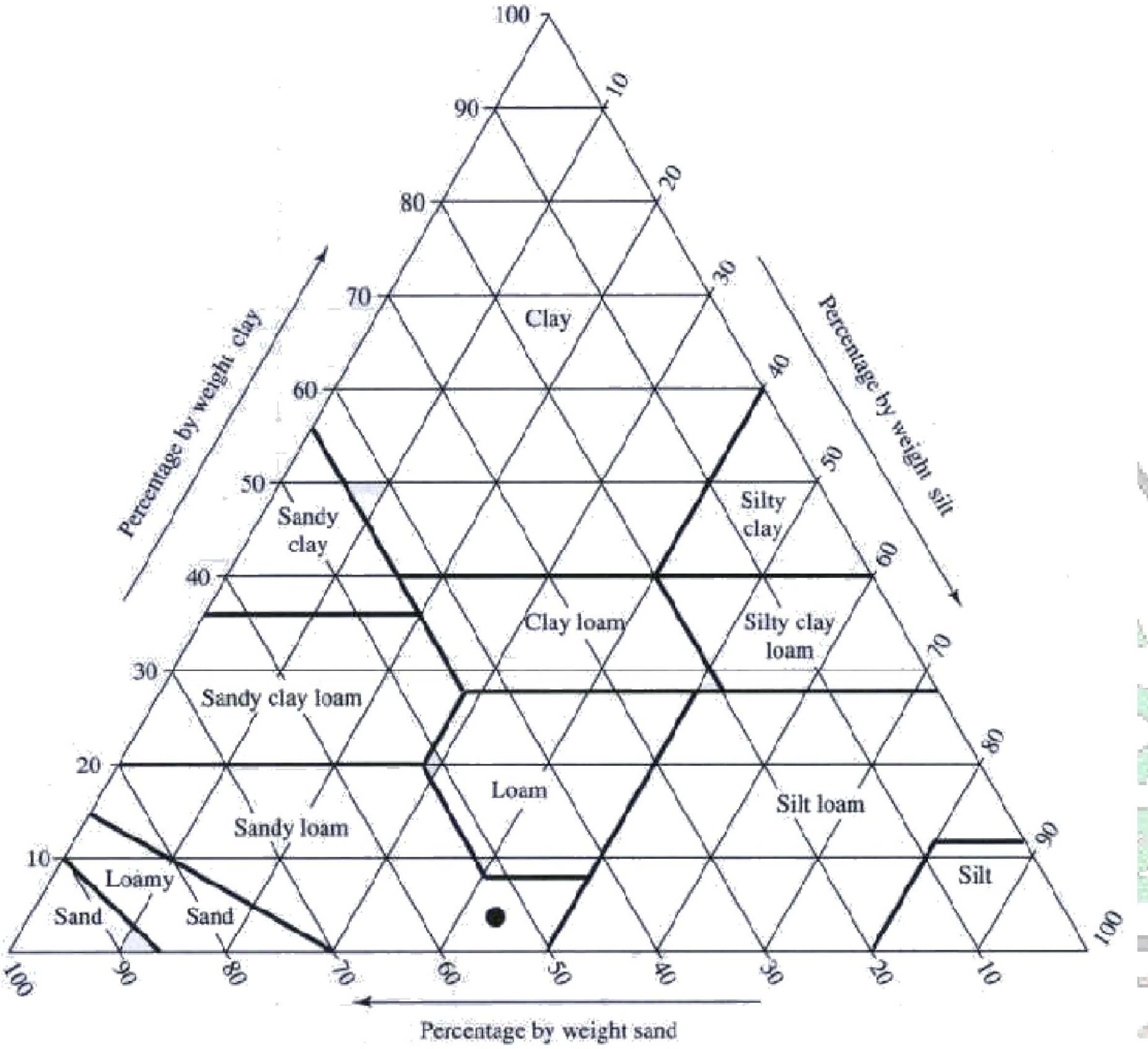
The term soil separate refers to a specific size of a particle and not the composition of that particle. However, certain minerals will tend to dominate or make up the various separates.

Sands	generally made up of quartz
Silts	commonly composed of quartz and feldspars
Clays	secondary minerals, clay minerals, and Fe oxides

A soil's texture is then the relative proportion of sand, silt, and clay. Together, the three separates must add up to be 100%. The organic matter is not a part of the soil's texture. Since there is such a large number of combinations that could occur, soil scientists group similar amounts of sand, silt and clay into groups called soil textural classes.

Textural Classes:

The main textural classes are sand, silt and clay. These textural classes may be modified by addition of suitable adjective based on relative amount of each separate that make up the soil e.g. Loam: Soil material with clay, silt and sand in close proportion (e.g. 7-27% clay; 28-50% silt and <50% sand). Loamy sand: Materials with about 80-90% sand. Sandy loam: <7% clay; <50% silt; about 52% sand. Other modifications include silty loam, sandy clay loam, clay loam, gravelly loamy sand etc.



The textural class is determined by the combined portion of sand, silt and clay; it affects properties and management of soils. The smaller the particle size, the greater the total surface area of a given volume of soil.

Surface Area affects the: Adsorption of water, area for chemical reactions, adsorption of nutrients, plasticity and shrink/swell. Texture also influences: porosity (amount and size of pores)

plant available water holding capacity

sand	few large pores	low water holding
silt	many medium pores	high plant avl. water holding
clay	many fine pores	high total water holding not all available to plants

Generally, texture of a field can't easily be changed

Soil Texture and Management

A) **Coarse Textured Soils (sands, loamy sands)**

Hold low amounts of water and nutrients - may have to irrigate and fertilize frequently

Not highly erosize - allows water to infiltrate; less runoff

Very permeable - good for waste disposal only if a deep soil

May compact to form a hardpan

B) Fine textured soils (clays, sandy clays, silty clays)

Hold large amounts of nutrients and water - may hold things too tightly

Erosion - slow infiltration; high runoff means much erosion.

Slow permeability - often unacceptable for septic tanks

May shrink/swell - depends upon the type of clay minerals present

C) Medium Textured Soils (loams, clay loams, sandy loams, silt loams)

Properties fall in between the other two.

Soil Structure and Classification

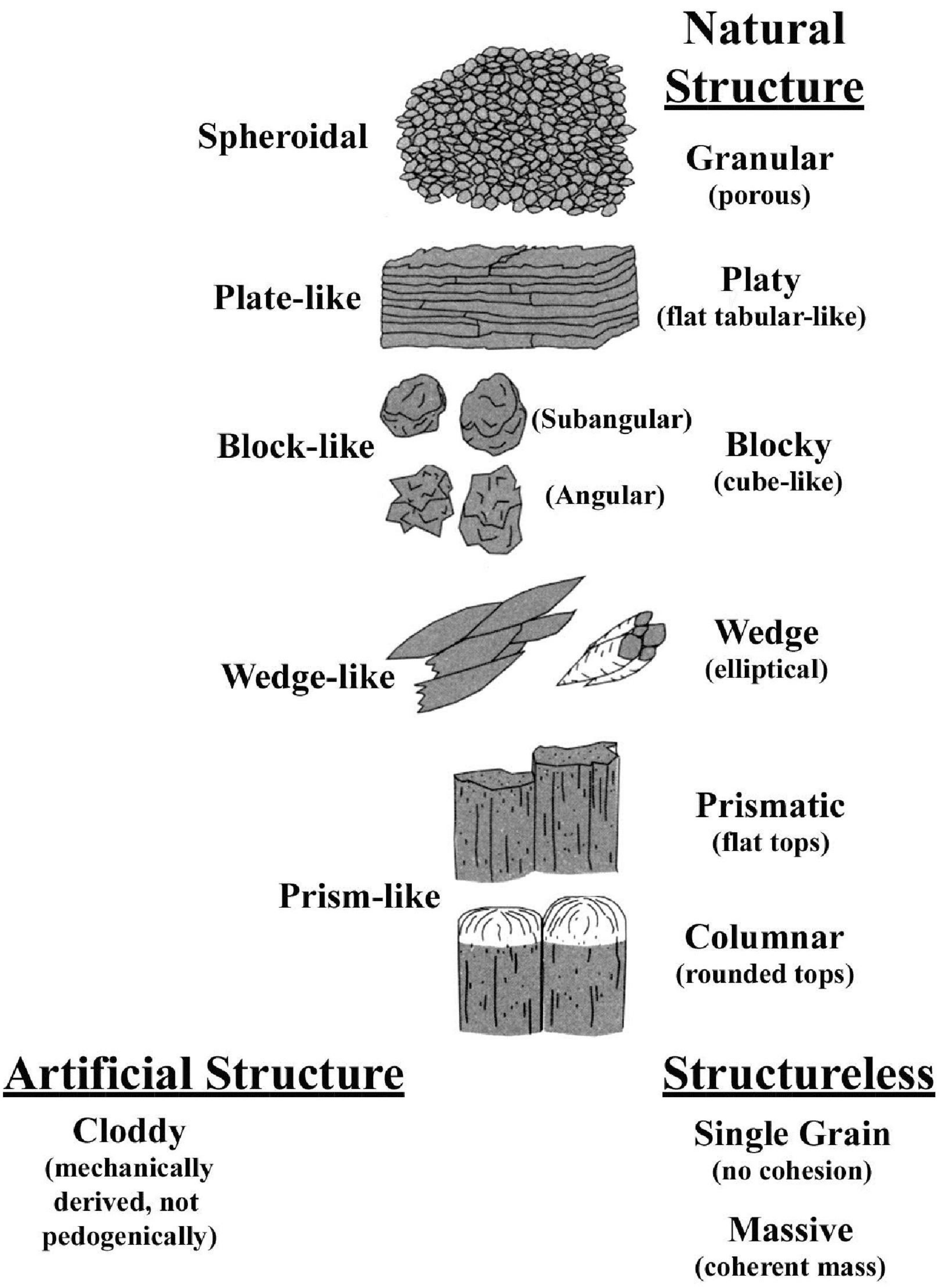
Structure is the arrangement of primary sand, silt and clay particles into secondary aggregates called peds or structural units which have distinct shapes and are easy to recognize. These differently shaped aggregates are called the structural type.

Classification of soil structure: There are three basic groups of classification

1. Classification based on shape of aggregate

(i) Simple structure: this includes (a) Single grain and (b) Massive structure

(ii) Compound structure: under this we have : **Spheroidal** (Granular, crumb), **Block-like** (Blocky; sub-angular blocky), **Prism-like** (Prismatic; columnar) **Platy** – flat, plate like.



Platy: Plate-like aggregates that form parallel to the horizons like pages in a book. This type of structure may reduce air, water and root movement. Common structure in an E horizon and usually not seen in other horizons.

Blocky: Two types--angular blocky and subangular blocky. These types of structures are commonly seen in the B horizon. Angular is cube-like with sharp corners while subangular blocky has rounded corners.

Prismatic: Vertical axis is longer than the horizontal axis. If the top is flat, it is referred to as prismatic.

1. **Granular:** Peds are round and pourous, spheroidal. This is usually the structure of A horizons.
2. **Structureless:** No observable aggregation or structural units.
    1. Single grain-sand
    2. Massive-solid mass without aggregates

If the top is rounded, it is called columnar.

2. Classification based on size and shape of pores

Coarse pore – >200 µm
Medium pore – 200 - 20 µm
Fine pore – 20 - 2 µm
Very fine pores - <2 µm

3. Classification based on grade

Poor e.g single grain structure
Weekly developed: contains high level of sand and silt
Well developed: contains some amount of binding agents

Strongly developed: contains high level of binding agents e.g. soil Organic matter.

Formation of soil structure

freeze / thaw, wetting / drying, root pressure, microorganisms and cementing by clay, organic matter, iron and aluminium compounds

Importance of Soil Structure

- ✓ Increases infiltration of water, thus reducing runoff and erosion and increases the amount of plant available water.

- ✓ Improves seedling emergence, root growth and rooting depth.
- ✓ Large continuous pores increase permeability.

Maintaining Soil Structure

- ✓ Till soil only at the proper moisture contents. Never till when the soil is too wet. This will cause the soil to become cloddy. Aggregates are easily destroyed.
- ✓ Add the proper amounts of lime and fertilizer. Proper plant growth will lead to the development of good soil structure.
- ✓ Grow grasses and legumes. These plants may help form unstable aggregates and their organic matter will help stablize the aggregate.
- ✓ Growth of legumes will also give the soil more microorganisms which give certain beneficial fungi which will stabilize peds.
- ✓ Maintain or increase organic matter contents Ap horizon.

  plant cover crops in fall and winter plant more grasses turn under crop residue add manure

Soil Aggregates and significance

Soil aggregates are groups of soil particles that bind to each other more strongly than to adjacent particles. The spaces between the aggregates provide pore space for retention and exchange of air and water. Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces (usually associated with water) are applied. Aggregate stability is not the same as *dry aggregate stability*, which is used for wind erosion prediction. Soil structure can be evaluated by determining the extent of aggregation, the stability of the aggregates and the nature of the pore space. All these characteristics change with tillage practices and cropping systems. The amount and distribution of pore space are highly related with the aggregates and the susceptibility of the aggregates to water and wind erosion.

Formation and Stabilization of soil Aggregates

The granular aggregation of surface soil is a highly dynamic soil property, for the formation of aggregates the soil particles should coagulate or flocculate and should be held together or bound together into clusters by some binding and cementing materials. Aggregate formation in soil is largely a function of

1. Silt and clay content

2. Organic compounds present in the soil
3. The microbial activity
4. The concentration of irreversible soil colloids and
5. The long range and van der Waals forces acting between the charged clay minerals and the polymers present.

Besides, these, many salts, parent materials, climate and some of the soil forming processes also affect granulation. Generally, smaller aggregates are more stable than larger one so maintaining the much prized larger aggregates requires great care.

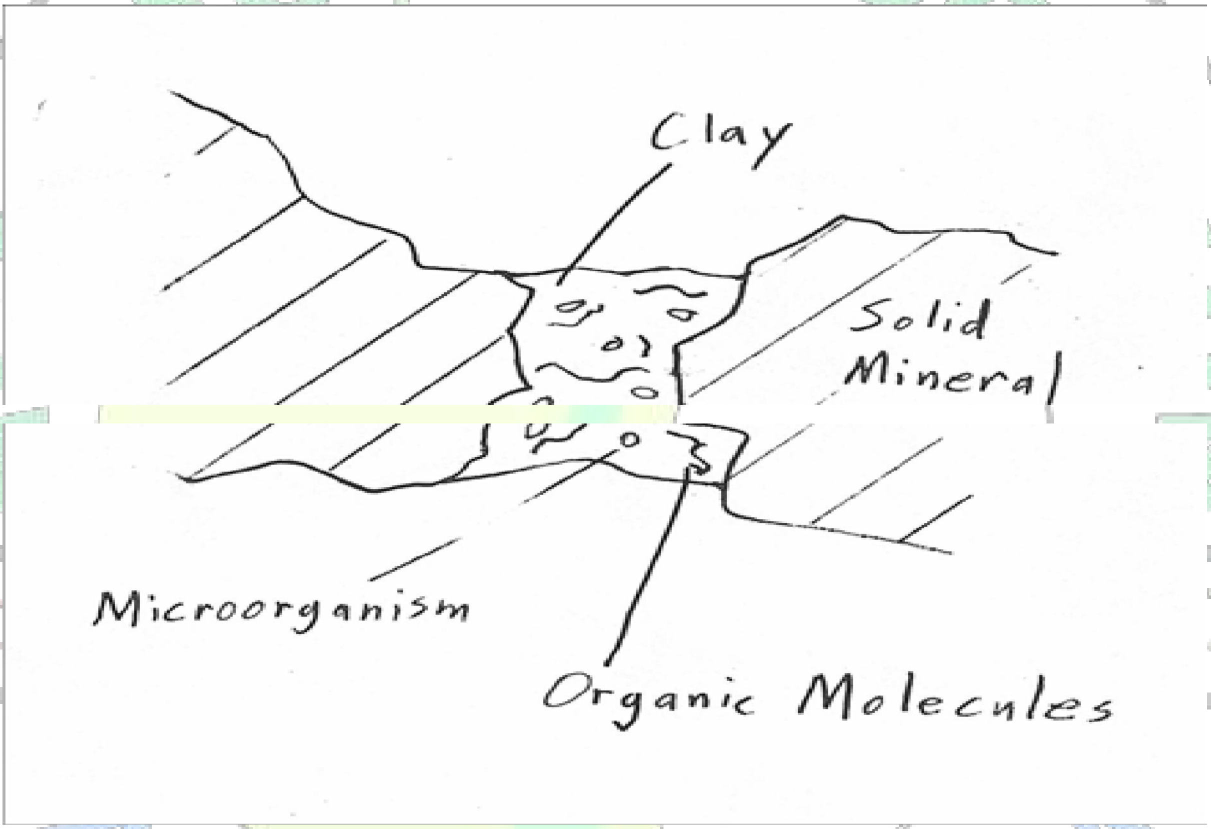


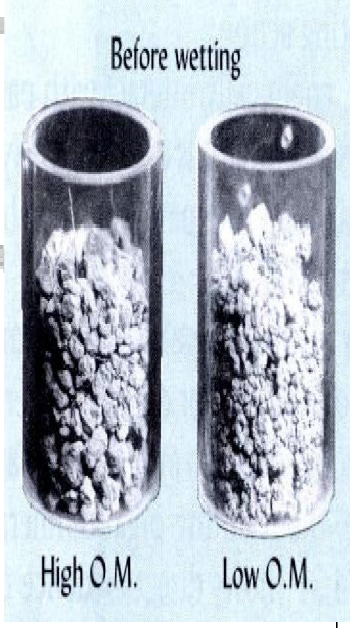
Figure: Diagram of the microscopic region between solid grains within an aggregate.

Why is aggregate stability important?

Aggregation affects erosion, movement of water, and plant root growth. Desirable 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. Optimum conditions have a large range in pore size distribution. This includes large pores between the aggregates and smaller pores within the aggregates. The pore space between aggregates is essential for water and air entry and exchange. This pore space provides zones of weakness through which plant roots can grow. If the soil mass has a low bulk density or large pore spaces, aggregation is less important. For example, sandy soils have low aggregation, but roots and water can move readily.

What influences aggregate stability?

The stability of aggregates is affected by soil texture, the predominant type of clay, extractable iron, and extractable cations, the amount and type of organic matter present, and the type and size of the microbial population. Some clays expand like an accordion as they absorb water. Expansion and contraction of clay particles can shift and crack the soil mass and create or break apart aggregates. Calcium ions associated with clay generally promote aggregation, whereas sodium ions promote dispersion. Soils with over about five percent iron oxides, expressed as elemental iron, tend to have greater aggregate stability. Soils that have a high content of organic matter have greater aggregate stability. Additions of organic matter increase aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products or mycelia have formed. Soil microorganisms produce many different kinds of organic compounds, some of which help to hold the aggregates together. The type and species of microorganisms are important. Fungal mycelial growth binds soil particles together more effectively than smaller organisms, such as bacteria. Aggregate stability declines rapidly in soil planted to a clean-tilled crop.



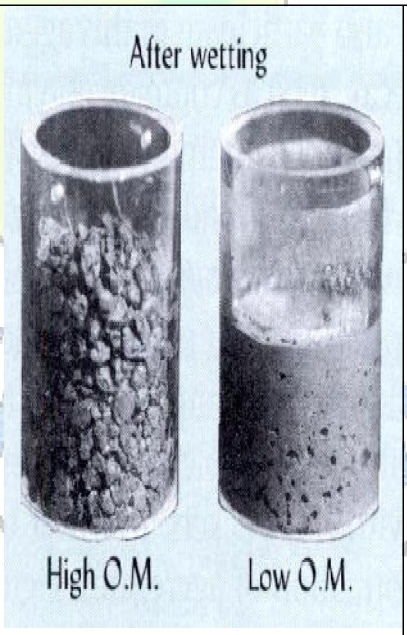


Figure: The aggregates of soils high in organic matter are much more stable than are those low in in this constituent. The low organic matter soil aggregates fall apart when they are wetted; those high in organic matter maintain their stability.	**Figure: Soil with aggregates partially separated, in a tray.**

The analysis of soil aggregation is important in a variety of applications. Aggregation is a major influence on the growth and effectiveness of roots. Aggregate stability and size information may be used to evaluate or predict the effects of various agricultural techniques, such as tillage or addition of organic matter. Aggregate analysis is often used in experiments where various tillage methods are applied and then evaluated by examining the stable aggregates that result. Because of their direct relation to cohesive forces, aggregate size and stability are important to the understanding of soil erosion and surface sealing. Analysis of dry aggregates is logically related to wind erosion effects while wet analysis may be more appropriate to evaluate or predict erosion due to rainfall impact and runoff. The stability of wet aggregates can be related to surface seal development and field infiltration, as water-stable cohesion among particles may lead to restriction of water entry and formation of surface seals. Through these erosion and sealing effects, as well as the relation between aggregation and structural features such as macropores, aggregate analysis may increase the understanding of most aspects of soil water behavior, -including runoff, infiltration, and redistribution, as well as soil aeration. Increasingly, aggregate properties are used in models that predict soil hydraulic properties, including water retention and unsaturated hydraulic conductivity.

Closely related terms include ped, clod, and crumb. A ped is an aggregated unit representative of the innate structural classification of the soil. It has a characteristic shape related to structural designations such as prismatic, columnar, and blocky. The term clod applies to an aggregate separated from the bulk soil by artificial means such as digging or plowing. “Crumb” is an archaic term referring to an aggregate less than about 5 mm in diameter.

Conclusions

The properties of individual particles and their proportionate distributions are subject to little human control in field soils. However it is possible to exert some control over the arrangement of these particles into aggregates and on the stability of these aggregates. Tillage and traffic must be carefully controlled to avoid undue damage to soil tilth, especially when soils are rather wet. Generally nature take good care of soil structure, and human can learn much about soil management by studying natural systems. Vigorous and diverse plant growth, generous return of organic residues, and minimal physical disturbance are attributes of natural systems worthy of emulation. Proper plant species selection; crop rotation; and management of chemical, physical and biological factors can help ensure maintenance of soil physical quality.

Bulk Density, Particle density, Porosity and their significance and manipulation

Bulk Density

Bulk density is an indicator of soil compaction and soil health. It affects infiltration, rooting depth/restrictions, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity, which influence key soil processes and productivity. **It is the weight of dry soil per unit of volume typically expressed in grams/cm3.** Total volume of surface soil is about 50% solids, mostly soil particles (45%), and organic matter (generally < 5%); and about 50% pore space which are filled with air or water. When determining bulk density, the amount of soil moisture must be determined. Available water capacity is the amount of soil moisture available to plants, varies by texture, and is reduced when compaction occurs. Bulk density can be managed, using measures that limit compaction and build soil organic matter.

- ✓ it is a measure of how compact or dense a soil is.
- ✓ it is weight of soil divided by the total volume (lbs/ft^3 or g/cm^3 or mg/cm^3)

Density = mass (weight) / volume

Bulk Density

- Relate weight of solids to total volume of soil including solids and pores.
- Affected by both the nature of solids and the volume of pores.
- Bulk Density = weight of oven dry soil divided by the soil volume
- If a 100 cubic cm soil sample has an oven-dry weight of 150 grams then

$$\text{Soil Bulk Density} = \frac{\text{Overdry Weight}}{\text{Volume}}$$

$$= \frac{150\ \text{g}}{100\ \text{cm3}}$$

$$= 1.5\ \text{g / cm3}$$

Bulk density is affected by the solids and porespace

- high pore space = low bulk density
- low pore space = high bulk density
- fine textures silt loams, clay, clay loam - generally lower bulk density 1-1.6 g/cc
- sandy soils may range 1.2 - 1.8 g/cc
- strong structure (well granulated topsoil) - low bulk density
- high organic matter = low bulk density

As bulk density increases:

- ✓ soil strength increases –
- ✓ pore space decreases
- ✓ soils become more compact

Note:

1. Remember that bulk density is related to the amount of pores in the soil. The greater the total pore space the lower the bulk density
2. As bulk density increases the amount of pore space decreases.

Bulk Density Management

Bulk density can be changed by management practices that affect soil cover, organic matter, soil structure, compaction, and porosity. Excessive tillage destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to erosion caused by water and wind. The following measures increase organic matter, and reduce compaction, which improve bulk density and porosity:

- ✓ Practices that increase organic matter such as continuous no-till, cover crops, solid manure or compost application, diverse rotations with high residue crops and perennial legumes or grass used in rotation;
- ✓ Minimize soil disturbance and avoid operating equipment when soils are wet;
- ✓ Use designated roads or rows for equipment;
- ✓ Reduce the number of trips across a field;
- ✓ Subsoil to disrupt existing compacted layers; and
- ✓ Use multi-crop systems involving plants with different rooting depths to help break up compacted soil layers.

Particle density

Soil particle density is a measure of the mass per unit volume of the soil solids only. Texture and structure do not affect particle density. However, organic matter, which is a soil solid, readily influences particle density. Organic matter weighs much less per unit volume than soil minerals. Soils high in organic matter have lower particle densities than soils similar in texture that are low in organic matter. Soil particle density generally increases with soil depth because of the concurrent decrease in organic matter. Particle density varies with the type of soil minerals present as well as the amount of organic matter. The particle density of most mineral soils is in the range of 2.60 to 2.75 Mg m^{-3}. Particle density is used in the calculation of pore space and bulk density on a coarse fragment free basis. When unknown, particle density of mineral soils is assumed to be 2.65 Mg m^{-3}. Generally quartz, feldspars, and colloidal silicates dominate the mineral fraction of soils. The particle density of these minerals averages about 2.65 Mg m^{-3}. When large amounts of heavy minerals, such as hornblende or magnetite, are present, the soil particle density is greater than 2.65 Mg m^{-3}. Soils formed in volcanic parent materials, such as pumice or ash, generally have particle densities less than 2.65 Mg m^{-3}.

Soil Porosity

Many important soil processes take place in soil pores (the air or water-filled spaces between particles). Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Coarse-textured soils have many large (macro) pores because of the loose arrangement of larger particles with one another. Fine-textured soils are more tightly arranged and have more small (micro) pores (Figure 6). Macro pores in fine-textured soils exist between aggregates. Because fine-textured soils have both macro- and micro pores, they generally have a greater total porosity, or sum of all pores, than coarse-textured soils.

Unlike texture, porosity and structure are not constant and can be altered by management, water and chemical processes. Long-term cultivation tends to lower total porosity because of a decrease in SOM and large peds (Brady and Weil, 2002). Surface crusting and compaction decrease porosity and inhibit water entry into the soil, possibly increasing surface runoff and erosion (SW 3 and 4). Calcareous and salt-affected soils can also alter porosity and structure (discussed later). In general, increasing SOM levels, reducing the extent of soil disturbance, and minimizing compaction and erosion will increase soil porosity and improve structure.

Calculating Soil Porosity

Scientists are also interested in knowing how much space is in the soil (porosity). This information tells them how much air and water can be stored in the soil profile. It also tells them the rate at which air, water and heat will move through the soil profile. By knowing this they can better understand the behavior of the soil, predict flooding, verify the types of life the soil can support, identify how the soil may change, and determine how the soil may be best used for human activities.

The amount of pore space, or porosity, of the soil is calculated according to the following equation:

Porosity = 1- (Bulk density/Particle density) X 100%

Bulk Density = mass of dry soil / total volume of soil and air (g/cm3)

Particle Density = mass of dry soil / volume of soil particles only (air removed) (g/cm3)

Bulk density/Particle density = Volume of dry soil / volume of dry soil and pore space

This value will always be less than or equal to 1. So the value (1 - Bulk Density/Particle Density) will be between 0 and 1. This value is then multiplied by 100 to calculate the percent porosity.

For example, students take three soil samples for bulk density and soil particle density for each horizon at the soil pit at their Land Cover Sample Site. After performing the *Bulk Density* and *Soil Particle Density Protocols*, they determine

Bulk Density:

Mass of dry soil = 395 g

Total soil volume = 300 cm3

Bulk density (mass of dry soil/total soil volume): 395 g/300 cm3 = 1.32 g/cm3

Particle Density:

Mass of dry soil = 25.1 g

Volume of dry soil = 9.5 mL (cm3)

To calculate particle density (mass of dry soil/volume of particles only):

25.1 g/9.5 cm3 = 2.64 g/cm3

Porosity:

Using these values in the equation for porosity:

Porosity = 1 – (Bulk density / Particle density) X 100%

1 – (1.32 / 2.64) X 100%

= 50%

Thus, 50% of the total soil is pore space. The pore space at this site may be filled by either air or water or a combination of both.

A good soil for growing most plants contains about 50% pore space and 50% solids. The pore space should be filled half with air and half with water, and the solids should be a mixture of minerals with some organic matter.

While **the porosity reveals the amount of total pore space the soil has, it does not tell exactly how much air or water is in the soil at a given time**. The total pore space can be determined and the amount of that space occupied by air and water.

Soil physical properties affect many processes in the soil that make it suitable for agricultural practices and other purposes. Texture, structure, and porosity influence the movement and retention of water, air and solutes in the soil, which subsequently affect plant growth and organism activity. Most soil chemical properties are associated with the colloid fraction and affect nutrient availability, biota growing conditions, and, in some cases, soil physical properties. Biological properties in soil contribute to soil aggregation, structure and porosity, as well as SOM decomposition and mineralization. Organism activity is controlled by various soil conditions and may be altered by management practices. Since many soil properties are interrelated with one another, it is difficult to draw distinct lines of division where one type of property dominates the behaviour of the soil. Therefore, understanding and recognizing soil properties and their connections with one another is important for making sound decisions regarding soil use and management.

Soil Compaction and Soil Colour

Soil Compaction

- ✓ In agricultural soils, compaction is caused by compression from machinery traffic or stock trampling.
- ✓ Poor root growth and swollen root tips can indicate a compacted layer, usually between 10 and 40 cm.
- ✓ Nearly 70 percent of the compaction caused by wheel traffic occurs on the first pass. This is the basis for adoption of controlled traffic farming.
- ✓ Compacted soil can cut crop yield by as much as 50% due to reduces aeration, Increased resistance to root penetration, poor internal drainage and limited availability of plant nutrients, prevention of compaction is better than treating it.

Compaction usually results in less plant root proliferation in the soil and lowers the rate of water and air movement. Because of the root restriction the amount of water available to the crop is often decreased. Slower internal drainage results in poorer subsurface drain performance, longer periods of time when the soil is too wet for tillage following rainfall or water application, increased denitrification and decreased crop production. Increased compaction also adds to the energy consumption by tractors for subsequent tillage.

Management of soil compaction

Varying the annual tillage depth

This will deal with tillage-induced compaction layers occurring just below the normal working depth of the primary tillage implement. The tillage depth is decreased in a wet year and is increased in a year when soil is dry enough to shatter a compacted layer.

Crop rotation and growing vigorous pasture

This is normally a long-term method of reducing compaction. A diverse rotation is essential to stabilise and build soil aggregates. Crops should include both deep rooted and fibrous rooted crops.

Deep ripping

Deep ripping involves breaking up the hard pan using strong tynes usually to a depth of 30–40 cm. This should be attempted only when soil is moist to dry and crumbles at the depth you are ripping. Operating depth should be no more than a few centimetres below the zone of compaction because operating any deeper uses more energy and risks the potential of deeper compaction. Yield benefits resulting from ripping have been measured for various soil types ranging from sands to clay loams but in heavier textured soils benefits can sometimes be short lived due to re-compaction by machinery.

Ways to reduce and prevent compaction

Since compaction problems are likely to persist for a prolonged period of time, the best defence is avoiding the problem altogether.

- ✓ Schedule farm operations, such as spreading fertiliser, to avoid working paddocks when wet. The soil should break easily and crumble at the deepest depth as it is being tilled. Dry soil will compact less than moist soil.
- ✓ Reduce secondary tillage passes as each additional tillage pass destroys aggregates and increases bulk density. Ideally, adopt minimum or zero tillage systems.
- ✓ Control traffic patterns using tramlines, as under conventional tillage systems as much as 90% of the land area can be tracked at least once.
- ✓ Remove excess weight on machinery and use only enough ballast to reduce slippage.
- ✓ Reduce surface pressure by reducing tyre pressure or by using lighter axle loads. Subsoil compaction increases dramatically with axle loads of greater than 5 tonnes.
- ✓ Traction versus compaction. A long narrow footprint is preferable to a short wide track (i.e. dual wheels). This can be accomplished by: using larger diameter tyres; replacing bias tyres with radials; using tandem axles; using 4-wheel drive or tracked vehicles.
- ✓ Avoid loaded trucks on paddocks and overloaded crop wagons.

- ✓ Improve drainage as this reduces the risk of being forced to work wet fields.

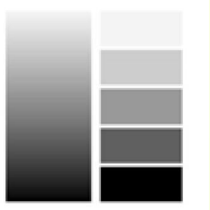
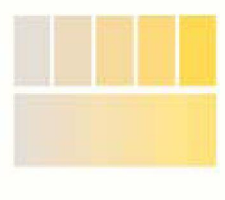
Soil Colour

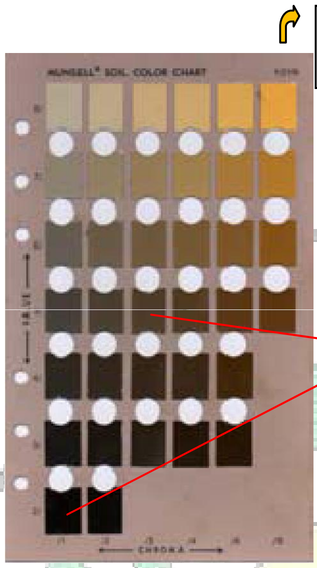
Soil colour provides clues to other soil properties and to soil conditions.

- In general:
  - dark colours are caused by organic matter.
  - Iron oxides provide brown and reddish coatings.
  - Reduced iron imparts gray and greenish colours.

Soil colour is determined using the Munsell Colour System

- A colour is defined by three parameters: Hue – H, Value- V and Chroma - C
- A colour is expressed as H V/C, e.g., 10 YR 3/2

	**Value** – Indicates the lightness of a colour – range between 0 (black) and 10 (white)
	**Chroma** – Indicates the degree of departure of a colour from the neutral colour of the same value – Lower limit is 0, but it has not upper limit. – In soils the chroma rarely exceeds 8. **Hue:** dominant spectral colour



Note: H is Hue, in this case 10YR

Soil colour: application

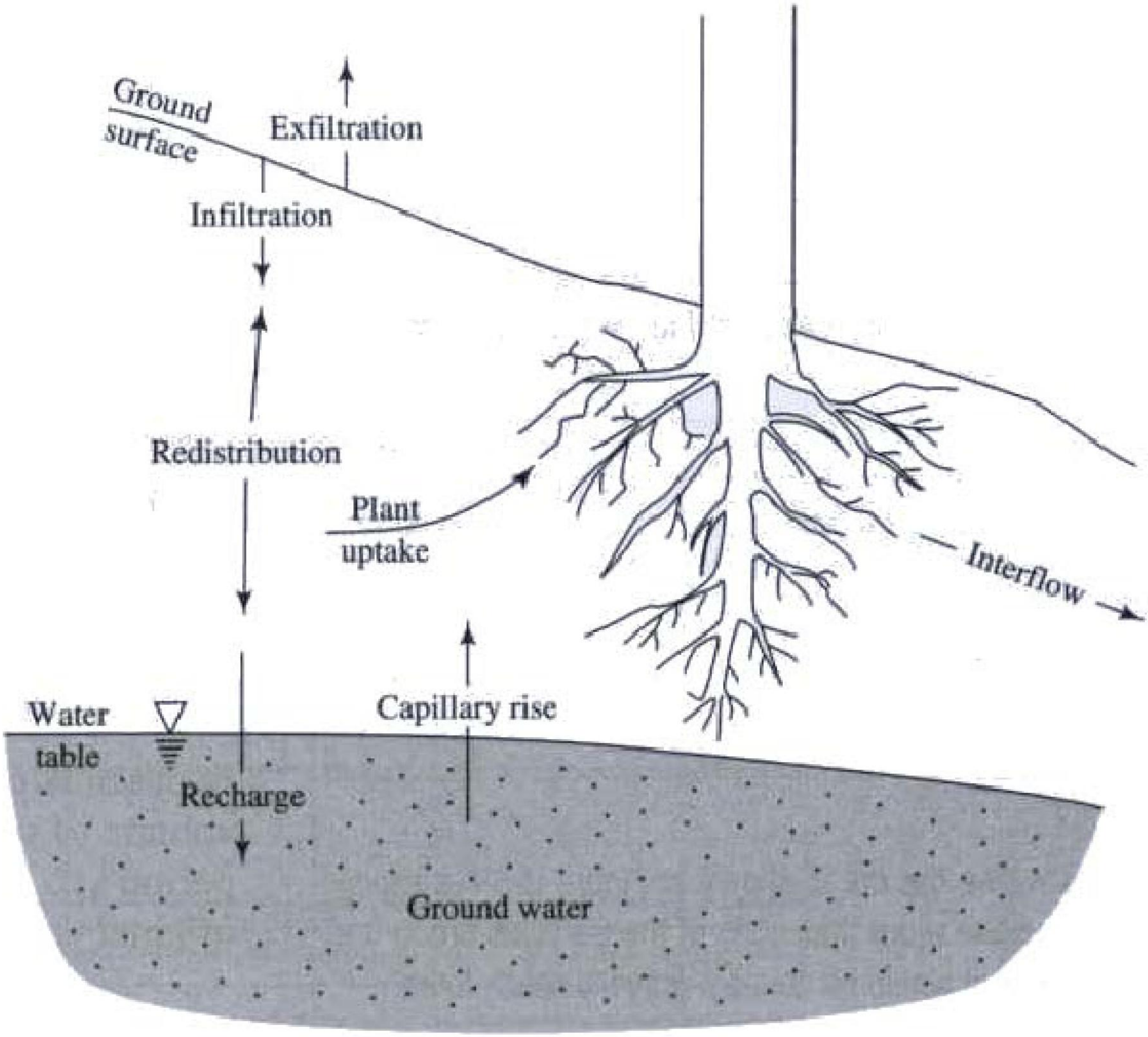
Colour	Range	Average
H 2/1	3 .5-7.0	5 .0
H 3/1	2 .5-4 .0	3 .5
H 3/2	2 .0-3 .0	2 .5
H 4/2	1 .5-2.5	2 .0
H 5/3	1 .0-2 .0	1 .5

Lecture : 6, Infiltration, Percolation, Permeability and Drainage

Infiltration

Infiltration: The movement of water from the soil surface into the soil

Redistribution the subsequent movement of infiltrated water in the unsaturated zone of a soil. This can involve exfiltration(evaporation from the upper layer of the soil), capillary rise (movement upward from the saturated zone to the unsaturated zone due to surface tension), recharge (movement of water from the unsaturated zone to the saturated zone) and interflow (flow that moves downslope). Percolation is a general terms for the downward flow in the unsaturated zone. Infiltration and redistribution depend critically on the material and hydraulic properties of soils



Factors affecting the infiltration rate

- ✓ Water input rate from rainfall, snowfall or irrigation
- ✓ The saturated hydraulic conductivity of the soil profile
- ✓ The degree to which pores are already filled with water when the infiltration process begins
- ✓ Variations in hydraulic conductivity through the soil profile
- ✓ The inclination and roughness of the soil surface
- ✓ Chemical characteristics of the soil surface
- ✓ Physical and chemical properties of water
- ✓ Organic surface layers -leaf litter, etc, has large openings
- ✓ Frost –a frozen surface can be nearly impermeable
- ✓ Rain compaction of the soil
- ✓ In-washing of fine sediments carries into larger pores

- ✓ Human modification of the soil surface
- ✓ Swelling and drying -some soils like vertisols, have clay minerals that swell land shrink with wetting and drying. Swelling can reduce the effective surface porosity. During dry periods, surface cracks that develop can accept high infiltration rates.

Percolation

Percolation is the movement of water within the soil matrix.

The phenomenon of absorption of water by soil is termed as percolation. The rate of absorption is different for different types of soils. The rate of absorption of a soil depends on its composition. A soil with more percolation rate can hold water for longer time. On the other hand a soil with poor percolation rate will hold water for shorter time. Percolation rate helps in selection of suitable soil for crop growth.

Percolation rate = Amount of water (ml) Percolation time (min)

Soil acts as a sponge to take up and retain water. Movement of water into soil is called ***infiltration***, and the downward movement of water within the soil is called ***percolation***, ***permeability*** or ***hydraulic conductivity***. Pore space in soil is the conduit that allows water to infiltrate and percolate. It also serves as the storage compartment for water.

Infiltration rates can be near zero for very clayey and compacted soils, or more than 10 inches per hour for sandy and well aggregated soils. Low infiltration rates lead to ponding on nearly level ground and runoff on sloping ground. Organic matter, especially crop residue and decaying roots, promotes aggregation so that larger soil pores develop, allowing water to infiltrate more readily.

Permeability also varies with soil texture and structure. Permeability is generally rated from very rapid to very slow. This is the mechanism by which water reaches the subsoil and rooting zone of plants. It also refers to the movement of water below the root zone. Water that percolates deep in the soil may reach a perched water table or groundwater aquifer. If the percolating water carries chemicals such as nitrates or pesticides, these water reservoirs may become contaminated.

Permeability

Soil Permeability

Permeability is the measure of the soil's ability to permit water to flow through its pores or voids.

> **Soil Permeability**: Permeability - ability of soil to transmit water or air. Expressed as cm of water/hour. Permeability is the speed of air and water movement in a soil -- this is affected by texture and structure. if permeability is high : water moves quickly. if permeability is low : water moves slowly. Sand could be permeable, but in a low landscape position and be poorly drained. A clay could be very permeable, but in a low landscape position and be poorly drained. A clay could be impermeable but well drained because it is at the top of a hill.

Factors affecting permeability

- Pore size present in the soil
- Water moves faster through larger pores than smaller pores. - the bigger the pore the more material it will move.
- Pore Continuity

High permeability - contains pores which are continuous and large enough for air and water to pass through. Just because a soil contains a large amount of pores doesn't mean it is permeable. The pores could be discontinuous or very small.

Any factor that will affect pore size or continuity of pores will affect permeability.

This means soil permeability is related to soil texture and soil structure.

Pores size decreases with smaller particle size. As the size of the separates decrease so does the pore size, but remembers that the surface area will increase quickly.

Textural class	Permeability
Sand	very high
Sandy loam	high
silt, loam	high
silt loam	med-low
Clay	low

Soil structure is related to the continuity of the pores.The more well structured a soil the more permeable it will be. A soil with good structure will be more permeable than a soil of the same texture that has poor structure.Natural aggregation of the separates will increase the large pore space. When soils with good structure are compacted the large pore space is lost because the big pores are squashed. This means for a soil manager, the only way to change permeability is to change soil structure. This is why it is important to maintain good soil structure if it already exists. If changes in pore size occur then changes in the permeability will occur.

Other ways to affect permeability: Root and worm channels:

increase permeability by forming large continuous pores throughout the soil. These pores must extend from the soil surface to depth. These allow for rapid water infiltration.

Organic matter: increases permeability by : increasing the stability of soil aggregates. Remember that organic matter decomposes to form glues, gums, etc. ... that help cement or stick soil particles together. Organic matter forms large pores when plant residues are added or left on the soil surface.

Drainage

Soil drainage refers to the soil's natural ability to allow water to pass through it. Dense soil will hold water, while loose soil will allow water to pass through quickly. Soil drainage may determine which types of plants grow well in it.

Clay soil is a very dense type of soil. Its particles are closely packed together and clay generally does not allow water to drain through. This type of soil slowly releases air and allows water to seep down into it. Clay soil generally sits on top of a solid rock bed.Once water draining slowly through clay reaches the rock bed, it no longer has an outlet and pools within the soil. Plants that grow in it are at risk for root rot. Roots that sit in standing water for long periods of time will become prone to disease and fungus and may wilt and die.Sandy soil is very loose. Its particles allow for the passage of both water and air. This soil drains water very quickly, which allows air to circulate around the plants within it. This can also cause the plants to dry out and some varieties grown in sandy soil may need to be watered more frequently for this reason.

Soil Drainage Solutions

- In some cases, shallow ditches following the land contour may be enough, in others the ditches may need to be deeper or the land may need to be graded or sloped to facilitate **soil drainage**. The ditches may follow a random pattern or a parallel pattern.

- One yard **drainage solution** for both flat and sloped yards involves improving the **soil**. Clay **soils** generally don't absorb water well.

Soil Drainage Problems

- Lack of **soil** porosity is one of the most common **drainage problems**. Generally, top **soil** that is mixed with organic materials will allow water to drain through the surface of the **soil** quicker and more efficiently.

- Dense clay **soil** is typically acidic and loose, while sandy **soil** is typically basic and holds a low amount of nutrition for plants. A well-balanced **soil** with good **soil drainage** will contain a mixture of both clay and sand, allowing for a gradual passage of both water and air to circulate around plant roots.

Improving Soil Drainage

- Organic compost is a common additive used to **improve soil** quality and **drainage**. It generally consists of lawn clippings, shredded leaves, and kitchen food scraps, not including dairy or meat.

- Other Preventative Measures Taking measures to divert water away from the foundation of a home or other structure is usually the best way to**improve drainage**, but smaller remedial measures can also help, at least in the short term.

Poor Soil Drainage

- **Drainage** pipes and ditches may be dug around the garden area or site of **poor soil drainage**. These pipes and ditches will direct water flow away from the problem area and allow air to move through the **soil**.

- The main factor involved in **soil drainage** is **soil** texture, which refers to the size of the particles in the **soil**.

THERMAL PROPERTIES OF SOIL, SOIL TEMPERATURE, INFLUENCE OF TEMPERATURE ON PLANT GROWTH

Heat is a form of energy and temperature is a measur e of the heat energy. The heat energy refers to kinetic energy or random motion (vibration) of molecules of a substance. The speed of vibration is directly proportional to temperature. Solar radiation is the source of soil heat. The flux of heat (colories or joules) into and out of the soil determines the soil thermal regime, which is characterized in terms of soil temperature (°C). On an average only 50% of solar radiation reaches the earth, because of clouds and dust particles intercept the sun rays. This energy is primarily utilized to evaporate water from soil or leaf surface or is radiated or reflected back to the sky. Only about 10% is absorbed by soil, which is of critical importance to soil processes and to plants growing on the soil. The fraction of incident radiation that is reflected by the land surface is termed the "Albedo", and ranges from 0.1 to 0.2 for dark coloured, rough soil surfaces to as high as 0.5 or more for smooth, light coloured surfaces.

Heat capacity or Thermal capacity

The "heat capacity" of a soil is defined as the ratio of heat supplied to a body to the corresponding rise in its temperature. The heat capacity per unit mass of a body is called the "specific heat (e) and is defined as the quantity of heat required to raise the temperature of a unit body through 1°C. **Thermal conductivity** is defined as the quantity of heat passing in a unit time through a unit area of soil under a unit temperature difference between the faces and is expressed as Joules / meter / second / °C. Actual heat conductance depends on thermal conductivity and on the heat gradient. Thermal conductivity of a soil depends on its water content, texture, structure, mineralogical composition, organic matter content and compaction. Thermal conductivity increases with increased water content, till about 50% of the soil saturation. It is observed to decrease with a reduction in particle size. Thermal conductivity of soil varies in the order : Sand > loam > clay > peat.

Thermal diffusivity (m2/s) is defined as the ratio of thermal conductivity to heat capacity. It is the measure of the rate at which changes in temperature occur in the body. The reciprocal of thermal diffusivity indicates the ability of the body to retain heat.

Thermal retentivity: The ability of the body to retain heat is thermal retentivity. It is equal to the reciprocal of thermal diffusivity.

Heat transfer in soils: The major physical processes responsible for the transport of heat are conduction, convection and radiation.

a) Conduction: It may be defined as " the flow of heat through an unequally heated body from the places of high temperature to lower temperature". It is through the momentum of molecules. The molecules of the body nearer to the source absorb heat and increase their kinetic energy and begin to vibrate about their positions faster than before. They collide with other molecules and in this process they share their energies with the adjacent molecules so that other molecules increase their K.E and behave similarly to transfer heat energy from one end to another.

b) Convection: May be defined as the motion of the hot body itself carrying its heat with it. In this process absorption of heat causes increase in volume there by decrease in density of molecules. Such a decrease in density makes the hotter molecules to go up, giving their places to the cooler molecules which also behave like that after absorbing heat energy. This process occurs only in fluids.

c) Radiation: Radiation may be defined as the process by which heat is transmitted from one place to other with out aid of intervening medium. In this process heat is transferred through the space in the form of electromagnetic waves

Management of soil temperature

The soil temperature depends upon the heat flux in to the soil and the heat transfer processes occurring in the soil and in between the soil and atmosphere, which in turn, depend upon the thermal characteristics of the soil solids, gases and water. The soil thermal regimes greatly modify the microclimate of the area and exercise a major influence on growth and development of plants, particularly during germination and early seedling development stages.

Soil temperature can be modified by a) regulating energy balance on the soil surface b) changing the soil thermal properties and c) heating the soil through artificial means.

a) Temperature regulation by energy balance

The source of heat for soil is the solar radiation. The rate at which the radiant energy reaches the earth's atmosphere from the sun is called the solar constant, which has the val ue of about 2 cal cm -2 min-1. The solar radiation, which reaches the soil surface, is partly reflected, partly used for heating soil, partly used as latent heat for evaporation and partly reradiated as long wave

radiation. About 90% of long wave radiation is absorbed by the water vapours present in the earth's atmosphere, which partly reradiate to the earth's surface. It implies that the energy available for heating the soil is function of the incoming and outgoing radiation. If a greater fraction of incoming radiation is absorbed by the soil than the fraction reflected or reradiated the soil will be heated. The energy balance on the soil surface and therefore be modified through tillage and shaping of fields, mulching and vegetation; and shading and row spacing.

Modification of soil thermal properties

Soil thermal characteristics can be modified by changing soil physical conditions through tillage practices, soil compaction, irrigation and drainage. Tillage will loosen soil, increase the soil porosity and decrease the soil thermal conductivity and heat capacity.

Importance of soil temperature:

- Too low or too high temperatures affect the germination of seeds. Different crops have different optimum temperature for germination.
- Absorption of water and nutrients is impaired under low temperatures.
- Temperature influences nutrient availability by affecting the weathering of minerals and decomposition of organic matter.
- Low soil temperature results in white succulent roots with less branching.
- Low temperature enhances disease incidence by parasitic fungi · Soil microbial activity and decomposition of organic matter is restricted below 10 ^{o}C and ceases below 5oC.
- Biological nutrient transformations like nitrification, ammonification etc are affected by very high or low temperature

Layer silicates, origin and sources of charge

There are two types of charges (i) **Permanent or pH independent (originates due to isomorphous substitution) (ii) pH dependent charge**

Isomorphous substitution

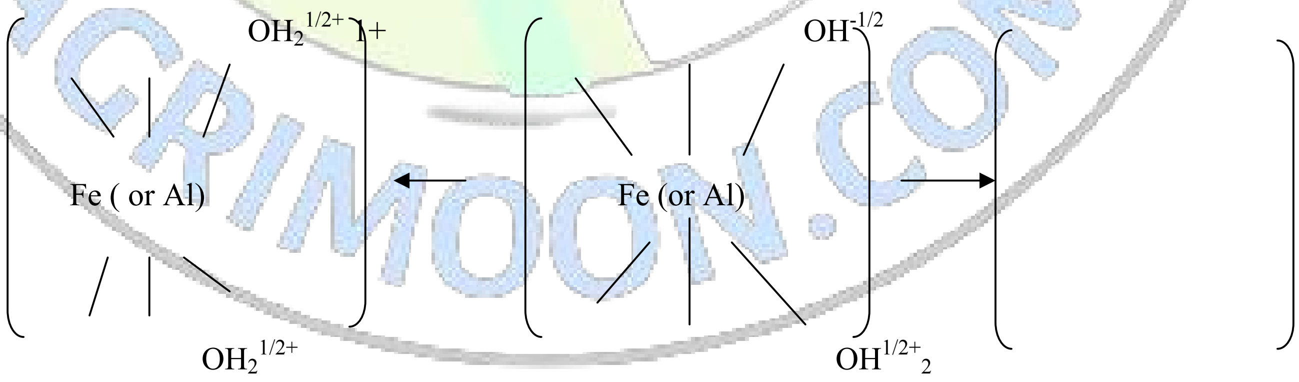
Isomorphous substitution occurs in accordance with ***Goldschmidt's Law I***, which states than in an ionic crystalline compounds, isomorphous replacement of one cataion by another, without incurring any change in the order of crystal pattern, is permitted provided that the radii of the cataion replaced and cataion substituting it agree within 10-15%.

Substitution of Si^{4+} ion in a tetrahedral sheet by Al^{+3} or that of Al^{+3} ion in dioctahedral sheet by Mg^{+2} or Fe^{+2} ion will cause excessive negative charge in sheet structures.

The charge of soil clays arising out of isomorphous substitution remains constant.

pHdependent charge

There is yet another source of charge of soil colloids, especially of kaolinite, the aluminosilicates clays and also for hydrous oxides and hydroxides of Fe and Al in clay size dimension , allophones and non crystalline clays as well as organic humic colloids of soils. The negative charge arises here through dissociation of proton from the exposed hydroxyl groups or bound water of constitution at edge and surface of the inorganic colloids and is naturally pH dependent.



Charge on organic soil colloids

Charge on humus colloids is pH dependent. Under strangely acid condition hydrogen is rigidly bound and not easily replaceable by other cataion. Humus colloids thereforeexhibits low negative charge.

Silicon tetrahedra: Geometrically it is possible to arrange only four oxygen anions (with radius of 1.32 Å) around a central silicon cataion (with a radius of 0.42Å) so that all are touching together. *Silicon tetrahedra are the fundamental building block of all the silicate minerals of earth crust.*

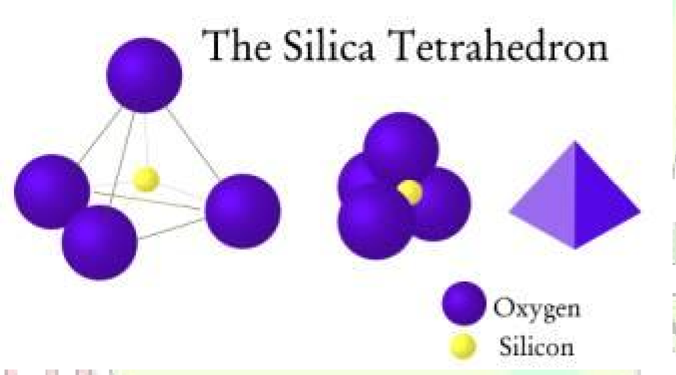
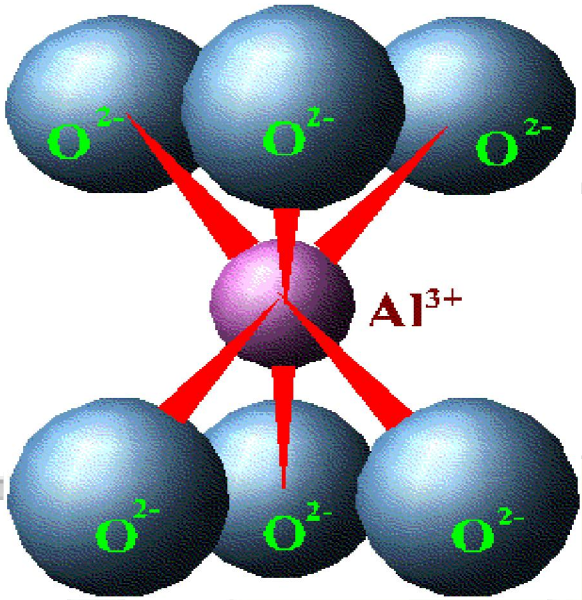


Fig. Silica tetrahedra

The amount of charge carried by Si is +4 and oxygen is -2. In order to attain neutrality, one Si would combine with two oxygen to form SiO_2, but geometrically stable structure is formed when one silicon ion combines with four oxygen ions to froma tetrahedra $(SiO_4)^{4-}$ which carries a negative charge of 4.

Aluminum octahedra

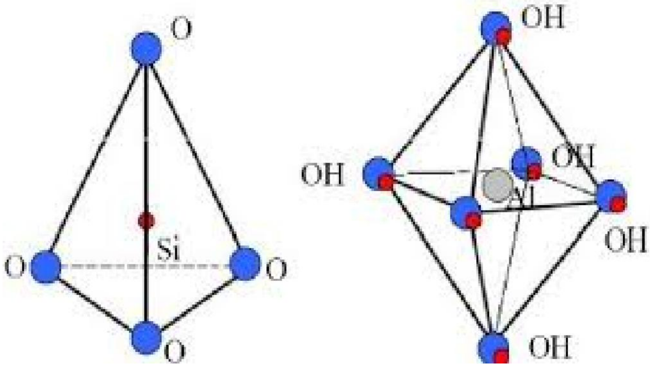
Aluminumoctahedral is an eight sided building block consisting of centralaluminum cataion surrounded by six hydroxyl or oxygen. Large numbers of aluminum octahedral, bound to each other by shared oxygen atoms in an octahedral layer are arranged in a plane forming an octahedral sheet. One silicon sheet and on octahedral sheet is a 1: 1 sheet and two tetrahedra sheet and one octahedral sheet is called 2:1 .



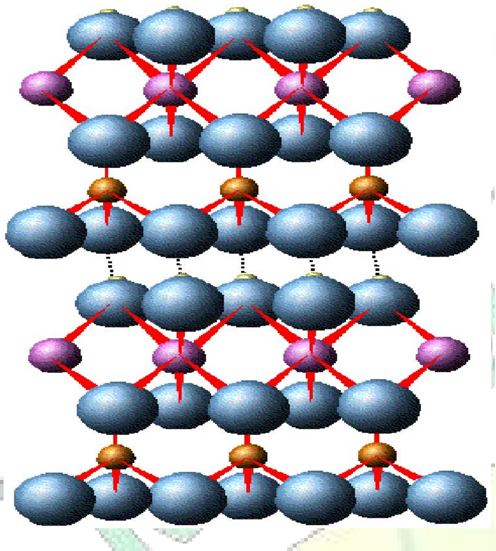
Classification of silicates

On the basis of the numbers and arrangement of silica and alumina sheets , silicates clays may be classified into four different groups.

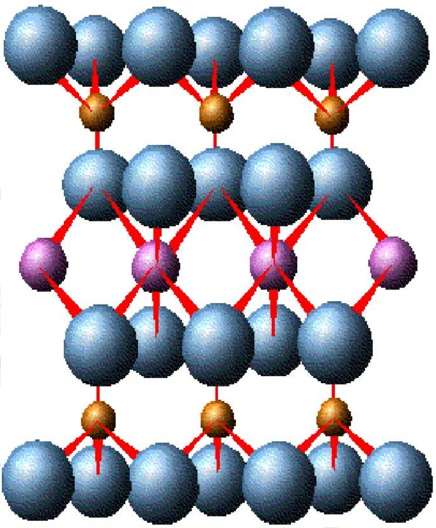
Si tetrahedra	Al octahedra	Type	Example
1	1	1:1	Kaolinite
2	1	2:1 (expanding)	Montmorillonites
		2:1 (non-expanding)	Vermiculites
2	2	2:2 or 2:1:1	Chlorites
Amorphous minerals	-	-	Allophanes, Chalcedony and Imogolite



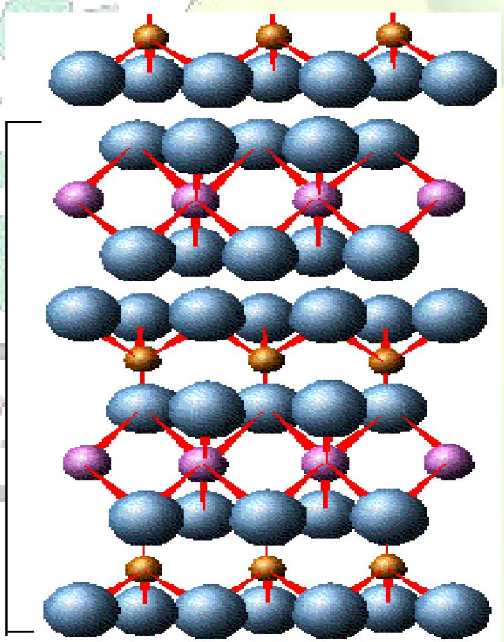
Si tetrahedra and Al octahedral



1:1 Kaolinite



2:1 minerals



2: 2 mineral or 2:1:1 minerals

Soil Colloids, Properties , types

Acolloidal system is a heterogeneous mixture of at least two phases in which one phase is dispersed in a state of fine subdivision (***particle size 1 µm to1 nm***) in another continuous medium.This continuous medium is termed as ***dispersion medium***. When dispersed phase is solid (soil colloidal particles) and dispersion medium is water (soil water), the colloidal system is referred to as **sol**.

Most of the important properties of colloidal system in soils may be attributed to the large specific surface (or interface) charge density.

Phase: In Physical Chemistry, phase is defined as any *homogenous* and *physically* distinct part of a system which is separated from other part of system by *definite bounding surfaces*.

Colloids (Greek, kola=glue; eidos=like) Any substances regardless of its nature can be converted into colloids by subdividing it into particle of colloidal size.

True solution: Sugar or salts in water, the solute particle are dispersed in the solvent as single molecules or ions. Thus the diameter of dispersed particle ranges from 1Å to 10 Å.

Suspension: Sand, stirred into water, the dispersed particles are aggregates of millions of molecules. The diameter of these particles is of the order of 2000 Å or more.

The **colloidal solution**s are colloidal dispersions are intermediate between true solutions are suspension. When the diameter of the particles of a substances dispersed in a solvent ranges from about 10Å to 2000Å , the system is called colloidal dispersion, solution or simply colloid.

Types of colloidal system:

The substances distributed as the colloidal particle is called the ***dispersed phase***. The second continuous phase in which the colloidal particles are dispersed is called ***dispersion medium***.

Eg. Colloidal solution of copper in water, copper particle is dispersed phase and water is dispersion medium

Type name	Dispersed phase	Dispersion medium	Examples
Foam	gas	liquid	Whipped cream,

			shaving cream, soda-water
Solid foam	gas	solid	Froth cork, pumice stone
Aerosol	liquid	gas	Fog, mist, clouds
Emulsion	liquid	liquid	Milk, hair cream
Solid emulsion (gel)	liquid	solid	Butter, cheese
Smoke	solid	gas	Dust, soot in air
Sol	solid	liquid	Paint, ink, colloidal gold
Solid sol	solid	solid	Ruby glass (gold dispersed in glass, alloys

Sols : Sols are colloidal system in which a solid is dispersed in a liquid.

Sols can be divided into two parts

(a) **Lyophilic sols (solvent loving)**: are those in which the dispersed phase exhibits a definite affinity for the medium or solvent. Eg.Of lyophilic sols are dispersion of starch, gum and protein in water. The affinity or attraction of the sol particles for the medium is due to hydrogen bonding with water.

(b) **Lyophobic sols (Solvent hating)** : Are those in which dispersed phase has no attraction for the medium or solvent.

Eg. Is dispersion of gold, iron hydroxide. And sulphur in water. Lyophobic sols no similar attraction forces are there.

Properties

Comparisons of lyophilic and lyophobic sols

Lyophilic sols	**Lyophobic sols**
Prepared by direct mixing with dispersion medium	Not prepared by direct mixing with medium
Little or no charge on particles	Particles carry positive or negative charge

Particle generally solvated	No salvation of particles
Viscosity higher than dispersion medium; set to a gel	Viscosity almost same as the medium, do not set to form gel
Precipitated by high concentration of electrolyte	Precipitated by low concentration of electrolyte
Reversible	Irreversible
Do not exhibit Tyndall effect	Exhibits tyndall effect
Particles migrate to anode or cathode or not at all	Particle migrate to either anode or cathode

Tyndall effect:

When a strong beam of light is passed through a sol, and viewed at right angles , the path of light shows up a hazy beam or cone. This is due to the fact that sol particle absorb light energy and then emit it in all directions in space. This scattering of light as it is called , illuminates the path of beam in the colloidal dispersion. The phenomenon of scattering of light by sol particles is called tyndall effect.

The illuminated beam or cone formed by the scattering of light by sol particle is often referred to as ***Tyndall beam or Tyndall cone***.

True solution do not show Tyndall effect.

Brownian movement:

Continuous rapid *zig-zag* movement executed by a colloidal particle in the dispersion medium is called Brownian movement.

Properties of colloids

The soil colloidal fraction is the site of important processes in soil, governing ion exchange, nutrient availability and fixation,soil physical properties especially soil structure, hydraulic conductivity, infiltration and also soil management.

Classification of colloids

Soil colloids can be broadly be classified into two categories, depending on the nature of linkages present and types of compound formed. These are

(i) **Inorganic colloids**: Aluminosilicates layer lattice clay minerals, hydrous oxides and hydroxides of Fe, Al , Si and Mn in clay size dimensions, amorphous silicates and clay sized primary minerals.

(ii) **Organic colloids**: Organic colloids dominated by soil humus

Humic colloids is the main fraction of soilorganic matter, which are widely distributed all over earth's crust.Nearly (70-80%) of soil organic matter consist of humic substances,***viz. humic acid, fulvic acid and humi***n. These are believe to be produced by continuous decomposition of plants ,animal and microbial bodies,encompassing alteration of carbohydrates,proteins, fats , resins , wax and so on, followed by synthesis of complex humic products.

Humic colloidsare dark in colour, partly aromatic, and amorphous with very high specific surface areas and charge density and essentially hydrophilic in nature. These substances are characterized by flexible poly electrolyte behavior,having polyfuntional groups and very high molecular weights ranging from fewhundred to several thousands. A typical value of CEC of soil humic colloids may be order of 200-250 cmol (p^+) kg^{-1} or even higher. The typicalfunctional groups of humic colloid are carboxylic,phenolic hydroxyl, amino,amide etc and as a result acts asproton donors or proton acceptors depending on pH.

Ion exchange in soils

Ion exchange in soil system refers to exchange of ***equivalent* amounts** of ions between two phases in ***equilibrium***in contact in a ***reversible*** process.

When cataion are involved the process is termed as cataion exchange, while for anions it is referred to as anion exchange. Such exchange may takes place between the soil solid (soil colloid or exchange) phase and the soil solution phase .

The experimental evidence of cataion exchange was provided around 1850 when Thompson, followed by J Thomas Way leached soil with ammonium sulphate solution and upon filtration , calcium and to a lesser extent magnesium, potassium was detected in the filtrate , while less of ammonium ions were recovered compared to what was used for leaching.

Initially the phenomenon was described as Base Exchange but on the recognition of the fact that hydrogen ions can also be exchanged, the wider term namely cataion exchange was used.

Changes in soil composition

Composition of soil solution changes as a result of (1) dilution of soil solution (during rain or application of irrigation water (2) ion uptake by plant and leaching (3) fertilizer application (4) use of brackish water for irrigation (5) reclamation of salt affected soil by leaching or use of chemical amendments (6) sewage and sludge farming and use of industrial effluents for irrigation. This leads to migration of cataion from colloidal phase to soil solution or vice-versa.

Cataion exchange capacity (CEC)

Interchange of cataion in soil solution phase with another on the surface of any surface-active material such as soil clay or organic matter in equivalent proportion in a reversible process is generally termed as cataion exchange.

CEC is defined as the capacity of the solid (soil) to adsorb and exchange cataion . In other words it is the sum total of exchangeable cataion that can be adsorbed by acolloidal surface. It is expressed in the units ofcmol(p^+) kg^{-1} (in S.I. system) or meq per 100 g in classical (CGS) units. Here (p+) denotes proton.

Similarly, the anion exchange capacity (AEC) of soil colloid can also be defined. It is expressed (in S.I. system) in the units of cmol (e-) kg^{-1}, (e-) representing electron.

Percent base saturation of soils

The percentage of the total cataion exchange capacity (CEC) satisfied with basic cataion is termed percent base saturation. It is defined as the extent to which the exchange complex of a soil is saturated with exchangeablecataion other than hydrogen and aluminum and is expressed as a percentage of the total cataionexchange capacity.

% BS= (S/T)×100

BS=Base saturation

S=me of basic cataion per 100 g soil

T= total exchangeable capacity me per 100 g soil.

H^+ and Al^{+3} are considered as acid or acid forming cataion.

The adsorbability of cataion to a charged surface (e.g. soil colloid) has been often discussed in terms of ***Hofmeister series or Lyotrophic series***. Thus the monovalent cataion can be put in the following sequence according to their adsorbaility

$Li^+<Na^+<K^+<Rb^+<Cs^+$

Bivalent caations follow the sequence given below

$Mg^{2+}<Ca^{2+}<Sr^{2+}<Ba^{+2}$

For cataions of varying valencies , the Lyotrophic series in respect of adosrbability is given as

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

Anion exchange

Positively charged sites exits on the edges of layer lattice silicate clay minerals (1:1) and surface of oxide (with low specific surface area) , mainly under acidic conditions. The total amount of anions held exchangeable by a unit mass of soil is termed as anion exchange capacity (AEC) and is much less than the Cataion Exchange capacity (CEC) of soils .

Capacity of soils to adsorb anion increases as pHdecreases or acidity increases, which increases pH dependent positive charge of soils. Adsorption of anions depends on the concentration of anions. Higher the concentration of anion , greater is the adsorption.

On the basis of experimental data, the preference of different anions for positive sites has been fund to follow the order

$SiO_4^{4-}> PO_4^{3-}>> SO_4^{2-}>NO_3^-=Cl^-$

Factors affecting ion exchange

Various factors affecting ion exchange are, nature and amount of clay, organic matter, mineralogical composition of soils, soil reaction, liming etc.

The term ***milliequivalen***t may be defined as one milligram of hydrogen or amount of any other ions that will combine with or displace it. If clay has CEC of 1 meq/100 g soil indicates that it is capable of exchanging 1 mg of hydrogen or its equivalent per 100 g soil.

The weight of one hectare furrow slice (0-15 cm) is 2.24×10^6 kg.

Negative Adsorption

The interaction between clay minerals and anions, in principles, comprises two different phenomenons,*viz*. the bonding of anions by positive charges presumably located on the broken edges of clay and the repulsion between anions and negative charges mainly on the planner surface of clays. The repulsion of anions by negatively charged sites leads to a local deficits of anions near a clay particles in comparison with equilibrium solution. This deficit has been termed as negative adsorption. Almost all soils found in nature posses net negative charge, ***negative adsorption or anion exclusion*** is exhibited to a certain extent by all soils.

Adsorption

Adsorption

The phenomenon of concentration of molecules of a gas or liquid at solid surface is called adsorption.

The substances that deposits at the surface is called ***adsorbate*** and the solid on which the deposition occurs is called ***adsorbent***.

Adsorption vs absorption

Adsorption implies deposition on the surface only; absorption implies penetration into the body of the solids.

Mc Bain introduced the general term **sorption** which includes both **absorption and adsorption**.

Types of adsorption

Physical adsorption

This is due to the gas molecules being held to the solid surface by ***van-der-waal's*** adsorption forces. This is referred to as ***van-der-waals*** adsorption. Eg. of adsorption of hydrogen or oxygen on charcoal is called physical adsorption.

Heat of adsorption is 5 kcal mole $^{-1}$.

Chemical adsorption or chemisorptions

In this kind of adsorption, the gas molecules or atoms are held to the solid surface by chemical bonds. This bond may be physical or chemical in nature. Hydrogen is chemisorbed on nickel.

Hydrogen molecule is first adsorbed by van-der-waals forces and then dissociates. The hydrogen atoms are thus chemisorbed on nickel.

Heat of adsorption for chemisorptions is 20 to 100 kcal mole $^{-1}$.

Heat of adsorption

Heat of adsorption is defined as the energy liberated when 1 gm mole of a gas is adsorbed on the solid surface.

Quantitative basis

The amount of materials adsorbed per unit mass of adsorbents depends largely on the nature of adsorbate and adsorbents, it also depends on the concentration of the adsorbate at equilibrium and temperature. Mathematically, it is expressed by equation

$x/m = f($ nature of adsorbate and adsorbent, $T)$

X= amount of adsorbate adsorbed on mass m of the adsorbent, C is the equilibrium concentration of adsorbate and T is the temperature.

Adsorption Isotherm

Adsorption data at equilibrium are reported in the form of **adsorption isotherms**. An adsorption isotherm is a plot between amount adsorbed per unit mass of the adsorbent and equilibrium concentration of adsorbate at a constant temperature.

The most commonly used isotherms are Langmuir (1918), Freundlich (1926) and Brunauer et al., (1938).

Freundlich Isotherm

Originally an empirical equation, implies that the bonding energy of adsorbate on a given adsorbent decreases with fractional coverage of surface area of adsorbent. This is the one of the most widely used adsorption equation to describe the experimental data on adsorption of ionic or molecular species in soil. ***However, the Freundlich equation does not predict any adsorption maxima.*** Mathematically it is expressed by an equation

$$X=KC^n \ (n<1)$$

X= amount adsorbed per unit mass of adsorbent and C is the equilibrium concentration of adsorbates. K and n are empirical constants. Generally the equation gives a ***parabolic curve***. The linear form of this equation is obtained by taking logarithms of its both sides, when we get expressions

$$\log x=\log K + n \log C$$

A plot of experimental data of log x versus log C should give a straight line with a slope of n and an intercept of log K.

Langmuir adsorption isotherm

The basic theory of adsorption of gases on solids is due to Langmuir (1918) and is based on following assumptions

(1) The surface of solids is made up of adsorption sites, each of which can adsorb one gas molecules. If other gas molecules hit the adsorbed molecules, it is defected back into the gas.

(2) All the adsorption sits are identical in their affinity for those gas molecules.

(3) The presence of gas molecules on one site does not affect the properties of neighboring sites

(4) The rate of adsorption is proportional to the number of adsorption sites and the pressure of gas. The rate of desorption is proportional to the number of occupied sites.

$$x/m = (k_1 \, k_2 \, C)/(1+k_2C)$$

x, m and C as defined in case of Freundlich equation , k1 and k2 are constants. This equation gives adsorption maxima where as Freundlich equation does not give it.

Brunauer, Emmett and Teller (BET) adsorption isotherms

The Langmuir adsorption equation represents the experimental adsorption data reasonably well in cases where adsorption becomes independent of pressure after formation of monolayer. However, for many gases and vapors it fails at high pressure because more than a monolayer of adsorbed molecules is found. The theory of BET extends Langmuir derivation to obtain an equation for multilayer adsorption.

The BET equation is based on following assumptions

(i) Heat of adsorption in the second, third….nth layer is same as heat of adsorption in the monolayer, *i.e.* heat of liquefaction or condensation of gases

(ii) The adsorption takes place on a free surface, than at P^0 (saturation pressure of gas), an infinite number of layers can be built up on the adsorbent.

SOIL BIOLOGY, BIOMASS

The soil consists of five major components. They are living organisms, organic matter, air, water and minerals. The soil is generally referred as the loose material of the earth’s surface, which supports the growth of plants, bacteria, fungi, algae and protozoa, which make up for the living organisms of soil. Fertile soil is inhabited by the root systems of higher plants, by many animal forms (ex: insects, worms) and by the tremendous number of microorganisms. The type and quantity of microorganisms present in a soil vary depending upon the physical characteristics and agricultural practices and other parameters such as amount and type of nutrients, available moisture, degree of aeration, temperature and pH. Soil has great variety of microorganisms of bacteria, fungi, algae, protozoa and viruses.

Important groups of microbes and their role in fertility of soil and plant growth

Microbial population in a fertile agricultural soil

Type	***Number per gram***	
Bacteria	2,500,000,000	(2.5×10^9)
Actinomycetes	700,000	(7.0×10^5)
Fungi	400,000	(4.0×10^5)

Algae	50,000	(5.0 × 10 4)
Protozoa	30,000	(3.0 × 10 4)

Bacteria:

The bacterial population of the soil exceeds population of all other groups of microorganisms in both number and variety. The types of bacteria that are present in the soil are autotrophs, heterotrophs, mesophiles, thermopiles, psychrophiles, aerobes, anaerobes, cellulose digesters, protein digesters, sulfur oxidizers, nitrogen fixers and others.

Fungi:

Hundreds of different species of fungi are present in the soil. They are most abundant in the surface soil. They decompose cellulose, lignin, and pectin. The physical structure of soil is improved by the accumulation of mold mycelium within it. Yeasts are more prevalent in soils of vineyards and orchards.

Algae:

Population is smaller than bacteria and fungi. Mostly they are present on surface or subsurface of the soil. The major types present are green algae and diatoms. The growth and activity of the initial algae and bacteria paved the way for the growth of other bacteria and fungi. The cyanobacteria play a key role in the transformation of rock to soil.

Protozoa:

Most soil protozoa are flagellates or amoebas. Their dominant mode of nutrition involves ingestion of bacteria and may be a factor in maintaining some equilibrium of microorganisms in soil.

Viruses:

Bacterial, plant and animal viruses find their way into soil, through additions of plant and animal wastes. The microbial population in the rhizosphere is considerably higher than that of root free soil and physiologically more active since they make use of the root extracts.

Classification of soil microorganisms

The soil microorganisms can be classified into different categories:

1. On the basis of oxygen requirement: a) Obligate aerobes, b) Facultative aerobes and c) obligate anaerobic microorganisms
2. On the basis of food habit: a) Heterotroph and b) Autotrophs
3. Temperature: a) Psychrophillic, b) Mesophyllic and c) Thermophillic

Importance of microorganisms:

Microorganisms have some characteristics, which make them ideal specimens for the study of numerous fundamental processes. At cellular level many life processes are performed in the same manner whether they may be in microbe, mouse or human.

1. They are the attracting models for studying the fundamental processes. They can be grown in test tubes or flask thus require less space. They grow rapidly, and reproduce at an unusually high rate. Some species undergo 100 generations in 24 hours period.
2. In microbiology we can study the organisms in great detail and observe their life processes while they are actively metabolizing, growing, reproducing, aging and dying.
3. Microorganisms have wider range of physiological and biochemical potentialities. Some bacteria can fix atmospheric nitrogen, while other species require Inorganic or Organic nitrogenous compounds for their metabolic activity.

BENEFICIAL ROLE OF SOIL MICROORGANISMS IN SOIL

Soil microorganisms serve as biological agents for the conversion of complex organic compounds into simple inorganic compounds or into their constituent elements. The overall process is called mineralisation. Soil microbes also fix or remove inorganic ions or mineral and this process is known as immobilization. Both immobilization and mineralisation are important for recycling of various nutrients required by plants and animals. The major nutrients essential for plant growth are C, H, O, N, P, K and S. Many of these elements undergo constant transformations in soil through the processes of immobilization, mineralisation, oxidation, reduction etc. by the soil microorganisms.

Biofertilizer

Biofertilizers are the preparations containing cells of effective microorganisms which may be nitrogen fixers, phosphorus solubilizer. Sulphur oxidizers or organic matter decomposers. In short, they are called as bioinoculants which on supply to plants improve their growth and yield. In recent years a need has arisen for organic fertilizers including biofertilizers to minimize our dependence on fertilizer nitrogen. The experiments conducted in India and abroad on biofertilizers revealed that legumes viz, beans, soybean, chickpea, pigeon pea can fix 50-500 kg atmospheric nitrogen per hectare under ideal conditions. In recent years a use of Rhizobium, culture has been routinely recommended as an input in pulse cultivation. In India about 30 million hectares of land is under pulses.

Types of Biofertilizers

1. Nitrogen fixers

Rhizobium: belongs to family Rhizobiaceae, symbiotic in nature, fix nitrogen 50-100 kg/ ha. with legumes only. It is useful for pulse legumes like chickpea, red-gram, pea, lentil, black gram, etc., oil-seed legumes like soybean and groundnut and forage legumes like berseem and lucerne. It colonizes the roots of specific legumes to form tumour like growths called root nodules, which acts as factories of ammonia production. Rhizobium has ability to fix atmospheric nitrogen in symbiotic association with legumes and certain nonlegumes like Parasponia and an increase in yield by 10-12%.

Azospirillum: belongs to family Spirilaceae, heterotrophic and associative in nature. In addition to their nitrogen fixing ability of about 20-40 kg/ha, they also produce growth regulating substances. Although there are many species under this genus like, *A. amazonense*, *A. halopraeferens*, *A .brasilense*, but, worldwide distribution and benefits of inoculation have been proved mainly with the *A. lipoferum* and *A. brasilense*. The Azospirillum form associative symbiosis with many plants particularly with those having the C4-dicarboxyliac path way of photosynthesis (Hatch and Slack pathway), because they grow and fix nitrogen on salts of organic acids such as malic, aspartic acid. Thus it is mainly recommended for maize, sugarcane, sorghum, pearl millet etc.

Azotobacter: belongs to family Azotobacteriaceae, aerobic, free living, and heterotrophic in nature. Azotobacters are present in neutral or alkaline soils and A. chroococcum is the most commonly occurring species in arable soils. *A. vinelandii*, *A. beijerinckii, A. insignis* and *A. macrocytogenes* are other reported species. The number of Azotobacter rarely exceeds of 104 to 105 g-1 of soil due to lack of organic matter and presence of antagonistic microorganisms in soil. The bacterium produces anti-fungal antibiotics which inhibits the growth of several pathogenic fungi in the root region thereby preventing seedling mortality to a certain extent. The occurrence of this organism has been reported from the rhizosphere of a number of crop plants such as rice, maize, sugarcane, bajra, vegetables and plantation crops.

2. Phosphate solubilizer

Several reports have examined the ability of different bacterial species to solubilize insoluble inorganic phosphate compounds, such as tricalcium phosphate, dicalcium phosphate, hydroxyapatite, and rock phosphate. Among the bacterial genera with this capacity are *Pseudomonas, Bacillus, Rhizobium, Burkholderia, Achromobacter, Agrobacterium, Microccocus, Aereobacter, Flavobacterium* and *Erwinia*. There are considerable populations of phosphatesolubilizing bacteria in soil and in plant rhizospheres. These include both aerobic and anaerobic strains, with a prevalence of aerobic strains in submerged soils. A considerably higher concentration of phosphate solubilizing bacteria is commonly found in the rhizosphere in comparison with non rhizosphere soil. The soil bacteria belonging to the genera *Pseudomonas* and *Bacillus* and Fungi are more common. The major microbiological means by which insoluble-P compounds are mobilized is by the production of organic acids, accompanied by acidification of the medium. The organic and inorganic acids convert tricalcium phosphate to di-and-monobasic phosphates with the net result of an enhanced availability of the element to the plant.

3. Zinc solubilizers

The nitrogen fixers like *Rhizobium, Azospirillum, Azotobacter*, BGA and Phosphate solubilizing bacteria like *B. magaterium, Pseudomonas striata*, and phosphate mobilizing Mycorrhiza have been widely accepted as bio-fertilizers. However these supply only major nutrients but a host of microorganism that can transform micronutrients are there in soil that can be used as biofertilizers to supply micronutrients like zinc, iron, copper etc., zinc being utmost important is found in the earth's crust to the tune of 0.008 per cent but more than 50 per cent of Indian soils exhibit deficiency of zinc with content must below the critical level of 1.5 ppm of available zinc. The plant constraints in absorbing zinc from the soil are overcome by external application of soluble zinc sulphate ($ZnSO4$). There appears to be two main mechanisms of zinc fixation, one operates in acidic soils and is closely related with cat ion exchange and other operates in alkaline conditions where fixation takes by means of chemisorptions, (chemisorptions of zinc on calcium carbonate formed a solid-solution of $ZnCaCO3$), and by complexation by organic ligands. The zinc can be solubilized by microorganisms viz., *B. subtilis, Thiobacillus thioxidans* and *Saccharomyces sp.* These microorganisms can be used as bio-fertilizers for solubilization of fixed micronutrients like zinc. The results have shown that a Bacillus sp. (Zn solubilizing bacteria) can be used as bio-fertilizer for zinc or in soils where native zinc is higher or in conjunction with insoluble cheaper zinc compounds like zinc oxide (ZnO), zinc carbonate ($ZnCO3$) and zinc sulphide (ZnS) instead of costly zinc sulphate.

4. Potassium solubilizer

Certain groups of micro-organisms including bacteria, fungi and actinomycetes are known to solubilize K bearing minerals (orthoclase, mica, illite, muscovite etc.) into soluble form which can be utilized by the plants. These microorganisms are known to produce amino acids, itamins and growth promoting substances like IAA and gibberellic acid which help in better growth in plant.

5. Phosphorus and other nutrient mobilizer

Mycorrhiza is an association with intracellular penetration of the host root cortical cells by the fungus as well as outward extension into the surrounding soil. Mycorrhizal The fungus initially grows between cortical cells, but soon penetrates the host cell wall and grows within the cell. It increased uptake of nutrients with hyphae, which explore the soil for nutrients, increase surface area for nutrient absorption transport them back to the plant. The nutrients P, Zn, C, N, Cu and S have been shown to be absorbed and translocated to the host by mycorrhizal fungi. Increased rootlet size and longevity, mycorrhizal plants have larger roots than nonmycorrhizal plants regardless of whether mycorrhizal fungi are present.

Harmful effect of soil microorganisms in the soil

Microorganisms occur everywhere in nature – In air, oceans, mountain tops etc. as the conditions for the growth and survival of the microorganisms are similar to those of human beings, they are in the air we breathe, and the food we eat. They are on the surface of our bodies, in our mouths, noses, alimentary tracts etc. Fortunately, most microorganisms are harmless to human beings and we have means of resisting invasion by those that are potentially harmful. Some microorganisms are beneficial and some are detrimental. Microbes are involved in making of cheese and wine, in the production of penicillin, interferon and alcohol, in the processing of domestic and industrial wastes. They can cause disease, spoil food; deteriorate materials like iron pipes, glass lenses and wood pilings.

Late Selman A Waksman –Microbiologist observed that there is no field of human endeavor whether it may be an industry or agriculture or in the preparation of food or in connection with problems of shelter or clothing or in the conservation of human or animal health and combating of disease where the microbe does not play an important and often dominant role. He discovered antibiotic Streptomycin produced by soil bacterium for which he got Noble Prize in 1952.