

Soil and Water Management in Agroforestry

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Dr. Rahul Chopra

Assistant Professor



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DEPARTMENT OF NATURAL RESOURCE MANAGEMENT

COLLEGE OF HORTICULTURE AND FORESTRY

AGRICULTURE UNIVERSITY, KOTA, RAJASTHAN

Soil as a natural body- major components

Soil: 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: The word ‘*soil*’ is derived from a Latin word, “Solum”, meaning ‘floor’. **Soil** is a complex system made up of mineral matter, organic matter, and soil water and soil air. Therefore, it contains not only the solid and liquid phases but also the gaseous phase.

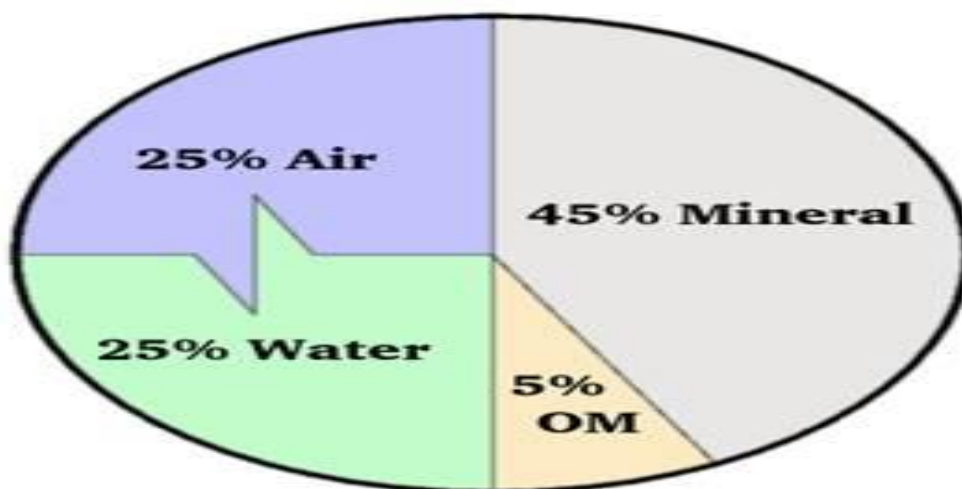
According to different scientist

Whitney (1892) Soil is more or less a loose and friable material in which plants, by means of their roots, find a foothold for nourishment as well as for other conditions of growth.

Dokuchaiev (1900) Russian scientist, also known as “Father of Soil Science” Soil is a natural body composed of mineral and organic constituents, having a definite genesis and a distinct nature of its own.

According to Joffe (1936),”The Soil is a natural body of minerals and organic constituents differentiate into horizons of variable depth, which differs from the materials below in morphology, physical make up, chemical properties and composition and biological characteristics.”

Jenny (1941) Soil is a naturally occurring body that has been formed due to combined influence of climate and living organisms acting on parent material as conditioned by relief over a period of time.



Components of Soil

Composition of Earth Crust

Interior of the Earth: Based on the records of earthquake waves, the inside of the earth is divided into 3 parts or concentric rings *i.e.* Crust, Mantle and Core.

1 Crust:

A) Crust thickness varies from 5 to 11 Km in the oceans and 35 to 56 Km in the continents.

B) It consist of rocks and density of crust is 2.6 to 3.0 gcm^{-3}

2 Mantle:

A) The mantle is a thick layer of solid rock below the crust.

B) It is 2900 Km thick.

C) The rock is composed of Silicon, Oxygen, Aluminum, Iron and Magnesium with density of 3.0 to 4.5 gcm^{-3} .

D) The temperature of mantle ranges between 870°C to 4400°C .

3. Core:

A) The core is the innermost portion of the earth.

B) It is 3500 Km in thickness

C) It is composed of metals such as iron and Nickel having density of 9.0 to 12 gcm^{-3} .

D) The outer core is about 2250 Km thick and is composed of melted iron and nickel. Its temperature varies from 2200°C to about 5000°C .

E) The ball shaped inner core make up the center of the earth. It is about 1300 Km thick and consist of solid iron and nickel. The temperature there may be as high as 5000°C .

Composition of Earth Crust: Out of 106 elements known 8 are sufficiently abounded to constitute 98.6 % of earth crust up to 16 Km.

Non Metallis	O^{2-}	46.6%
	Si^{4+}	27.72%
Metals	Al^{3+}	8.13%
	Fe^{2+}	5%

Ca ²⁺	3.63%
Na ⁺	2.83 %
K ⁺	2.59%
Mg ²⁺	2.09%
Others	1.41 %

The materials of the earths crust fall into two principle categories, namely

1 Mineral

2 Rocks

Rocks in earth crust: Composition of upper 5 Km

1 Sedimentary Rocks

A Shals	52%
B Sandstones	15%
C Limestones and Dolomite	7%

2 Igneous Rocks

Granite	15%
Basalt	3%
Others	8%

Composition of earth crust whole basis:

A Igneous rocks 95%

B Sedimentary rocks 5%

i Shales	4%
ii Sandstones	0.75%
iii Limestones	0.25%

Formation of Rocks and Minerals

It is important to understand from the beginning what is the difference between minerals and rocks. Simple, but useful definitions are:

Mineral – a naturally-occurring solid material with a limited range of chemical composition and a specific structure;

Rock – a naturally-occurring solid material composed of one or more minerals.

A mineral is a naturally occurring inorganic substance having a definite chemical composition and distinct physical characteristics. It usually consists of two or more elements in chemical combination in definite proportions. **A mineral that forms owing to crystallization of molten magma is known as primary minerals (more than 2 μ) (e.g., feldspar, hornblende, mica, etc.). While a mineral which has been formed, deposited or introduced as a result of subsequent changes in pre-existing rocks is known as a secondary minerals (less than 2 μ) (limestone, gibbsite, etc., and clay minerals like kaolinite, montmorillonite, etc.).** A mineral may occur both as a primary or original and as a secondary constituent. As primary mineral quartz is one of the components of granite. As a secondary mineral it is deposited in the form of veins, amygdales, and other aggregates in trap. **Those minerals which form the chief constituents of a rock, and which are regarded as the characteristic components of that rock, are known as essential minerals (95-98%) while those which occur only in small quantities and whose presence or absence is of no consequence as far as the character of the rock is concerned, are called accessory minerals (2-5%).** Felspars, pyroxenes, amphiboles and micas are few e.g. of essential minerals, while tourmaline, ilmenite, magnetite, etc., are e.g. of accessory minerals.

Each mineral possesses, in addition to a definite chemical composition, certain physical characteristics, which enable it to be differentiated from others. The important physical properties that characterize them are crystal form, colour, streak, luster, opacity, hardness, specific gravity, cleavage and fracture. About a thousand minerals are known to be present in the earth's crust, but those that are of frequent occurrence and are important from the point of view of soil formation form a comparatively small number.

According to Clarke, the most abundant minerals present in igneous rocks, which represent the original rocks in the earth's crust, are feldspars which constitute 60%,

pyroxenes and amphiboles 18%, quartz 12%, micas 4%, and all other 6%. The mineralogical make up of the parent material from which a soil is formed is an important factor influencing its nature and character. For instance, the deficiency or excess of certain elements in a soil brought about by low or high concentration of a particular mineral may have a profound effect on the growth and development of plants and animals. Some minerals decompose more quickly than others and thus liberate plant nutrients more readily.

Quartz: It is one of the four silica minerals viz., quartz, cristobalite, tridymite and opal that occur in nature. The first three are crystalline while opal is amorphous. Quartz is most abundant of them all. A number of varieties of quartz are present and they differ from each other mainly in colour and form. Some of the important crystalline varieties are rock crystal (colour-less), amethyst (purple), rose quartz (pink), citrine (yellow), carnelian (red), bloodstone (green with red spots), and smoky quartz (brown or black). Charcedony (white), agate (banded), flint and chert (massive), and moss agate belong to the crypto-crystalline varieties. Quartz is an important constituent of all the three classes of rocks and is the dominant mineral in granite, rhyolite, sandstone and conglomerate. Among metamorphic rocks, gneiss and quartzite contain appreciable quantities of this minerals. It is present in almost all soils of which sand and coarse silt fractions contain the largest amount. Even the clay fraction of some soils contains quartz.

Feldspars: It may be divided into two groups- orthoclase and plagioclase. Orthoclase feldspars are mainly potash feldspars while plagioclase feldspars are either **soda feldspars**, e.g. albite, or **calcium feldspars**, e.g., anorthite, or **soda-lime feldspars**, e.g., oligoclase, labradorite, etc. Potash feldspars are present in granite, syenite and similar other igneous rocks while plagioclase feldspars form important constituents of basic igneous rocks like basalt, gabbro, etc. In the soil, feldspars are usually present in the sand and silt fractions.

The important minerals belonging to the pyroxene group are **augite** and **enstatite**. These minerals are usually predominant in basic igneous rocks like basalt, dolerite, gabbro and others. They are rich in calcium, magnesium and iron, and belong to the group of minerals known as ferromagnesian minerals.

Hornblende and **actinolite:** These are two important minerals of the amphibole group of silicates, are also known as ferromagnesian minerals. In addition to calcium, magnesium, and

iron, these minerals contain a number of other bases, e.g., iron (ferric), manganese, titanium, sodium, potassium, etc. Their composition as well as constitution is thus much more complex than that of pyroxenes. Hornblende is more abundant of two, being very widely distributed in acid as well as basic igneous rocks. It is found in soil, especially in sand and silt fractions.

The next important group is **mica**, of which muscovite (white mica) and biotite (black mica) are two most widely distributed primary minerals. These minerals have a very characteristic plate like structure. They are present in all the three classes of rocks, viz., igneous, aqueous and metamorphic. **Biotite** which is usually darker in colour is richer in iron and magnesium than muscovite. As they are fairly resistant to weathering, they are found in soils mainly in the fine sand fraction. These minerals along with orthoclase feldspars are the usual source of potassium in the soil.

Other important primary minerals are **apatite**, **magnetite** and **ilmenite**. They are usually present in very small quantities and constitute the accessory minerals of a number of rocks. They are more resistant to weathering and are usually found in the sand fraction of soils.

Among the secondary minerals, the **clay minerals** are the most important. Apatite, calcite, dolomite, gypsum, gibbsite, haematite and limonite are some of the other secondary minerals found in rocks and soil.

Rocks

Rocks may be defined as mass of minerals matter. It is composed of one or more minerals. Some rocks are **hard and compact e.g., granite, basalt**, while others are **loose and feebly aggregated e.g., sandstone and loose sand**. Each rock possesses certain characters like structure, colour, specific gravity, cleavage or fracture, and microbiological make-up which help to distinguish one from another.

Petrography: That deals with the description of rocks.

Petrogenesis: That deals with the study of the origin of rocks.

Rocks are divided into three main classes according to their origin or mode of formation i.e. igneous rocks, aqueous rocks and metamorphic rocks. They are further sub-divided into

groups depending upon the chemical and mineralogical composition, structure and mode of occurrence.

1. Igneous rocks: They are formed by the action of heat. These rocks were formed when the molten mass cooled and consolidated into solid rocks. The igneous rocks constitute nearly 95% of the earth's crust and are about 10 miles thick. These rocks are mostly crystalline and they are therefore known as **crystalline** rocks. As they occur in big masses, therefore they are also known as **massive** rocks. **Igneous rocks are mainly consists of primary minerals of which quartz, feldspars, amphiboles, pyroxenes and micas are most common.**

According to their **mode of formation or occurrence they are divided into three groups like extrusive, intrusive and plutonic.** **Extrusive rocks** are those that were formed when the molten mass was poured out on the surface of the earth where it is consolidated on cooling (rocks of volcanic eruption or origin). **E.g., rhyolite, obsidian, trachyte, dolerite and basalt.** **Intrusive rocks** are those that were formed when molten mass was cooled and consolidated beneath the surface. Among the intrusive rocks, those that consolidated at a much greater depth than others are **plutonic rocks**. Granite, syenite, diorite and gabbro belong to this group. Some rocks consolidated in vertical and horizontal cracks of pre-existing rocks and formed wall-like and plane masses are respectively known as **dykes and sills.** **Veins** are consolidated molten materials present in narrow cracks and fissures. Rocks present in the globular cavity (are known as vesicle) or vesicles is known as **vesicular rocks.** The rocks having minerals deposited into the vesicles by infiltration of water carrying substances in solution is studded with almonds or amygdales are known as **amygdaloidal rocks.** E.g., **quartz, calcite, zeolite, glauconite** etc.

The igneous rocks are divided into four main classes according to their chemical composition (relative amount of acid and basic components). The acid components are silicic acid or silica, while soda, potash, alumina, lime, magnesia and iron oxides constitute the main bases.

1. Acid rocks – more than 65% silica (granite, rhyolite, obsidian & pitchstone)
2. Sub-acid rocks – 60-65% silica (syenite & trachyte)
3. Sub-basic rocks – 55-60% silica (diorite & andesite)
4. Basic rocks – 45-55% silica (gabbro, dolerite & basalt)

2. Sedimentary (Aqueous) rocks: They are formed through the action of water (sediments brought by water). Hence they are also known as sedimentary rocks. The sediments consist

of various types of substances and of various sizes of particles. The particles are cemented together by substances like silica, iron oxide or lime to give a consolidated form. **Many of these rocks are deposited in layers or strata and hence they are also known as stratified rocks.** In some cases these rocks are formed of substances which were at one time in solution in water and were deposited as rock masses either by cooling, evaporation or by direct chemical precipitation. In whatever way they were formed, all aqueous rocks are of secondary or derivative origin, as they consist of materials that have previously existed on or beneath the surface of the earth. The transportation, accumulation and consolidation of these materials gave rise to new rocks. Hence these rocks consist mainly of secondary minerals together with some quantities of primary minerals.

Aqueous rocks are divided into six groups as under: arenaceous, argillaceous, calcareous, siliceous, carbonaceous and precipitated salts.

3. Metamorphic rocks: The igneous and aqueous rocks sometimes undergo a considerable change, then rocks is said to have undergone metamorphosis is brought about by the action of water, heat, or pressure, or by the combined action of any two of these or all three. The change brought about **by water is known as hydro-metamorphism**, that **by heat thermo-metamorphism**, and that **by pressure, dynamo-metamorphism**. Action of pressure tends to change the structure of the rock. In some cases it also brings about chemical changes. The pressure may be produced by the movement of the earth's crust. Due to this pressure, the crystals of the original rock get pressed or flattened and the new rock looks foliated. **When the foliation is slight, so that the layers are not separable**, the structure is known as **gneiss**. E.g., **granite-granite gneiss**, and **diorite-diorite gneiss**. If the **foliation is complete so that the layers are distinct and separable**, the new structure is known as **schist**. The masses of **diorite and hornblende-diorite schist and hornblende schist**, respectively, other e.g., are **talk schist, quartz schist, and chlorite schist**. **Shale & mudstone** is very often converted into **slate** by the action of pressure e. i. compression and alteration. **Marble is metamorphosed limestone**, frequently colored by inclusions of various other minerals and resistant to weathering. **Quartzite is metamorphosed sandstone**, enriched in interstitial silica; it is extremely resistant to weathering.

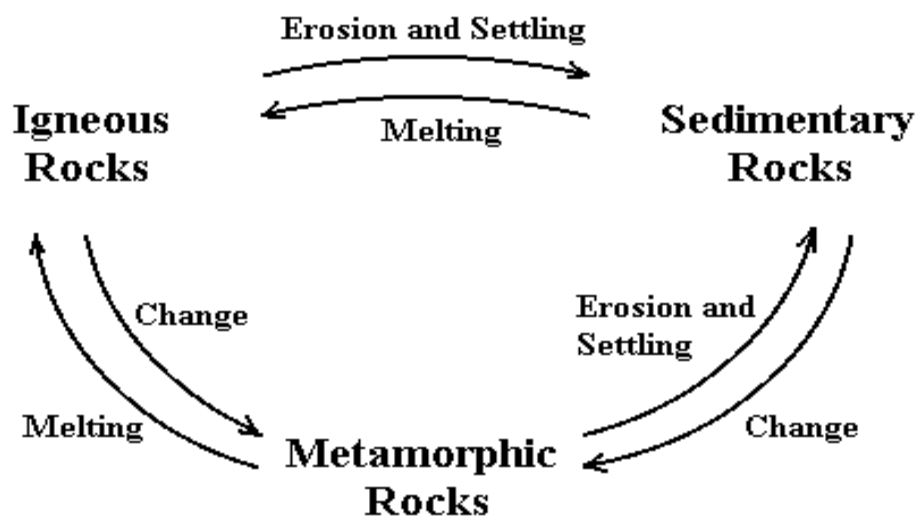


Fig 1: Formation of Rocks

Weathering Process of Rocks and Minerals

A process of disintegration and decomposition of rocks and minerals which are brought about by physical agents and chemical processes, leading to the formation of regolith (unconsolidated residues of the weathering rock on the earth's surface or above the solid rocks).

The process of transformation of solid rocks into parent material or regolith.

There are two basic process of weathering: **Physical (mechanical) – disintegration** and **chemical – decomposition**. In addition, another process is **biological** - disintegration and decomposition and all these processes work simultaneously. Depending upon the agents taking part in weathering processes, it is classified into three types.

Table 8: Different agents of weathering

Physical/mechanical (disintegration)		Chemical (decomposition)		Biological (disintegration + decomposition)	
1	Physical condition of rock	1	Hydration	1	Man & animals
2	Change in temperature	2	Hydrolysis	2	Higher plants & their roots
3	Action of water (fragmentation & transport, action of freezing, alternate wetting & drying, and action of glaciers)	3	Solution	3	Microorganisms
4	Action of winds	4	Carbonation		
5	Atmospheric electrical phenomenon	5	Oxidation		
		6	Reduction		

The principal agents that take part in the process of weathering are: (1) temperature (2) water (3) air (4) plants and (5) animals. Each of these agents acts on the rock both mechanically as well as chemically. Some of the processes of weathering are simple, others are very complex. All these changes take place almost simultaneously and thereby help them to bring about a more rapid transformation of the solid rock into soil than if each one acted separately.

Physical Weathering: Physical weathering is a mechanical process, causing disintegration of consolidated massive rocks into small pieces. The rocks are disintegrated and broken down to comparatively smaller pieces, without producing any new substances. Under very cold or very hot and dry conditions, such as in the central Himalayas or the Thar Desert, physical weathering is prominent and is operated through various agents, viz. temperature, water, ice, wind and living organisms. The roles of various agents are discussed below:

1. Physical condition of rocks: The permeability of rocks is the most important single factor. Coarse textured sand stone weather more rapidly than fine textured basalt. Unconsolidated volcanic ash weather quickly as compared to unconsolidated coarse deposits such as gravels.

2. Effect of temperature: The effect of temperature in weathering rocks is mainly mechanical. Rocks are of two types, viz. mono-mineralic (made up of one mineral), and poly-mineralic (made up of more than one mineral). In nature, poly-mineralic rocks are common. As a result of

diurnal temperature variation, the rocks get heated during the day and cooled during the night. The variation in diurnal temperature exerts great influence on the disintegration of rocks. The rock gets heated at day time due to the sun's heat and expands. At night when the temperature falls, the rock gets cooled and contracts. This alternate expansion and contraction goes on continuously day after day weakens the surface of the rock and crumbles (cracks and rifts) it because the rocks do not conduct heat easily.

Due to this differential expansion of minerals in a rock surface generates stress and strain between the heated surface and cooled unexpanded parts of rock resulting in fragmentation of rocks in the form of layers. This process causes the layer to peel off from the parent rock/mass and the rock ultimately disintegrates. This process is called **exfoliation**. The effect of temperature is most evident in hot countries and in desert regions where disintegration forms the predominant process of weathering.

3. Effect of water: Water acts on the rock both mechanically as well as chemically. It is the most potent agent that is responsible for the weathering of rocks. Water acts as disintegrating, transporting and depositing agent. The rainwater falls on the land and travels towards the low lying areas such as rivers, lakes and oceans, continuously detaching, and shifting, sorting and reworking the sediments that it carries. When loaded with sediments, flowing water has tremendous cutting power, resulting in the formation of gorges, ravines and valleys. Among all the agents of physical weathering, the effect of water perhaps is more pronounced and widespread.

i) Fragmentation & transport: Rain that falls beats over the surface and starts flowing towards the oceans through streams and rivers. Moving water has great cutting and carrying capacity/force. It forms gullies, ravines and carries with the suspended soil material of varying sizes. The transporting power of stream water varies as the sixth power of its velocity that is greater the speed of water, more is the transporting power and carrying capacity. The grinding action of flowing water carrying materials in suspension depends on the two factors: (1) the speed with which it flows, and (2) the amount of material it carries in suspension.

Speed/sec	Carrying capacity
15cm	Fine sand
30cm	Gravel
1.2m	Stones (1kg)
9m	Boulders(several tons)

ii) Freezing action: Frost is more effective than heat in producing physical weathering. A part of rain water that falls on the earth is carried underground through cracks, crevices and fissures in the rocks, and a part flow over the ground in the form of streams and rivers. In the cold regions, where the temperatures are low, the water freezes at times. The water that may be present in the chinks and crevices of the rocks also freezes into ice. On freezing the water expands in volume to one tenth. The increase in volume exerts considerable pressure to be of the order of 150 tons per sq. ft. or about 140 atmospheres. As the freezing starts from the top there is no possibility of its

upward expansion. Hence, the increase in volume creates enormous outward pressure which breaks part of the rocks into loose mass of stones.

iii) Alternate wetting and drying: Some natural substances increase considerably in volume on wetting and shrink on drying. Eg., smectite, montmorillonite. During the dry summer weather – these also shrink forming deep and wide cracks. On subsequent wetting, it swells. This alternate swelling and shrinking/wetting or drying of clay enriched rocks make them loose and eventually breaks.

iv) Action of glaciers: In cold regions, when snow falls, it accumulates and turns into ice. Owing to continuous snowing big blocks of ice are formed. When ice is formed in mountainous regions on slopes and hill sides, it begins to move. Such a block of ice in motion is known as a **glacier**. When the glacier begins to move, they exert tremendous pressure on the rocks over which they pass and carry the loose materials (due to the cutting, crushing and grinding action of glaciers). These materials get deposited on reaching the warmer regions, where its movement stops with the melting of ice.

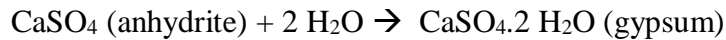
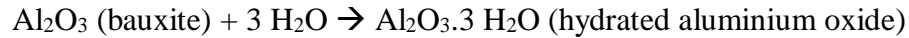
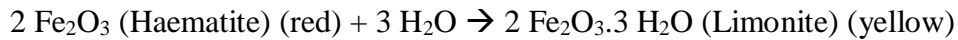
Due to the continuous action of the waves of the waters of the sea and ocean, the rocks on the shore get broken into pieces. These loosened pieces of rocks are lifted by waves and dashed against the rock themselves. Due to this continuous beating even some of the very hard rock crumbles to pieces.

4. Action of wind (air): Wind, an important agent of transportation of suspended particles, also exerts an abrasive action which is more pronounced during arid climates. The effect of air is partly mechanical and partly chemical. Moving air or wind has a great destructive effect on rocks. Wind has an erosive and transporting effect. Often when the wind is laden with fine material viz., fine sand, silt or clay particles, it has a serious abrasive effect and the sand laden winds itch the rocks and ultimately breaks down under its force. The dust storm may transport tons of material from one place to another. The shifting of soil causes wind erosion problem and may render cultivated land as degraded e.g., Rajasthan deserts.

5. Atmospheric electrical phenomenon: It is an important factor causing break down during rainy season and lightning breaks up rocks and or widens cracks.

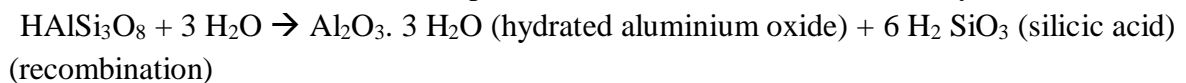
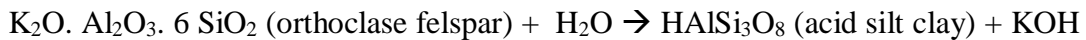
Chemical Weathering: Decomposition of rocks and minerals by various chemical processes is called weathering. It is the most important process for soil formation. It takes place mainly at the surface of rocks and minerals with disappearance of certain minerals and the formation of secondary products (new materials). This is called chemical transformation. The chemical action of water on rocks is largely due to the presence of substances that are dissolved in it. When gases like oxygen and carbon dioxide, or organic acids obtained from the decomposition of plant remains, are dissolved in it, the water readily attacks them and reduces them to fine powder. A number of chemical reactions takes place due to which the rock undergoes several changes. Some of the important reactions taking place are hydrolysis, oxidation, reduction, hydration, carbonation and solution.

1. Hydration: Chemical combination of water molecules with a particular substance or mineral leading to a change in structure. Soil forming minerals in rocks do not contain any water and they undergo hydration when exposed to humid conditions. Upon hydration there is swelling and increase in volume of minerals. The minerals lose their luster and become soft. It is one of the most common processes in nature and works with secondary minerals, such as aluminium oxide and iron oxide minerals and gypsum. When haemetite absorbs water it is changed to limonite:



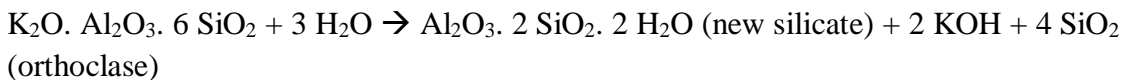
The ferrous oxide (FeO) so liberated is oxidized to ferric oxide (Fe₂O₃), which is then further hydrated to ferric hydroxide (2 Fe₂O₃ · 3 H₂O). Due to this reaction the minerals increase in volume and become soft at the same time. The rock thereupon crumbles to powder.

2. Hydrolysis: It brings about most important change during weathering of minerals. It is probably the first step in the chemical decomposition of rocks and minerals. It is due to the decomposition of H₂O into H⁺ and OH⁻ ions which chemically combine with minerals and bring about change, such as exchange, decomposition of crystalline structure and formation of new compounds. Water acts as a weak acid on silicate minerals. Many alumino-silicate minerals enter into double decomposition when they come in contact with water give rise to a hydroxide and a new alumino silicate.



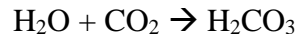
This reaction is important because of two reasons:

1. Clay, bases and silicic acid – the substance formed in this reactions – are available to plants
2. Water often containing CO₂ (absorbed from atmosphere), reacts with the minerals directly to produce insoluble clay minerals, positively charged metal ions (Ca⁺⁺, Mg⁺⁺, Na⁺, K⁺) and negatively charged ions (OH⁻, HCO₃⁻) and some soluble silica – all these ions are made available for plant growth.



3. Solution: Some substances present in the rocks are directly soluble in water. When the soluble substances are removed by the continuous action of flowing or percolating water, the rocks no longer remain solid and form holes, rills or rough surface and ultimately fall to pieces or decomposes very soon. The solvent action of water is considerably increased when it is acidulated or acidified by the dissolution of organic and inorganic acids in it e.g., halites, NaCl. Such waters dissolve not only alkali and alkaline earths but also silica.

4. Carbonation: The rain water brings with it a part of the carbon dioxide that is present in the atmosphere. When it is dissolved in water it forms carbonic acid.



This carbonic acid or carbonated water attacks many rocks and minerals and brings them into solution. The carbonated water has an etching effect upon some rocks, especially limestone (removed from parent rock). The removal of cement that holds sand particles together leads to their disintegration.

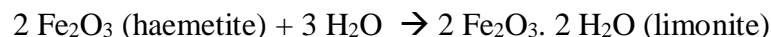
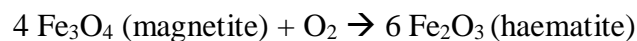
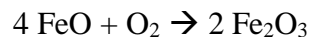
CaCO_3 (limestone) + $\text{H}_2\text{CO}_3 \rightarrow \text{Ca}(\text{HCO}_3)_2$ (calcite- slightly soluble to Ca bicarbonate- readily soluble)

It also attacks the insoluble silicate minerals like feldspar, mica, hornblende, etc., and converts them into simple silicates liberating carbonates of alkali and alkaline earth as under:

$\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6 \text{SiO}_2$ (felspar) + $2 \text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{Al}_2\text{O}_3 \cdot 2 \text{SiO}_2 \cdot 2 \text{H}_2\text{O}$ (kaoline) + $\text{K}_2\text{CO}_3 + 4 \text{SiO}_2$

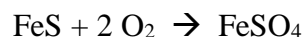
$\text{K}_2\text{O} \cdot 3 \text{Al}_2\text{O}_3 \cdot 6 \text{SiO}_2 \cdot 2\text{H}_2\text{O}$ (muscovite) + $2 \text{H}_2\text{O} + \text{CO}_2 \rightarrow 3 (\text{Al}_2\text{O}_3 \cdot 2 \text{SiO}_2 \cdot 2 \text{H}_2\text{O})$ (kaoline) + K_2CO_3

5. Oxidation: The process of addition and combination of oxygen to minerals. Oxygen, in the presence of water in atmosphere, is capable of converting many minerals into oxides. The oxides are further converted to hydroxides. Oxidation is usually restricted to the surface of the rock. It is particularly noticeable in those rocks that contain iron. Rocks containing minerals like biotite, amphiboles, pyroxenes, etc., are particularly affected (mineral containing Fe and Mg). Ferrous oxide liberated during the weathering of these minerals is immediately oxidized to ferric oxide:



The phenomenon is very similar to the rusting of iron. A rusty-looking crust is very often formed on the surface of the rock. The crust thickens and then slowly gets separated from the parent rock. The rock changes its colour and becomes red due to the formation of iron oxide. Oxidation also brings about an increase in the bulk of the minerals so acted upon. As the process continues, the changes produced in the mineral weakens the rock, and ultimately the rock itself crumbles to pieces.

Another change due to the presence of oxygen in water is the conversion of sulphides to sulphates. Iron sulphide is changed to sulphate of iron:



The conversion of sulphides into sulphates is attended by an increase in volume which helps to disintegrate the minerals. The sulphates, being soluble, are removed in solution. This helps further to loosen the rock.

6. Reduction: The process of removal of oxygen and is the reverse of oxidation and is equally important in changing soil colour to grey, blue or green as ferric iron is converted to ferrous iron compounds. This action occurs in places which are not properly drained, or where there is an accumulation of organic matter. Some of the higher oxides are thereby reduced to lower oxides:



Very often such a reaction is attended by the development of a blue or green colour. Similarly, other oxides and even some salts like sulphates are reduced by the withdrawal of oxygen. This reaction is not very important from the point of view of soil formation.

Biological weathering: Unlike physical and chemical weathering, the biological or living agents are responsible for both decomposition and disintegration of rocks and minerals. The biological life is mainly controlled largely by the prevailing environment. Joffe states: There is no biological weathering. Essentially it is physical and chemical weathering by biological agencies.

1. Effect of man and animals: The **action of man** in disintegration of rocks is well known as he **cuts rocks** to build dams, channels, construct roads play ground and buildings. All these activities result in increasing the surface area of the rocks for attack of chemical agents and accelerate the process of rock decomposition.

A large number of **animals and birds**, by their activities they **make holes** in them and thus aid for weathering. Like **rats, rabbits**, etc., which **burrow in the ground, dig out large quantities of the partially decomposed rock** from below and expose it to the atmosphere. The material so dug out gets thereby more easily and rapidly decomposed. The burrows opened by these animals serve as tunnels or passages through which more water and air penetrates into the lower layers. This brings about the disintegration and decomposition of the rocky material in the interior. The **smaller animals like insects, worms**, etc., also possess great destructive powers. **Earthworms and certain types of marine animals pass great quantities of soil or mud through their bodies** (alimentary canal) due to which the particles are pulverized.

2. Effect of higher plants and roots: The effect of vegetation on the weathering of rocks is **both physical and chemical**. The **roots of trees and other plants penetrate into the joints and crevices of the rocks**. As they grew, they exert a great disruptive force and hard rock may break apart. E.g., papal tree growing on walls/rocks.

3. Effect of micro organisms: In early stages of mineral decomposition and soil formation, **the lower forms of plants and animals like mosses, bacteria and fungi and actinomycetes** play an important role. They **extract nutrients from the rock and N from air and live with a small quantity of water**. In due course of time, the soil develops under the cluster of these micro organisms.

These organisms closely associated with the decay of plant and animal remains and thus liberate nutrients for the use of next generation plants and also produce CO₂ and organic compounds which aid in mineral decomposition.

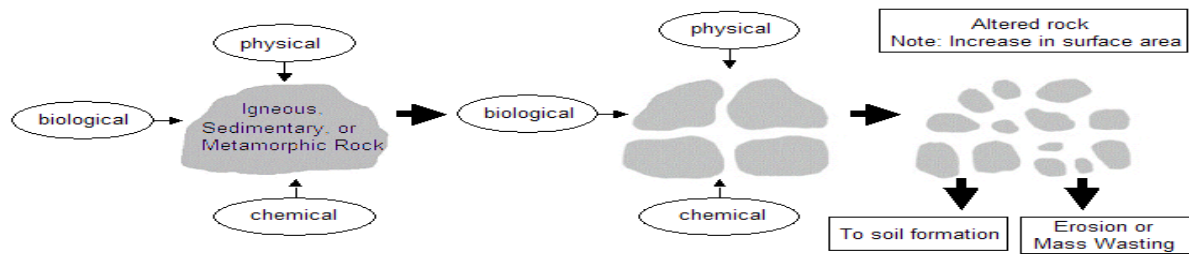


Fig:1 Weathering process

Weathering Sequence: Quartz (most resistant) > muscovite, K-feldspars > Na and Ca-feldspars > biotite, hornblende and augite > olivine > dolomite and calcite > gypsum (Least resistant)

Soil Formation

Soil formation is a very slow process, particularly sensitive to climatic conditions and to the weathering susceptibility of the parent rocks.

Soil formation – factors and processes

The conversion of rocks into soil is known as **soil formation**. The soil formation is the process of two consecutive stages.

1. The weathering of rock (R) into Regolith
2. The formation of true soil from Regolith

The evolution of true soil from regolith takes place by the combined action of soil forming factors and processes.

1. The 1st step is accomplished by weathering (disintegration & decomposition)
2. The 2nd step is associated with the action of soil forming factors



Dokuchaiev (1889) established that the soils develop as a result of the action of soil forming factors.

$$S = f(P, Cl, O)$$

Further, **Jenny (1941)** formulated the following equation

$$S = f(Cl, O, R, P, T, \dots)$$

Where,

- Cl – environmental climate
- O – organisms and vegetation (biosphere)
- R – Relief or topography
- P – parent material
- T – time
- – additional unspecified factors

The **five soil forming factors**, acting simultaneously at any point on the surface of the earth, to produce soil are grouped in two.

1. Passive: i) parent material ii) relief iii) time
2. Active: i) climate ii) vegetation and organism

A. Passive soil forming factors: Are those which represent the source of soil forming mass and conditions affecting it. These provide a base on which the active soil forming factors work or act for the development of soil.

(i) **Parent material:** It is the mass (the unconsolidated material) from which the soil has formed. There are two groups of parent material i.e. sedentary (formed in original place and is residual parent material, they differ as widely as rocks) and transported (The parent material transported from their place of origin, and are named according to the main force responsible for the transport and redeposition). **By gravity** – colluvial; **by water** – alluvial, marine, locustrine; **by ice** – glacial; **by wind** – eolian.

Colluvium – It is the poorly sorted materials near the base of strong slopes transported by the action of gravity.

Alluvium – The material transported and deposited by water is, found along major stream courses at the bottom of slopes of mountains and along small streams flowing out of drainage basins.

Lustrine – Consists of materials that have settled out of the quiet water of lakes.

Moraine – Consists of all the materials picked up, mixed, disintegrated, transported and deposited through the action of glacial ice or of water resulting primarily from melting of glaciers.

Loess or Aeolian – These are the windblown materials. When the texture is silty – loess; when it is sand.

Eolian – The soil developed on such transported parent materials bear the name of the parent material; viz., alluvial soils from alluvium, colluvial soils from colluviums etc. In the initial stages, however, the soil properties are mainly determined by the kind of parent material.

Endodynamomorphic soils: Soil formed under the condition where the influence of the parent material is supreme are known as **endodynamomorphic soils**. With advanced development and excessive leaching, the influence of parent material on soil characteristics gradually diminishes. There are soils wherein the composition of parent material subdues the effect of climate and vegetation. These soils are temporary and persist only until the chemical decomposition becomes active under the influence of climate and vegetation.

Ectodynamomorphic soils: Soil formed under the influence of climate and vegetation is predominant and has obliterated the effect of the parent material. Development of normal profile under the influence of climate and vegetation.

Soil properties as influenced by parent material: Different parent materials affect profile development and produce different soils, especially in the initial stages.

Acid igneous rocks (like granite, rhyolite) produce light textured soils (**Alfisols**)

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

Basic alluvium or Aeolian materials produce fine to coarse textured soils (**Entisols** or **Inceptisols**).

The nature of the elements released during the decaying of rocks has a specific role in soil formation. (e.g.) **Si** and **Al** forms the skeleton for the production of secondary clay minerals.

Iron and manganese are important for imparting red colour to soils and for oxidation and reduction phenomenon.

Sodium and potassium are important dispersing agents for clay and humus colloids.

Calcium and magnesium have a flocculating effect and result in favorable and stable soil structure for plant growth.

(ii) **Relief or Topography:** The relief or topography of a land may hasten or delay the work of climatic forces according to its nature. A hilly or mountainous topography is called macro-topography. It is conducive to endo-dynamomorphism. Erosion, thus, interferes with the

development and formation of a distinct soil profile as it removes from the slope some of the products of weathering. Therefore, the soil remains immature or young (underdeveloped). In smooth flat countries soil profile development occurs completely resulting in a well developed and mature soil. Soils containing large stones, boulders, etc., are called skeletal soils. Thus, topography of a land may hasten or delay the work of the climatic factors according to its nature.

Land Surface	with slopes of
Flat to almost flat	0 – 2 %
Gently undulating	2 – 5 %
Undulating	5 – 10 %
Rolling	10 – 15 %
Hilly	15 – 30 %
Steeply dissect	> 30 % with moderate range of elevation (<300m)
Mountainous	> 30 % with great range of elevation (>300m)

- **Milne (1935) introduced the term catena which refers to a sequence of topographically related soils which have comparable parent material, climate and age but show different characteristics owing to variation in relief and drainage.**

(iii) Time: The actual length of time during which the materials are subjected to development plays an important role in soil formation. Mature soils are formed due to principal factors acting for a longer period of time than in young soils. Sometimes in spite of a longer period of time soils remain young. Therefore, the age of the soil is judged in terms of maturity stage of development of the profile rather than geological age of the parent material. Intense above the water table, red and yellow hydrous oxide clays are finally formed. Naturally **calcium carbonate is absent and iron concretions are found indicating the translocation of the sesquioxide.** Where drainage is not satisfactory, **soft deposits of these compounds occur at or near the water table.** In some countries these are cut in convenient sized blocks which harden on drying and are used as excellent building material.

The process of laterisation is so intense and leaching so thorough that hydrous oxide clays that develop are very low in exchangeable bases.

B. Active soil forming factors: Are those which supply energy that acts on the mass for the purpose of soil formation. These factors are climate and vegetation (biosphere).

(i) Climate: It is the most influential/significant of all the soil forming factors. It affects soil formation both directly and indirectly. **Climate is determined by precipitation (rainfall) and temperature.** Thus, climate supplies water and heat to react with the parent material and affects soil formation directly. Indirectly climate affects the biosphere (fauna and flora) which furnishes organic matter which is the source of energy. Organic matter decomposes and releases acids and salts which act on rocks and minerals.

Precipitation affects percolation and leaching, which in turn affects soil formation. Percolating water is responsible for solution and translocation of constituents of the parent material and their

deposition at another point. Thus rainfall brings about a redistribution of substances both soluble as well as in suspension in soil body.

Temperature in arctic and subarctic regions is a negative factor in soil formation. Due to the low temperatures, there is no percolation during the long winter or even during summer. In **arid regions** also there is low percolation due to higher evaporation. In **subarctic (cold temperature) regions and in high mountain countries** which have long winters, percolation through the profile is low so that lakes, swamps, peat and muck deposits are formed. Organic matter accumulation also occurs due to restricted microbial activity at low temperatures. Thus the organic matter layer (A_0) in such region is extensive, peat is formed and no soil body forms under peat. In **humid tropics and subtropics** there is luxuriant vegetation and decomposition of plant residues which result in very little organic matter accumulation in the A_0 layer excepting in areas having anaerobic conditions.

Jenny (1941) computed that in the tropical regions the rate of weathering proceeds three times faster than in temperate regions and nine times faster than in arctic.

(ii) Organisms and vegetation: Plant, animals, microorganisms and man are active components of ecosystem. The role of microorganisms in soil formation is related to the humification and mineralization of vegetation. The action of animals especially burrowing animals to dig and mix-up the soil mass and thus disturbs the parent material. The man influences the soil formation through his manipulation of natural vegetation, agricultural practices etc. Compaction by traffic of man and animals decrease the rate of water infiltration into the soil and thereby increase the rate of runoff and erosion.

The roots of the plants penetrate into the parent material and act both mechanically as well as chemically. They facilitate percolation and drainage and bring about greater dissolution of minerals through the action of carbon dioxide and acidic substances secreted by them. The decomposition and humification of the materials further add to the solubilization of minerals. Forests – reduces temperature, increases humidity, reduce evaporation and increases precipitation. Grasses reduce runoff and result greater penetration of water in to the parent material.

Fundamental soil forming processes

The pedogenic processes, although slow in terms of human life, yet work faster than the geological processes in changing lifeless parent material into true soil full of life.

- The pedogenic processes are extremely complex and dynamic involving many chemical and biological reactions, and usually operate simultaneously in a given area.
- One process may counteract another, or two different processes may work simultaneously to achieve the same result.
- Different processes or combination of processes operate under varying natural environment.

The collective interaction of various soil forming factors under different environmental conditions set a course to certain recognized soil forming processes. The basic process involved in soil formation (Simonsen, 1959) includes the following:

- Gains or additions of water, mostly as rainfall, organic and mineral matter to the soil.
- Losses of the above materials from the soil.
- Transformation of mineral and organic substances within the soil.
- Translocation or the movement of soil materials from one point to another within the soil.
It is usually divided into: a) movement of solution (leaching) and b) movement of suspension (eluviation) of clay, organic matter and hydrous oxides.

Humification: The process of transformation of raw organic matter into humus, which is extremely complex process involving various organism. Initially, simple compounds such as sugars and starches are attacked followed by proteins and cellulose and finally very resistant compounds, such as tannins, are decomposed and the dark coloured substance known as **humus** is formed.

Eluviation: It is the mobilization and translocation of certain constituents viz., clay, Fe₂O₃, Al₂O₃, SiO₂, humus, CaCO₃, other salt etc. from one point of soil body to another. It means washing out. It is the process of removal of constituents in suspension or solution by the percolating water from the upper to lower layers. It encompasses mobilization and translocation of mobile constituents resulting in textural differences. The horizon formed by the process of eluviations is termed as **eluvial** horizon (**A₂** or **E** horizon). Translocation depends upon relative mobility of elements and depth of percolation.

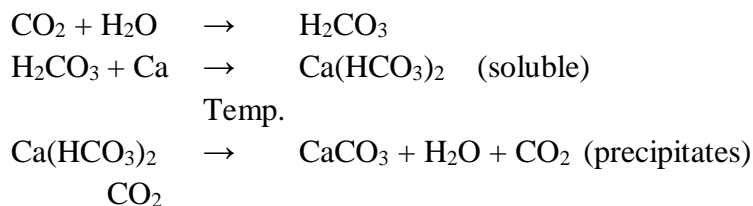
Illuviation: The process of deposition of soil materials (removed from the eluvial horizon) in the lower layer (or horizon of gains having property of stabilizing translocated clay materials). The horizon formed by this process are termed as **illuvial** horizons (**B** horizons especially **Bt**). It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

Horizonation: The process of differentiation of soil in different horizons along the depth of the soil body. The differentiation is due to the fundamental processes like humification, eluviations and illuviation.

Specific soil forming processes

The basic pedologic processes provide a framework for later operation of more specific processes.

Calcification: The process of precipitation and accumulation of calcium carbonate (CaCO₃) in some part of the profile. The accumulation of CaCO₃ may result in the development of a **calcic** horizon. Calcium is readily soluble in acid soil water and/or when CO₂ concentration is high in root zone as:



The process of precipitation after mobilization under these conditions is called **calcification** and the resulting illuviated horizon of carbonates designated as **Bk** horizon (**Bca**).

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



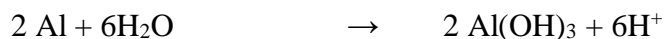
Podzolization: The process of formation of **Podzols** and **Podzolic** soils. In many respects, podzolization is the negative of calcification. The calcification process tends to concentrate/accumulate calcium in the lower part of B horizon, whereas podzolization leaches the entire solum of calcium carbonates. Apart from calcium, the other bases are also removed and the whole soil becomes distinctly acidic. In fact, the process is essentially one of acid leaching. The process operates under the following favorable environmental combinations.

i) **Climate:** A cold and humid climate is most favorable for podzolization.

ii) **Parent material:** Siliceous (sandy) material, having poor reserves of weatherable minerals, favor the operation of podzolization as it helps in easy percolation of water.

iii) **Vegetation:** Acid producing vegetation such as coniferous pines is essential.

iv) **Leaching and translocation of sesquioxide:** In the process of decomposition of organic matter various organic acids are produced which act with sesquioxide and the remaining clay minerals, forming organic – sesquioxide and organic clay complexes, which are soluble and move with the percolating water to the lower horizons (Bh, Bs). Aluminium ions in a water solution hydrolyze and make the soil solution very acidic.



As iron and aluminium move about, the A horizon gives a bleached grey or ashy appearance. The Russians used the term Pozols (pod means under the and zola means ash like i.e. ash like horizon appearing beneath the surface horizon) for such soils. To conclude, **the podzolization is a soil forming process which prevails in a cold and humid climate where coniferous and acid forming vegetations dominant. The humus and sesquioxide become mobile and leached out from the upper horizons and deposited in the lower horizon.**

Laterization: The term laterite is derived from the word later meaning brick or tile and was originally applied to a group of high clay Indian soils found in Malabar hills of Kerala, Tamilnadu, Karnataka and Maharashtra. It refers specifically to a particular cemented horizon in certain soils which when dried, become very hard, like a brick. Such soils (in tropics) when massively impregnated with sesquioxides (iron and aluminium oxides) to extent of 70 to 80 per cent of the total mass, are called **laterites** or **latosols (Oxisols)**. The soil forming process is called **Laterization** or **Latozation**. **It is the process that removes silica, instead of sesquioxides from the upper layers and thereby leaving sesquioxides to concentrate in the solum**, which operates under the following conditions.

i) **Climate:** Unlike podzolization, laterization operates most favorable in warm and humid (tropical) climate with 2000 to 2500 mm rainfall and continuous high temperature (25°C) throughout the year.

ii) **Vegetation:** the rain forests of tropical areas are favorable for the laterization process.

iii) **Parent material:** Basic parent material having sufficient iron bearing ferromagnesian minerals (pyroxene, amphiboles, biotite and chlorite), which on weathering release iron are congenial for the development of laterites.

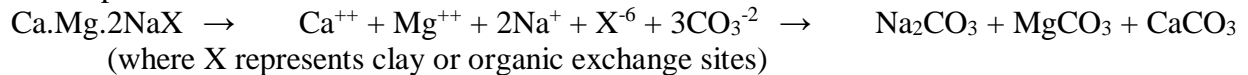
Gleization: the term *glei* is of Russian origin means blue, grey or green clay. **It is a process of soil formation resulting in the development of a glei (or gley horizon) in the lower part of the soil profile above the parent material due to poor drainage condition (lack of oxygen)**

and where waterlogged conditions prevail. Such soils are called **hydro orphic** soils. The process is not particularly dependent on climate (high rainfall as in humid regions) but often on drainage conditions. The poor drainage conditions result from: a) lower topographic position, such as depression land where water stands continuously at or close to the surface b) impervious soil parent material, and c) lack of aeration. Under such conditions, iron compounds are reduced to soluble ferrous forms. The reduction of iron is primarily biological and requires both organic matter and microorganisms capable of respiring anaerobically. The solubility of Ca, Mg, Fe and Mn is increased and most of the iron exists as Fe^{++} organo – complexes in solution or as mixed precipitate of ferric and ferrous hydroxides. This is responsible for the production of typical bluish to grayish horizon with mottling of yellow and/or reddish brown colours.

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

Desalinization: It is the removal by leaching of excess soluble salts from horizons or soil profile (that contained enough soluble salts to impair the plant growth) by ponding water and improving the drainage conditions by installing artificial drainage network.

Solonization or Alkalinization: The process involves accumulation of sodium ions on the exchange complex of the clay, resulting in the formation of sodic soils (solonetz). All cations in solution are engaged in a reversible reaction with the exchange sites on the clay and organic matter particles.



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



Pedoturbation: It is the process of mixing of the soil. Mixing to a certain extent takes place in all soils. The most common types of pedoturbation are: a) **Fenual pedoturbation:** It is the mixing of soil by animals such as ants, earthworms, moles, rodents, and man himself b) **Floral pedoturbation:** It is the mixing of soil by plants as in tree tipping that forms pits and mounds c) **Argillic pedoturbation:** It is the mixing of materials in the solum by the churning process caused by swell shrink clays as observed in deep black cotton soils.

Soil Structure – Classification

Soil conditions and characteristics such as water movement, heat transfer, aeration, and porosity are much influenced by structure. In fact, the physical changes imposed by the farmers in ploughing, cultivating, draining, liming, and manuring his land are structural rather than textural.

Arrangement and organization of primary and secondary particles in a soil mass is known as soil structure. While texture is of great importance in determining the relationship that exists between soil water and plant, structure has a great bearing on the soil-air-water system. It controls the amount of water and air present in soil. Plants are able to utilize nutrients only if there is a sufficient supply of water in the soil. Plant roots and germinating seeds require sufficient air and oxygen for respiration. Bacterial activities also depend upon the supply of water and air in the soil. The presence of abundant nutrients in the soil is not sufficient to ensure proper crop growth and high yields unless an optimum air-water-nutrient relationship is maintained by providing proper soil structure.

Formation of soil structure (Aggregation): Soil particles may be present either as single individual grains or as aggregates, i.e., groups of particles bound together into granules or compound particles. A majority of particles in a sandy or silty soil are present as single individual grains, while in a clayey soil they are present in a granulated condition in the form of aggregates, or **compound** or **secondary** particles. Soils in which single grain particles predominant are said to be **structureless**, while those which possess a majority of compound particles are said to have an **aggregate, granulated, or crumb structure**.

Mechanism of Aggregate Formation: The bonding of soil particles into structural unit is the genesis of soil structure. The bonding between individual particles in the structural units is generally considered to be stronger than the structural unit themselves.

In aggregate formation, a number of primary particles such as sand, silt and clay are brought together by the cementing or binding effect of soil colloids. The cementing materials taking part in aggregate formation are colloidal clay, iron and aluminium hydroxides and decomposing organic matter. Whatever may be the cementing agents, it is ultimately the dehydration of colloidal matter accompanied with pressure that completes the process of aggregation.

Colloidal Clay: The mineral colloids, i.e., the clay particles themselves, by virtue of their properties of adhesion and cohesion, stick together to form aggregates. Colloidal particles form aggregates only if they are flocculated. There is a vast difference between flocculation from the purely colloidal point of view and aggregation from the stand point of structure. Though both lead to the formation of compound particles, they are two separate processes. While flocculation is brought about by the coalescence of colloidal particles, aggregation requires the cementation of flocculated particles. Flocculation is the first step in the process of aggregate formation. Aggregation is, therefore, something more than flocculation involving a combination of different factors such as hydration, pressure, dehydration, etc. Flocculation not only proceeds aggregation but also helps the formation of stable aggregates. The cementation may be caused by cations, oxides of Fe and Al, humus substances and products of microbial excretion and synthesis. Clay

particles form aggregates only if they are wetted by a liquid like water whose molecules possess an appreciable dipole moment.



The aggregation also depends upon the nature of clay particles, size and amount of clay particles, dehydration of clay particles, cations like Ca and anions like phosphates.

Fe and Al oxides: The colloidal Fe oxide acts as cementing agent in aggregation. Al oxides bind the sand and silt particles. These act in two ways. A part of hydroxides acts as a flocculating agent and the rest as a cementing agent.

Organic matter: It also plays an important role in forming soil aggregation.

- During decomposition, cellulosic substances produce a sticky material very much resembling mucus or mucilage. The sticky property may be due to the presence of humic or humic acid or related compounds produced.
- Certain polysaccharides formed during decomposition.
- Some fungi and bacteria have cementing effect probably due to the presence of slimes and gums on the surface of the living organisms produced as a result of the microbial activity.

Classification: The primary particles – sand, silt and clay – usually occur grouped together in the form of aggregates. Natural aggregates are called **peds** where as **clod** is an artificially formed soil mass. Structure is studied in the field under natural conditions and it is described under three categories.

- 1 Type – shape or form and arrangement pattern of peds
- 2 Class – size of peds
- 3 Grade – degree of distinctness of peds

Type of Soil Structure: There are **four principal forms** of soil structure are as follows:-

Plate like (platy) structure: In this type, the aggregates are arranged in relatively thin horizontal plates or leaflets. The horizontal axis or dimensions are larger than the vertical axis. When the units/layers are **thick**, they are called **platy**. When they are **thin**, then it is **laminar**. Platy structure is most noticeable in the surface layers of virgin soils but may be present in the subsoil. This type is inherited from the parent material, especially by the action of water or ice.

Prism like structure: In this type, the vertical axis is more developed than horizontal axis, giving a pillar like shape which varies from 1 to 10 cm in length. Commonly occur in subsoil horizons of arid and semi arid regions. When the **tops are rounded**, the structure is termed as **columnar** but when the **tops are flat/plane, level and clear cut**, the structure is termed as **prismatic**.

Block like structure: In this type, all three dimensions are about the same size. The aggregate have been reduced to blocks. Irregularly, six faced with three dimensions more or less equal. When the **faces are flat and distinct and the edges are sharp angular**, the structure is named as **angular blocky** and when **the faces and edges are mainly rounded** it is called **sub angular blocky**. This type usually are confined to the subsoil and characteristics have much to do with soil drainage, aeration and root penetration.

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

Classes of structure: Each primary structural type of soil is differentiated into **five size classes** depending upon the size of the individual peds. The term commonly used for the size classes are: 1. Very fine or very thin; 2. Fine or thin; 3. Medium; 4. Coarse or thick; 5. Very coarse or very thick. The terms **thin and thick are used for platy types**, while the terms **fine and coarse are used for other structural types**.

Grades of structure: It indicates the degree of distinctness of the individual peds. It is determined by the stability of the aggregates. Grade of structure is influenced by the moisture content of the soil. It also depends on organic matter, texture etc. **Four terms commonly used to describe the grade of soil structure** are:

- 1. Structureless:** There is no noticeable aggregation, such as conditions exhibited by loose sand.
- 2. Weak structure:** Poorly formed, indistinct formation of peds, which are not durable and much un aggregated material.
- 3. Moderate structure:** Moderately well developed peds, which are fairly durable and distinct.
- 4. Strong structure:** Very well formed peds, which are quite durable and distinct.

For naming a soil structure the sequence followed is grade, class and type: for example strong coarse angular blocky, moderate thin platy, weak fine prismatic etc.

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

- 1. Climate:** It has considerable influence on the degree of aggregation as well as on the type of structure. In arid regions, there is very little aggregation of primary particles. In semi arid regions, the degree of aggregation is greater.
- 2. Organic matter:** It improves the structure of a sandy soil as well as of a clay soil. In case of a sandy soil, the sticky and slimy material produced by the decomposing organic matter and the associated microorganisms cement the sand particles together to form aggregates. In case of clayey soil, it modifies the properties of clay by reducing its cohesiveness. This helps making clay more crumbly.
- 3. Tillage:** Cultivation implements breakdown the large clods into smaller fragments and aggregates. For obtaining good granular and crumbly structure, optimum moisture content in the soil is necessary. If the moisture content is too high it will form large clods on drying. If it is too low some of the existing aggregates will be broken down.
- 4. Plants, roots and residues:** Excretion of gelatinous organic compounds and exudates from roots serve as a link. Root hairs make soil particles to cling together – Grass and cereal roots Vs other roots

Pressure exerted by the roots also held the particles together

Dehydration of soil – strains the soil due to shrinkage – result in cracks – lead to aggregation

Plant tops and residues – shade the soil – prevent it from extreme and sudden temperature and moisture changes and also from rain drop impedence.

Plant residues – serve as a food to microbes – which are the prime aggregation builders.

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

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

7. Fertilizers: Fertilizers like Sodium nitrate destroys granulation by reducing the stability of aggregates. Few fertilizers for example, CAN help in development of good structure.

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

9. Exchangeable cations:

Ca, Mg -----	H, Na
Flocculating	Deflocculating
Good structure	Poor structure

10. Inorganic cements: CaCO_3 and sesquioxides

11. Clay

12. Water

Effect of soil structure on other physical properties:

Porosity – Porosity of a soil is easily changed. In plate like structure, pore spaces are less where as in crumby structure pore spaces are more.

Temperature – Crumby structure provides good aeration and percolation of water in soil. Thus these characteristics help in keeping optimum temperature in comparison to plate like structure.

Density – Bulk density varies with the total pore space present in the soil. Structure mainly influences pore spaces. Platy structure with less total pore spaces has high bulk density where as crumby structure with more total pore spaces has low bulk density.

Consistence - Consistence of soil also depends on structure. Plate like structure exhibits strong plasticity.

Colour - Bluish and greenish colors of soil are generally due to poor drainage of soil. Platy structure normally hinders free drainage.

Importance of Soil Structure: It influence rather indirectly by the formation of an array of pores of various shapes and sizes. These pores are controlling factors governing water, air and temperature in soil.

Role of Soil Structure in relation to Plant growth:

- It influences the amount and nature of porosity.

- It controls the amount of water and air present in the soil and their movement and circulation too.
- It affects tillage practices.
- It controls runoff and erosion.
- Platy structure normally hinders free drainage whereas sphere like structure (granular and crumby) helps in drainage.
- Crumby and granular structure provides optimum infiltration, water holding capacity, aeration and drainage. It also provides good habitat for microorganisms and supply of nutrients.

Table 10: Class of Soil Structure as differentiated by size of soil peds

Class	Platy	Prismatic	Columnar	Blocky	S A Blocky	Granular	Crumb
V fine/V thin	< 1	<10	< 10	< 5	< 5	< 1	< 1
Fine/thin	1-2	10-20	10-20	5-10	5-10	1-2	1-2
Medium	2-5	20-50	20-50	10-20	10-20	2-5	2-5
Coarser thick	5-10	50-100	50-100	20-50	20-50	5-10	-
V coarse/V thick	> 10	> 100	> 100	> 50	> 50	> 10	-

Soil Aggregates

Soil aggregates are clumps of soil particles that are held together by moist clay, organic matter, organic compounds (from bacteria and fungi) and by fungal hyphae. The spaces, or pores, within and between soil aggregates are essential for storing air and water, microbes, nutrients and organic matter. Soils with many aggregates are known as well aggregated. Such soils are more stable and less susceptible to erosion.

Bacteria involved in soil aggregation in two ways: first by producing organic compounds called polysaccharides which are more stable than plant polysaccharides, resisting decomposition long enough to be involved in holding soil particles together in aggregates. Other, by developing a small electrostatic charge that attracts the electrostatic charge on clay surfaces, bringing together small aggregates of soil.

Fungi grow in long, threadlike structures, called hyphae which enmeshing soil particles with their hyphae and forming cross-links between soil particles. Mycorrhizal fungi and fungi that colonise on fresh organic matter are believed to be the most important for assisting with stabilization of soil particles into aggregates.

The outside of soil aggregates has dark colour surface film (clay skin), which is chemical compounds originated from decomposing organic matter, synthetic soil conditioners such as *krillium* act as glues to hold the individual soil particles together to form aggregates. Besides organic matter, other gluing materials are plant roots, lime, oxides of iron and aluminium, colloidal organic matter, polyuronoides, polysaccharides. Many salts also help in flocculation. Electrochemical properties of humus and clay are effective in organization and later of stabilization of aggregates. Soil aggregation is affected by two conditions: one, those which are

responsible for soil aggregation and other, those which are responsible for giving stability to aggregates after they are formed. Both these factors operate simultaneously, therefore it becomes difficult to separate their relative effects on the development of stable granules.

Aggregate stability – some granules succumb readily to the beating of rain, ploughing, etc., whilst others resist disintegration which helps in the maintenance of suitable soil structure. Aggregate stability is directly correlated to the presence or absence of certain binding agents. Organic compounds, some kind of clay (kaolinite has better binding power than montmorillonite), iron oxide, etc., affect the stability of aggregates. In general, the presence of larger aggregates, lowers the soil stability.

Significance of soil aggregation: Crop growth is often affected by poor root development, by slow water infiltration and water movement through the soil, and by poor soil aeration. These constraints are often associated with poor soil porosity. Thus, soil aggregation is important for the development and maintenance of good soil porosity and hence to good root growth and for the movement of soil water and gases. With more soil in water stable aggregates, it is expected that: the rate of water infiltration and percolation will increase; soil crusting will be less – which improves root penetration and access to soil moisture and nutrients and emergence of seedlings; resistance to the splash effect of raindrops will increase, thereby decreasing soil erodibility; and runoff will decrease, making more water available to the crop.

Soil Consistence

Soil consistence refers to the resistance of soil material (particles) to deformation or rupture (mechanical stresses or manipulations). It depends upon the degree and kind of forces which attract one molecule to another. There are two types of forces which hold one particle to another – the forces of **adhesion** (is the force between different materials) e.g. water & soil particles and **cohesion** (is the force between similar materials) e.g. holding a solid or liquid together, which decreases with rise in temperature.

Factor affecting soil consistence:

- The size, shape and arrangement of soil particles
- The nature of water film around soil particles
- The nature and amount of organic and inorganic colloid
- The amount of moisture

The amount of moisture has an important influence on consistence. Water exhibits cohesion; as is indicated by its surface tension. Water molecules are dipolar; therefore they are also adsorbed and oriented on negatively charged soil particles. When water film around the soil particles dries, soils develop greater cohesive force and mechanical strength. The soil particles are, therefore, drawn together and get oriented. Orientation of soil particles further tightens the soil-water bond and results in shrinkage. The effect of adding water is just the reverse. When the water is added to soil particles the water layer around the soil particles thickens, the soil becomes plastic and loses its cohesion and finally resembles a fluid in mechanical properties.

Soil consistence is described in three moisture levels viz., wet, moist and dry.

Wet soils: Consistency is described by terms stickiness and plasticity.

Stickiness – is grouped into four categories: **non sticky; slight sticky; sticky & very sticky**

Plasticity – It is the capacity of a soil to be moulded (to change its shape depending on stress) and to retain the shape even when the stress is removed. Soils containing more than 15% clay exhibit plasticity – pliability and the capacity of being molded. Plasticity is grouped into four categories: **non plastic; slightly plastic; plastic & very plastic**.

Moist soils: Moist soil with least coherence adheres very strongly and resists crushing between the thumb and forefinger. The different categories are: **loose** (non coherent); **very friable** (coherent but very easily crushed); **friable** (easily crushed); **firm** (crush with moderate pressure); **very firm** (crush under strong pressure) and **extremely firm** (complete resistant to crushing) type and amount of clay and humus influence this consistency.

Dry soils: In the absence of moisture, the degree of resistance is related to the attraction of particles for each other. The different categories are: **loose** (non coherent); **soft** (breaks with slight pressure and becomes powder); **slightly hard** (breaks under moderate pressure); **hard** (difficulty in break with pressure); **very hard** (very resistant to pressure) and **extremely hard** (extreme resistant and cannot be broken).

Atterberg's Constants

Atterberg (1912) studied plasticity from the point of view of moisture range over which plasticity range is maintained. The constants are also known as Atterberg's limits. There are three limits namely i) shrinkage limit or lower plastic limit, ii) plastic limit and iii) liquid limit or upper plastic limit. From the upper and lower limits, plasticity number or index is calculated. Plasticity number or index is an indirect measure of the force required to mould the soil.

i) Shrinkage limit (or) lower plastic limit (SL) It is the soil moisture content below which the soil becomes friable. The maximum water content at which a reduction in moisture will not cause a decrease in the volume of the soils. This defines the arbitrary limit between solid and semi-solid states.

ii) Plastic limit (PL) Moisture content at which a soil cannot be deformed without cracking. Water content corresponding to an arbitrary limit between the plastic and semisolid states. It is the moisture content at which the soil begins to exhibit plasticity. Soil cannot be deformed without cracking. Soils should not be ploughed at moisture contents above the plastic limit.

iii) Liquid limit (or) upper plastic limit (LL) The moisture content at which soil ceases to be plastic, becomes semi-fluid and tends to flow like a liquid.

iv) Plasticity number The difference between the moisture content (consistency) of upper and lower plastic limits.

Factors affecting Atterberg's constants

i) Clay content: Plasticity is a function of finer soil fractions and moisture content. Because of the plate like shape of clay particles and the lubricating effect of water, the fine soil fractions tend to slide over each other. High clay content increases the moisture contents of different plastic limits and increases the plasticity index / number. (Higher clay content requires more water to exhibit plasticity because of higher surface area)

ii) Nature of clay minerals: Quartz and feldspars are non plastic. Kaolinite, illite, talc, muscovite, biotite, vermiculite, montmorillonite clays are plastic.

iii) Nature of exchangeable cations: Sodium saturated soils have lower plastic limits than potassium, calcium and magnesium saturated soils.

iv) Organic matter content: Organic matter favors plasticity.

Decomposition of Soil Organic Matter and Humus Formation

Decomposition of SOM

Definition:

Breakdown of dead plant and animal material and release of inorganic nutrients

or

Decomposition is a biological breakdown and biochemical transformation of complex organic molecules of dead material into simpler organic and inorganic molecules (Juma, 1998).

The organic materials (plant and animal residues) incorporated in the soil are attacked by a variety of microbes, worms and insects in the soil if the soil is moist. Some of the constituents are decomposed very rapidly, some less readily, and others very slowly. The list of constituents in terms of ease of decomposition:

1. Sugars, starches and simple proteins Rapid Decomposition
2. Crude proteins
3. Hemicelluloses
4. Cellulose
5. Fats, waxes, resins
6. Lignins Very slow Decomposition

Decomposition Process

•Three Main Processes:

1) Assimilation Conversion of substrates materials into protoplasmic materials. E.g. OM carbon to microbial carbon. E.g. protein to microbial protein

2) Mineralization Conversion of organic substance to inorganic form. E.g. protein from OM will be converted to inorganic nitrogen in the soil.

3) Immobilization Conversion of inorganic form into organic. E.g. inorganic nitrogen from the soil converted into microbial protein.

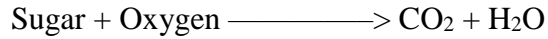
The organic matter is also classified on the basis of their rate of decomposition

Rapidly decomposed: Sugars, starches, proteins etc

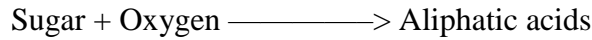
Less rapidly decomposed: Hemicelluloses, celluloses etc

Very slowly decomposed: Fats, waxes, resins, lignins etc

A. Decomposition of soluble substances: When glucose is decomposed under aerobic conditions the reaction is as under:



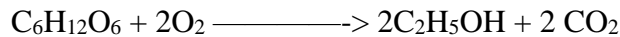
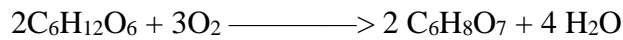
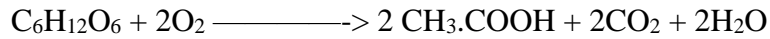
Under partially oxidized conditions,



(Acetic, formic etc.) or Hydroxy acids

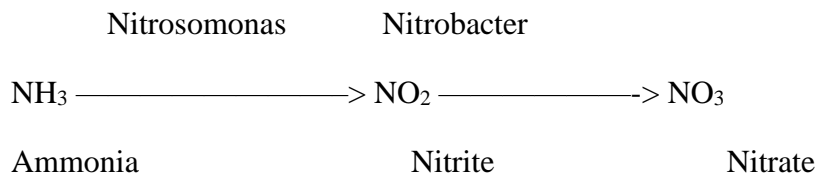
(Citric, lactic etc.) or Alcohols (ethyl alcohol etc.)

Some of the reactions invoiced may be represented as under:

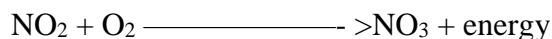
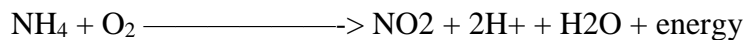


i) Ammonification: The transformation of organic nitrogenous compounds (amino acids, amides, ammonium compounds, nitrates etc.) into ammonia is called ammonification. This process occurs as a result of hydrolytic and oxidative enzymatic reaction under aerobic conditions by heterotrophic microbes.

ii) Nitrification: The process of conversion of ammonia to nitrites (NO_2) and then to nitrate (NO_3) is known as nitrification. It is an aerobic process by autotrophic bacteria.



The net reactions are as follows:



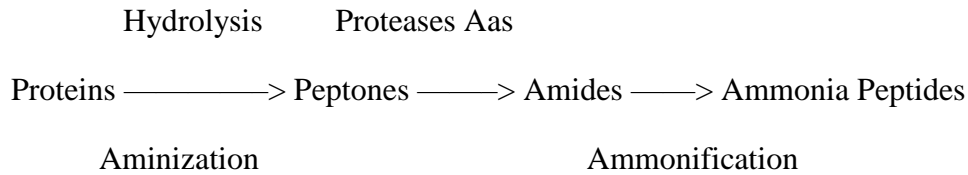
iii) Denitrification: The process, which involves conversion of soil nitrate into gaseous nitrogen or nitrous oxide, is called Denitrification. Water logging and high pH will increase N loss by Denitrification.

Pseudomonas / Bacillus

Nitrate —————> Nitrogen Gas

B. Decomposition of Insoluble Substances

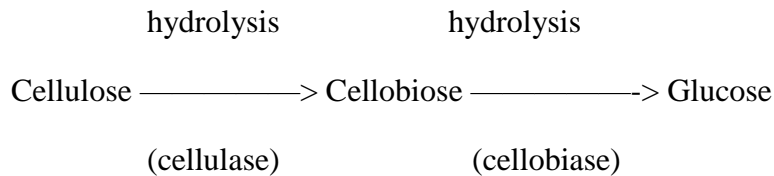
i) Breakdown of Protein: During the course of decomposition of plant materials, the proteins are first hydrolyzed to a number of intermediate products and may be represented as under:



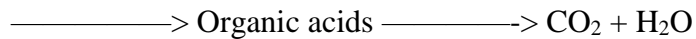
Aminization: The process of conversion of proteins to aminoacids.

Ammonification: The process of conversion of aminoacids and amides to ammonia.

ii) Breakdown of cellulose: The decomposition of the most abundant carbohydrates is as follows:



oxidation



This reaction proceeds more slowly in acid soils than in neutral and alkaline soils. It is quite rapid in well aerated soils and comparatively slow in poorly aerated soils.

iii) Breakdown of Hemicellulose: Decompose faster than cellulose and are first hydrolyzed to their components sugars and uronic acids. Sugars are attacked by microbes and are converted to organic acids, alcohols, carbon dioxide and water. The uronic acids are broken down to pentose and CO₂. The newly synthesized hemicelluloses thus form a part of the humus.

iv) Breakdown of Starch: It is chemically a glucose polymer and is first hydrolyzed to maltose by the action of amylases. Maltose is next converted to glucose by maltase. The process is represented as under:



C. Decomposition of ether soluble substances:

Fats —————> glycerol + fatty acids

Glycerol —————> CO₂ + water

D. Decomposition of lignin: Lignin decomposes slowly, much slower than cellulose. Complete oxidation gives rise to CO₂ and H₂O.

Role of organic matter:

1. Organic matter creates a granular condition of soil which maintains favorable condition of aeration and permeability.
2. Water holding capacity of soil is increased and surface runoff, erosion etc., are reduced as there is good infiltration due to the addition of organic matter.
3. Surface mulching with coarse organic matter lowers wind erosion and lowers soil temperatures in the summer and keeps the soil warmer in winter.
4. Organic matter serves as a source of energy for the microbes and as a reservoir of nutrients that are essential for plant growth and also hormones, antibiotics.
5. Fresh organic matter supplies food for earthworms, ants and rodents and makes soil P readily available in acid soils.
6. Organic acids released from decomposing organic matter help to reduce alkalinity in soils; organic acids along with released CO₂ dissolve minerals and make them more available.
7. Humus (a highly decomposed organic matter) provides a storehouse for the exchangeable and available cations.
8. It acts as a buffering agent which checks rapid chemical changes in pH and soil reaction.. It also acts as an oxidation-reduction buffer
9. Humus is an important source of nutrients for higher plants.
10. Although humus is transitional and does not remain in the soil forever, it has a certain permanency and disappears from the soil only slowly.

Humus – Fractionation of organic matter

HUMUS

Humus is a complex and rather resistant mixture of brown or dark brown amorphous and colloidal organic substance that results from microbial decomposition and synthesis and has chemical and physical properties of great significance to soils and plants. Humus is a product of the decomposition of plant and animal residues. It covers a wide variety of substances derived from the dead and decomposing bodies of all kinds of animals and plants. It is thus likely to include almost every known type of organic compound. It differs from the original plant and animal materials from which it was produced as it no longer possesses their structural form and other characteristics. It is one of the important components of all cultivated soils and is responsible to a very great extent in controlling the relations between soil condition and plant growth.

Organic matter in soil one must clearly distinguish between two main groups of organic substances which differ vitally from one another: (1) reserve organic matter or that part of soil organic matter which is still undecomposed and which, through continued biochemical

influences, is gradually changed into humus, and (2) humus, i.e., that part which is fully decomposed to the colloidal state and which is able to fulfill the important functions.

Humus Formation

The humus compounds have resulted from two general types of biochemical reactions: Decomposition and Synthesis.

1. Decomposition: a) Chemicals in the plant residues are broken down by soil microbes including lignin. b) Other simpler organic compounds that result from the breakdown take part immediately in the second of the humus-forming processes, biochemical synthesis. c) These simpler chemicals are metabolized into new compounds in the body tissue of soil microbes. d) The new compounds are subject to further modification and synthesis as the microbial tissue is subsequently attacked by other soil microbes.

2. Synthesis: Involved such breakdown products of lignin as the phenols and quinines. a) These monomers undergo polymerization by which polyphenols and polyquinones are formed. b) These high molecular weight compounds interact with N-containing amino compounds and forms a significant component of resistant humus. c) Colloidal clays encourage formation of these polymers. d) Generally two groups of compounds that collectively make up humus, the humic group and the nonhumic group.

Soil Organic Matter Fraction

- Humic matter
- Non humic matter
- When soil is extracted with alkali the humic substances go into solution. The insoluble portion forms the non humic matter.

Humic Group

- This group makes up about 60 – 80 % of the soil organic matter.
- They are most complex. They are most resistant to microbial attack.
- Humic substances have aromatic ring type structures.
- These include polyphenols and poly quinines.
- These are formed by decomposition, synthesis and polymerization.

The humic substances are classified based on resistance to degradation and solubility in acids and alkalis into

- **Fulvic Acid:** Fulvic acid lowest in molecular weight and light in color. Soluble in both acid and alkali. Most susceptible to microbial attack.
- **Humic Acid:** Medium in molecular weight and color. Soluble in alkali but insoluble in acid .It is intermediate in resistance to degradation.
- **Humin:** Highest in molecular weight, darkest in color, insoluble in both acid and alkali. Most resistant to microbial attack.

Non Humic Group

- This group makes upto 20 – 30% of the organic matter in soil.

- These are less complex and less resistant to microbial attack as compared to humic substances.
- They are polysaccharides, polymers having sugar like structures and polyuronides.
- These include proteins, carbohydrates, lignins, fats, waxes, resins, tannins and some compounds of low molecular weight.

Properties of Humus

1. The tiny colloidal particles are composed of C, H and O₂.
2. The colloidal particles are negatively charged (-OH, -COOH or phenolic groups) has very high surface area, higher CEC (150 – 300 cmol/kg), 4 – 5 times higher WHC than that of silicate clays.
3. Humus has a very favorable effect on aggregate formation and stability.
4. Impart dark brown to black colour to soils.

Cation exchange reactions are similar to those occurring with silicate clays.

Clay ----- Humus Complex

5. It has a great water absorbing and water holding capacity. One hundred parts of humus, by weight nearly 181 parts of water against 70 for clay and 25 for sand.
6. It possesses the power of adhesion and cohesion. Humus is however, much less adhesive and cohesive than clay. It is because of this property that it acts as a cementing agent in crumb formation.
7. It has a high ion adsorbing capacity, nearly four to six times that of clay. The adsorbed cations undergo base exchange as they do in the case of colloidal clay. Hence it has a high base exchange capacity. Because of the highly heterogenous nature of the material, its cation exchange capacity varies very widely, from 30 to 350 meq. per cent.
8. It is insoluble in water. It dissolves readily in dilute alkali giving a dark coloured liquid. It is re-precipitated to a large extent when the alkaline solution is neutralized with acid.
9. It behaves like a weak acid and forms salts with bases. With alkalis it forms soluble salts such as sodium and potassium humates, while with alkaline earths it forms insoluble salts. Humus is electronegative like clay acid. It is usually present in the soil in combination with bases mainly calcium forming calcium nitrate.

A simple fractionation scheme for soil organic matter or humus is depicted below

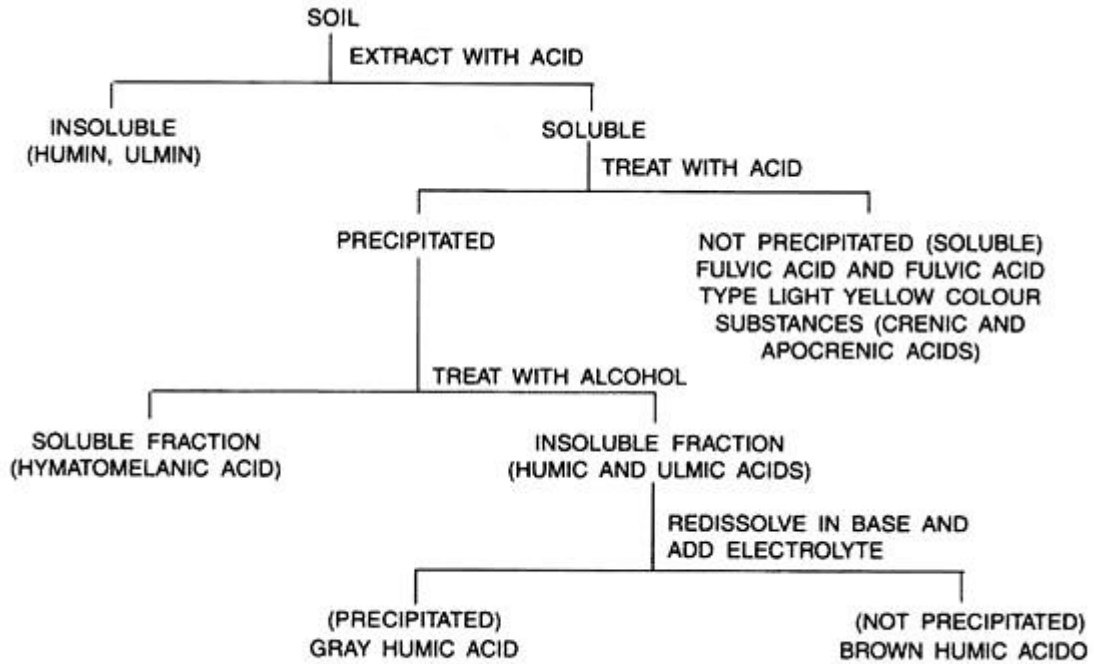


Fig. 19.5. Fractionation Scheme of Soil Organic Matter.

Biochemical Cycling of Nutrients and Organic Matter Decomposition

N- Transformation and availability in soils

N- Availability in soil.

Dynamics and transformation of nitrogen in soil is very important with respect to plant nutrition. A bulk of total N is present in the organic form (98%) and only about 2% in inorganic form. However there are continuous transformations between these two pools. The crops utilize nitrogen in the inorganic forms only such as NO_3N and NH_4N . The inorganic form of N is also liable to undergo different types of losses like runoff, ammonia volatilization, leaching, denitrification and fixation by clay minerals.

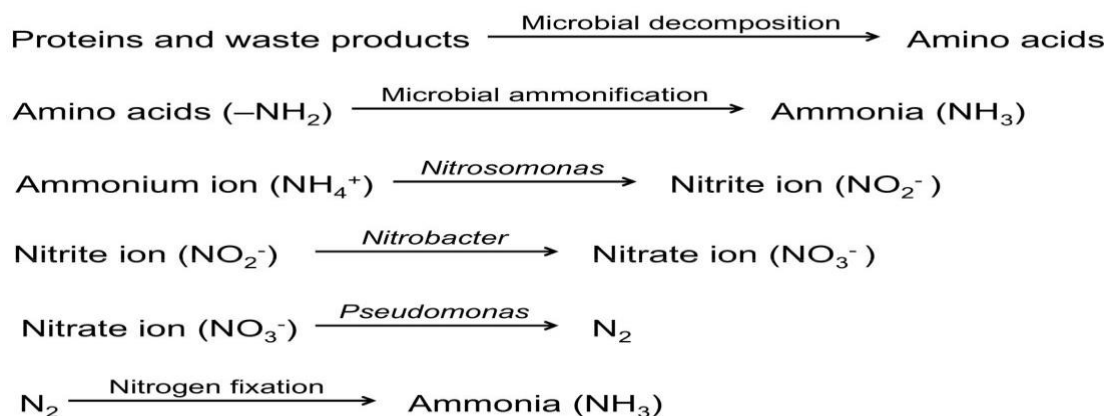
N- Transformation in soils

The Nitrogen cycle mainly includes transformations such as

1. Nitrogen mineralization : In which N containing organic complexes are decomposed and converted into inorganic compounds for use by plants

2. N immobilization : In which N containing inorganic compounds are assimilated

N_2 is acted on by certain micro organism sometimes in symbiosis with a higher plant, which can use it as a N source for growth. The process of nitrogen fixation, results in the accumulation of new organic compounds in the cells of responsible micro organisms. The N_2 thus fixed reenters general circulation when the newly formed cells are inturn mineralized. By means of these reactions the subterranean microflora regulates the supply and governs the availability and chemical nature of N in soil.



I. Nitrogen mineralization

The conversion of organic N to the more mobile, inorganic state is known as nitrogen mineralization. As a consequence of mineralization, ammonium and nitrate are generated and organic N disappears. This takes place in two distinct microbiological steps.

1. Ammonification

It is the process of mineralization in which proteins, nucleic acids and other organic components are degraded by micro organism with the eventual liberation of ammonia. This is called ammonification. A part of the liberated ammonia is assimilated by the micro organism themselves. The first step in ammonification process is the hydrolysis of proteins, nucleic acids and other organic nitrogenous compounds into amino acids (proteolysis). The amino compounds are then deaminated to yield ammonia. Ammonification usually occurs under aerobic conditions while under anerobic conditions protein decomposition leads to conversion of ammonia into amines and related compounds (eg) clostridium. The anaerobic decomposition of protein called as putrefaction. These amines are subsequently oxidized in the presence of O₂ to release ammonia.

Break down of nitrogenous substance is brought about by the activity of a multitude of microbial species.

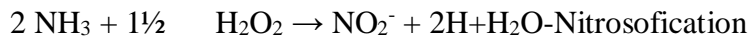
Almost all bacteria, actinomycetes and fungi can bring about proteolysis and the amino acids produced are utilized for the growth of these organisms.

(2) Nitrification

The biological oxidation of ammonium salts (in soil) to nitrites and the subsequent oxidation of nitrites to nitrates is called as nitrification. i.e. the biological conversion of N in soil from a reduced to a more oxidized state, called nitrification.

Nitrification occurs in two steps;

First ammonia is oxidized to nitrite.

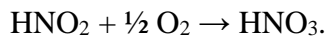


This change is brought about by chemoautotrophic bacteria of the genera *Nitrosomonas*, *Nitrosolobus*, *Nitrosococcus*, *Nitrospira*. These bacteria obtain their energy requirement by the oxidation of NH_4^+ to NO_2^- . Among the nitrifiers *Nitrosomonas* are most important in soils.

Some heterotrophs involved; *Streptomyces*, *Nocardia*

Second step

Nitrite is further oxidized to nitrate



Organisms: *Nitrobacter*, *Aspergillus*, *Penicillium*, *Cephalosporium*.

Factors influencing the growth of nitrifying bacteria in soil

Levels of ammonia and nitrite, aeration, moisture, temperature, pH and organic matter. In acid soils – nitrification is poor. Waterlogged soils – deficient in O_2 – not congenial for nitrification.

3. Denitrification

The conversion of nitrate and nitrite into molecular N_2 or nitrous oxide through microbial processes is known as denitrification. Certain bacteria are capable of using nitrate as the terminal electron acceptor under anaerobic conditions. This is called **nitrate respiration**. As a

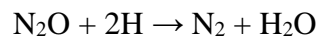
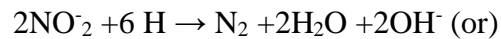
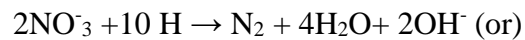
consequence of nitrate respiration, NO_3^- is reduced to N_2 gas or nitrous oxide. Denitrification leads to the loss of N from the soil. It depletes N, and therefore it is not a desirable reaction.

The escape of molecular N into the atmosphere is also known as **volatilization**.

Denitrification occurs mostly in waterlogged anaerobic soils with a high organic matter content. Denitrification of bound nitrogen to gaseous N is mediated by numerous species of bacteria, which normally use O_2 as hydrogen acceptor (aerobically) and, also use nitrates and nitrites (anaerobically).

Anaerobic conversion of nitrate into molecular nitrogen is known as nitrate respiration.

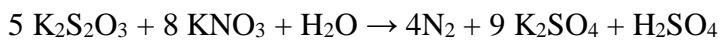
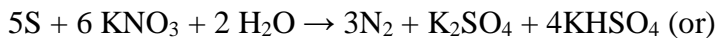
Bacterial genera which bring about denitrification *Pseudomonas, Achromobacter, Bacillus, Micrococcus*



Since nitrates are used as a source of electron acceptor, there is a net loss of N from soil. This process is termed also as **dissimilatory nitrate reduction**. Many soil bacteria like.

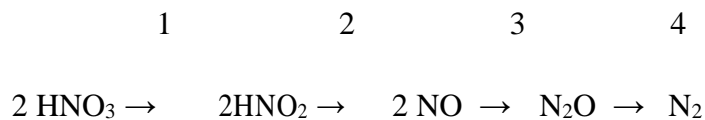
Thiobacillus denitrificans

Oxidize S (chemoautotrophically) and also reduce nitrate to nitrogen



General pathway of denitrification

Nitrate is first reduced to nitrite, which is then transformed to nitrous oxide (NO). The nitrous oxide is converted to N_2 with N_2O as an intermediate.



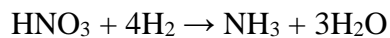
The enzymes involved

1. Nitrate reductase
2. Nitrite reductase
3. Nitric oxide reductase
4. Nitrous oxide reductase

- Fallow soils flooded with water are more congenial for denitrification than well drained and continuously cropped soils.
- Though it is a undesirable reaction in point of view of plant nutrition, but have ecological importance. Because with out denitrification the supply of N on the earth world have got depleted and NO₃ would have accumulated.
- High concentration of NO₃ are toxic, denitrification is a mechanism by which some of the N is released back to the atmosphere.

5. Nitrate reduction

The reverse of nitrification process. That is the reduction of nitrate to nitrite and then ammonia. Since organisms are able to obtain cellular Nth ammonia assimilation, the process is called as assimilatory nitrate reduction.



II. Nitrogen immobilization

The process of microbial assimilation of inorganic nitrogen is referred as immobilization. In contrast to mineralization, microbial immobilization leads to the biosynthesis of the complex molecules of microbial protoplasm from ammonium and nitrate. Immobilization results in a marked depression of nitrogen uptake by the plant.

The mineralization of organic N and the microbial assimilation of inorganic ions proceeds simultaneously. Both mineralization and immobilization take place regardless of the % of N in the organic N in organic matter. On the death of micro organism, the immobilized N is however released through mineralization. It is also a loss of nitrogen. NO₃ when accumulated in microbial protoplasm it is referred as assimilatory NO₃ reduction.

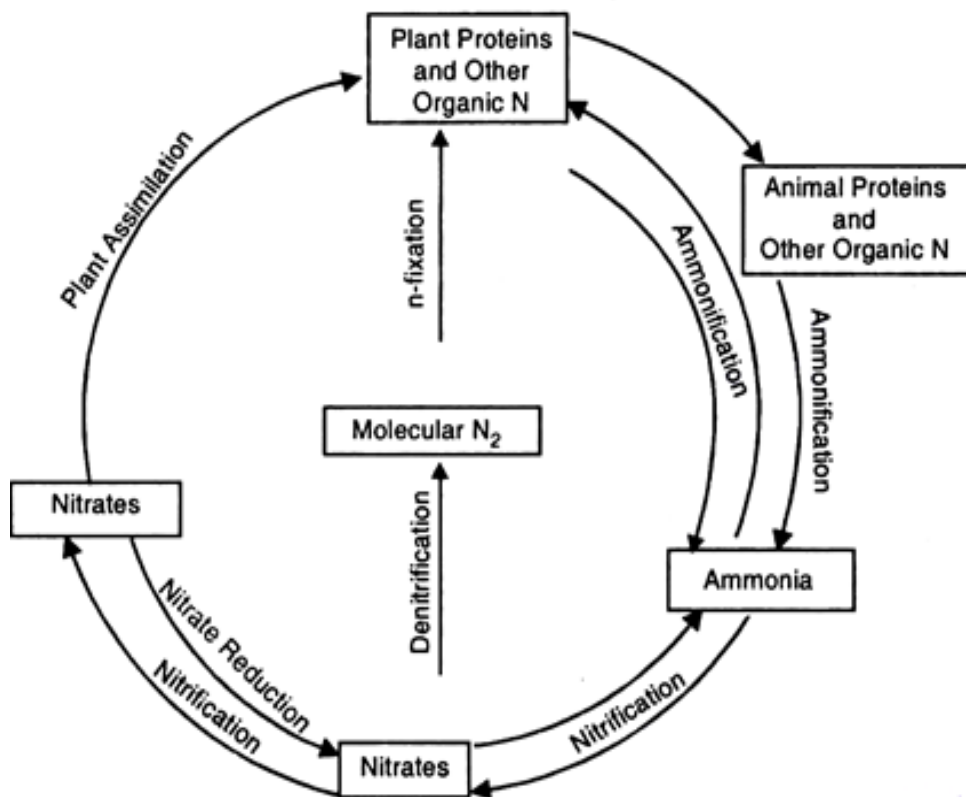


Fig. 12.11. Nitrogen cycle in ecosystem.

P- transformation in soil

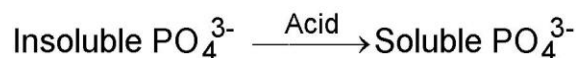
Soil P exists in various chemical forms including inorganic P (Pi) and organic P (Po). These P forms differ in their behavior and fate in soils. Pi usually accounts for 35% to 70% of total P in soil. Primary P minerals including apatites, strengite, and variscite are very stable, and the release of available P from these minerals by weathering is generally too slow to meet the crop demand though direct application of phosphate rocks (i.e. apatites) has proved relatively efficient for crop growth in acidic soils. In contrast, secondary P minerals including calcium (Ca), iron (Fe), and aluminum (Al) phosphates vary in their dissolution rates, depending on size of mineral particles and soil pH. With increasing soil pH, solubility of Fe and Al phosphates increases but solubility of Ca phosphate decreases, except for pH values above 8. The P adsorbed on various clays and Al/Fe oxides can be released by desorption reactions. All these P forms exist in complex equilibria with each other, representing from very stable, sparingly available, to plant-available P pools such as labile P and solution P.

Key Points

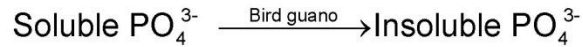
- Phosphorus in phytin, phospholipids and nucleic acids is found as phosphates
- Phytin is the calcium – magnesium salt of phytic acid
- Phospholipids are compounds in which phosphate is combined with a lipid, contained 10% of cell phosphorus.
- Inorganic polyphosphates are quite abundant in certain fungi
- In soil, from 15-85% of the total P is organic. Soils rich in organic matter contain abundant organic P.
- Ratios of organic C to P of 100 to 300:1 N: organic P = 5 to 20: 1

In cultivated soil P present in abundant about 1100 kg/ha but most of them as not available to plants; only about 1% of the total P is in available form.

PO_4^{3-} in rocks and in cells



- Acid from *Thiobacillus*



Microorganisms bring about a number of transformations of the element.

1. Altering the solubility of inorganic compounds of P
2. Mineralization of organic compounds with the release of inorganic phosphate
3. Converting the inorganic, available anion into cell components, an immobilization process (analogous to that occurring with N)
4. Bringing about an oxidation or reduction of inorganic P compounds

Particularly, important to P cycle are the microbial mineralization and immobilization reactions.

(1) Solubilization of inorganic phosphorus

Insoluble inorganic compounds of P are largely unavailable to plants, but many microorganisms can bring the PO_4 into solution. P solubilizing are 10^5 to 10^7 / g soil.

Eg: *Pseudomonas striata*, *Microoccus Bacillus sp.*, *Fusarium*, *pergillus sp*, Solubilises calcium salts, iron, aluminum, magnesium manganese phosphate.

- P is solubilized by the production of organic acids. The acids convert $\text{Ca}_3(\text{PO}_4)_2$ to di and monobasic phosphates and releases P to plants.
- Solubilization of phosphates by plant roots & micro organism is dependent on soil pH. In neutrals and alkaline soils having a content of calcium, precipitation of CaPO_4 takes place. Micro organism and plant root readily dissolve such PO_4 and make them available to plants.
- On contrary, acid soils are generally poor in Ca ions and phosphates and precipitated in the form of ferric or aluminum compounds which are not soluble. There, it is solubilized by the addition of PO_4 solublizing micro organism.
- Phosphorus exists mainly as apatides, with the basic formula $\text{M}_{10}(\text{PO}_4)_6\text{X}_2$.

Commonly the mineral (M) is Ca, less often Al or Fe. The anion (X) is either F^- or Cl^- or OH^- or CO_3^{2-} . Diverse combinations of M and X results in 200 forms of P.

(2) Mineralization of organic phosphorus

Organic form of P is the larger reservoir of P in soil. By the action of bacteria, fungi and actinomycetes, bound element in remains of the vegetation and in soil organic matter is made available to succeeding generations of plants.

Among the organic phosphorus compounds, lecithin, nucleic acids and phytin occupy a prominent place. Lecithin contains 9.39 % P_2O_5 , 1.6% N and 65.36% C.

It is a process of conversion of organic forms of phosphorus into inorganic available forms of P a highly significant correlation is observed between the rates of N and P conversion to inorganic forms.

- Mineralization is favoured by warm temperature, with the thermophilic range being more favourable than mesophilic range.
- Neutral pH increases PO_4 release, which favours microbial metabolism
- Quantity of substrate i.e. presence of organic P. If more P, more of mineralization
- Mineralization is mediated by the enzymes called phosphatases. These enzymes cleave phosphorus from more frequently encountered organic substrates.
- Phytases liberates PO_4 from phytic acid or its Ca-Mg, Salt, Phytin. They remove PO_4 -s, one at a time, yield penta – tetra, di- and mono PO_4 and then finally free inositol.
- *Bacillus*, *Pseudomonas*, *Aspergillus*, *Penicillium*, *Rhizopus* can synthesize this enzyme. Mycorrhizal (fungi) are also able to mineralize the organic forms of P and increases P uptake by the plants.

(3) Immobilization

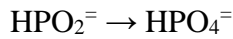
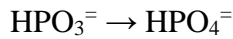
Process of assimilation of P into microbial nucleic acids, phospholipids or other protoplasmic substances is called immobilization. It leads to the accumulation of non utilizable forms of the element.

P accounts for 0.5-1.0% of fungus mycelium and 1.0 to 3.0% of the dry weight of the bacteria and actinomycetes.

(4) Oxidation reduction reactions

Biological oxidation of reduced phosphorus compounds into oxidized state.

Phosphite (HPO_3^-) is oxidized to phosphate. A number of heterotrophic (bacteria), (fungi) & (actinomycetes) utilize phosphite as sole P source. Hypophosphites (HPO_2^-) can also be oxidized to phosphate by heterotrophs.



Reductive process, reductive pathway has also been functioned. PO_4 is reduced to phosphite and hypophosphite. $\text{H}_3\text{PO}_4 \rightarrow \text{H}_3\text{PO}_3 \rightarrow \text{H}_3\text{PO}_2$

Clostridium butyricum, *E. coli* form phosphite and hypophosphite from orthophosphate. It is biochemically analogue to the process of denitirification. Only little information is available about this process.

P exist in an organic form in the protoplasm on the death of living organism, this (P) is changed to inorganic phosphoric acid. This is soon converted into insoluble salts of Ca, Fe, Mg and Al. Phosphorus thus alternates between organic and inorganic, and soluble and insoluble forms. In soluble P is solubilized by various acids produced by micro organism.

Microbial activities involved in the cycling of C, N and P are absolutely essential for maintenance of soil fertility.

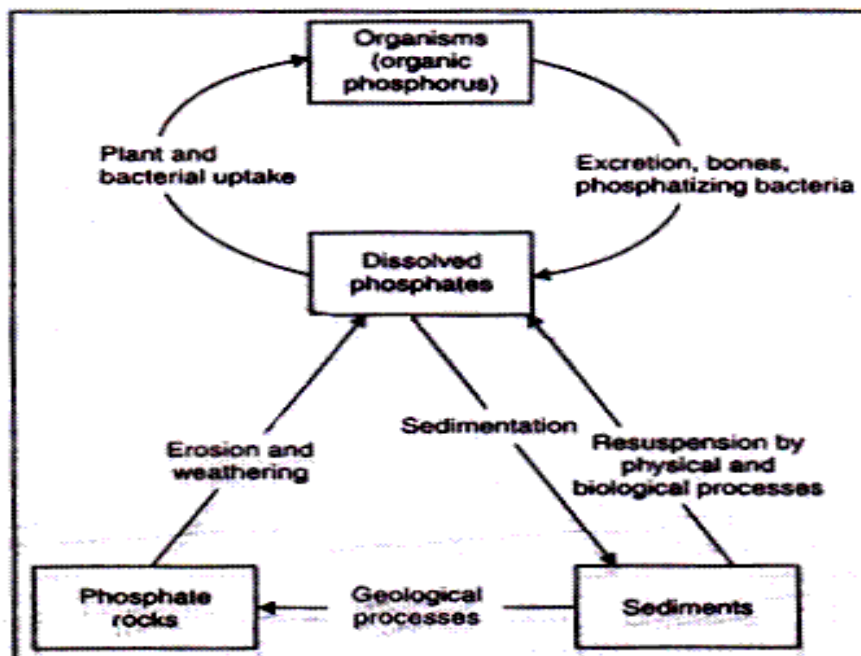
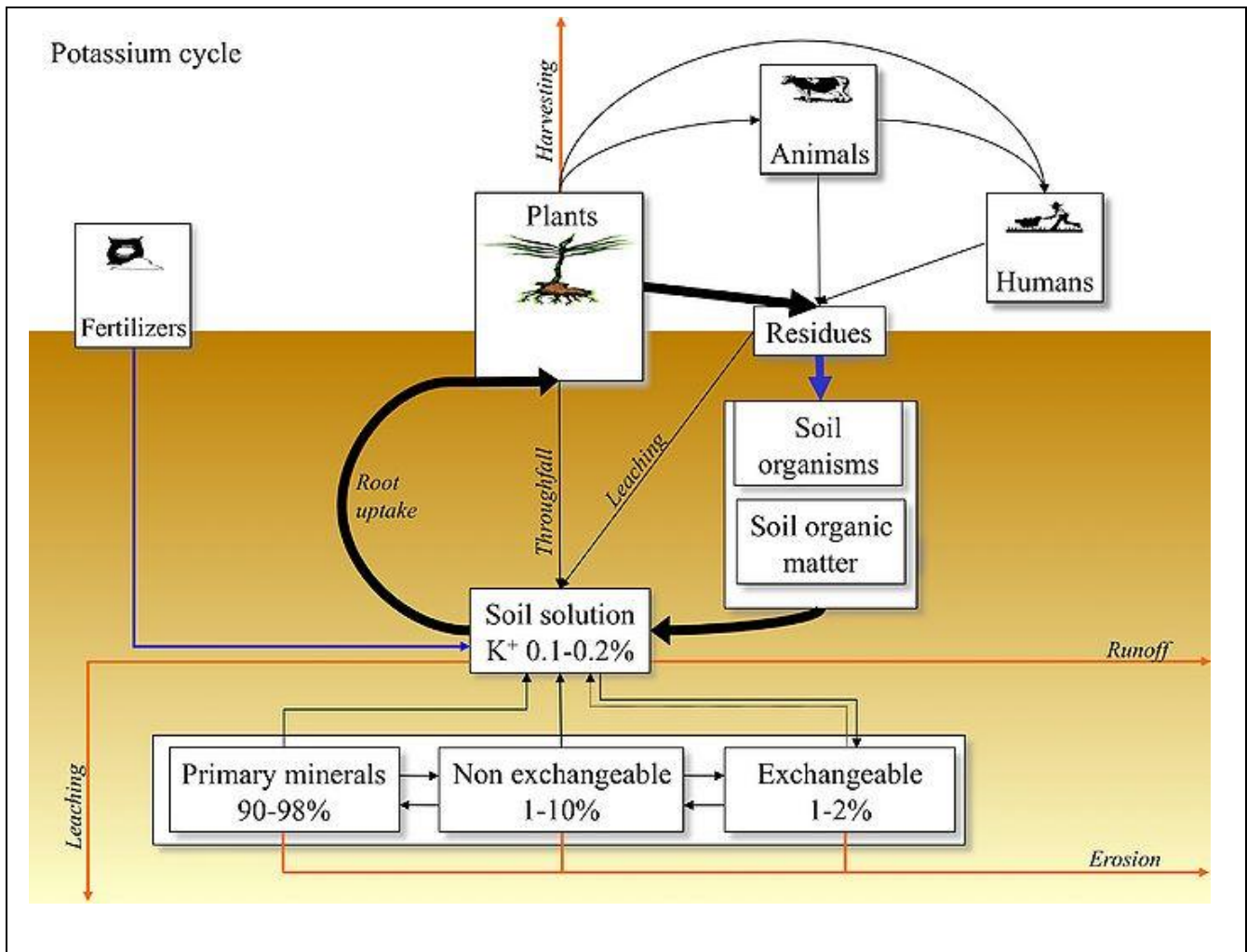


Fig. 5.9. A simplified diagram of the phosphorus cycle. (after E.P. Odum, 1993)

K-transformations & availability in soils

K- Availability in soil

Potassium is present in soil solution as K^+ ion which is readily available to plants. But this form is in dynamic equilibrium with exchangeable K which intern with fixed K. Fixed K is in equilibrium with mineral K. The available K is the solution-K and Exchangeable K which can be easily absorbed by plants.



Calcium and Magnesium availability in soils

Ca & Mg availability in soils:

Ca and Mg are the most abundant cations occupying the exchange sites of the soil colloids of both inorganic (clay) and organic (humus). Soil Ca and Mg mainly come from the weathering of rocks and minerals (Calcite and Apatite). Thus most soils contain enough Ca and Mg except

highly weathered leached acid soils and alkali soils. Deficiencies of Ca and Mg most commonly occur in coarse textured soils, acidic soils of high rainfall area due to leaching losses. In soil solution occurs as cations and also adsorbed cation on the clay and humus surfaces and involved in exchange process. The critical limits of exchangeable Ca and Mg vary widely among soils. However average value of <2.0 m.eq/100g for exchangeable Ca and < 0.5 m.eq/ 100g for exchangeable Mg are considered critical limits for availability.

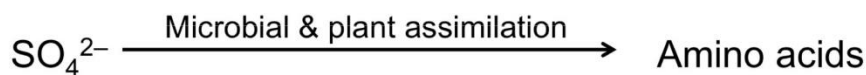
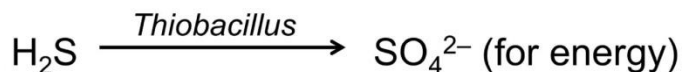
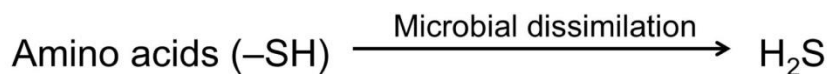
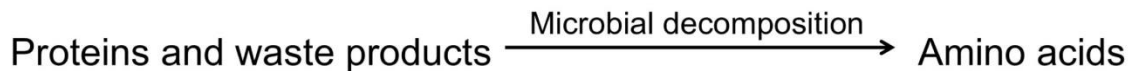
Ca & Mg Transformations:

Ca and Mg occupying the exchange sites of the soil colloids (clay & humus) are subjected to cation exchange reactions with other monovalent and divalent cations then released into soil solution for plants absorption or adsorbed on the clay and organic matter surfaces. Soils usually contain less Mg than Ca because Mg²⁺ ions are not adsorbed as strongly by clay and organic matter as Ca²⁺ ions and further Mg²⁺ ions are more susceptible to leaching than Ca²⁺ ions. The solution Ca and Mg is subjected to leaching/erosion losses and crop uptake, thus it may deplete the Ca and Mg content soil.

S transformation and cycle:

Four distinct transformations are recognized

1. **Decomposition/Mineralization** of larger organic S compounds to smaller units and their conversion into inorganic compounds
2. **Oxidation of inorganic ions and compounds** such as sulphides, thiosulphates, sulphates
3. **Reduction** of Sulphates and other sulphides
4. Microbial associated **immobilization**



Mineralization

Conversion of organic bound S into inorganic state, mediated through M.O. The released S is either absorbed by plants or escaped into atmosphere in the form of oxides

Oxidation

- Occurs both in aerobic and anaerobic condition
- Bacteria
- Nonfilamentous forms- Thiobacillus
- Filamentous forms – Beggiatoa, Thiiothrix and Thioloa
- Fungi and actinomycetes
- Aspergillus, Penicillium and Microsporium

Sulphate reduction

Reduces inorganic sulphate into Hydrogen sulphide –reduces the availability of S for plant nutrition. *Desulphovibrio desulphuricans* –anaerobe

Immobilization: Conversion of inorganic S to organic S by microorganism.

Importance of Thiobacillus

Produces Sulphuric acid ,lower down the soil pH – Hence used in controlling plant disease

- Apple and Potato scab –*Streptomyces scabiei* ,Sweet potato rot – *S. ipomea*
- S+ *Thiobacillus* application is used for the control
- Remediation of alkali soil
- Increases the solubilization of other nutrients (P,K,Ca,Mn,Al and Mg)
- Preparation of biosuper- Rock phosphate + T.thiooxidans and S--- Australia
- Lipman's process- Compost preparation
- Soil + manure + elemental S + rock phosphate

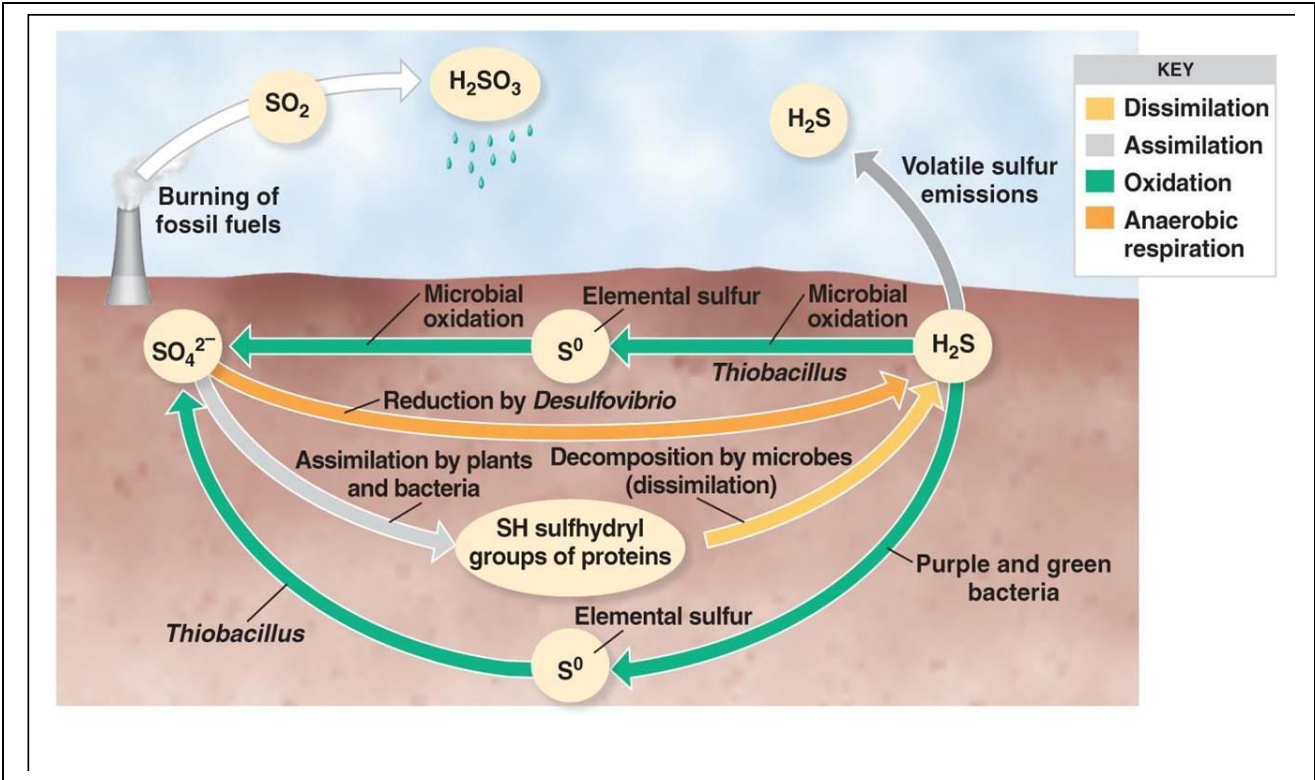
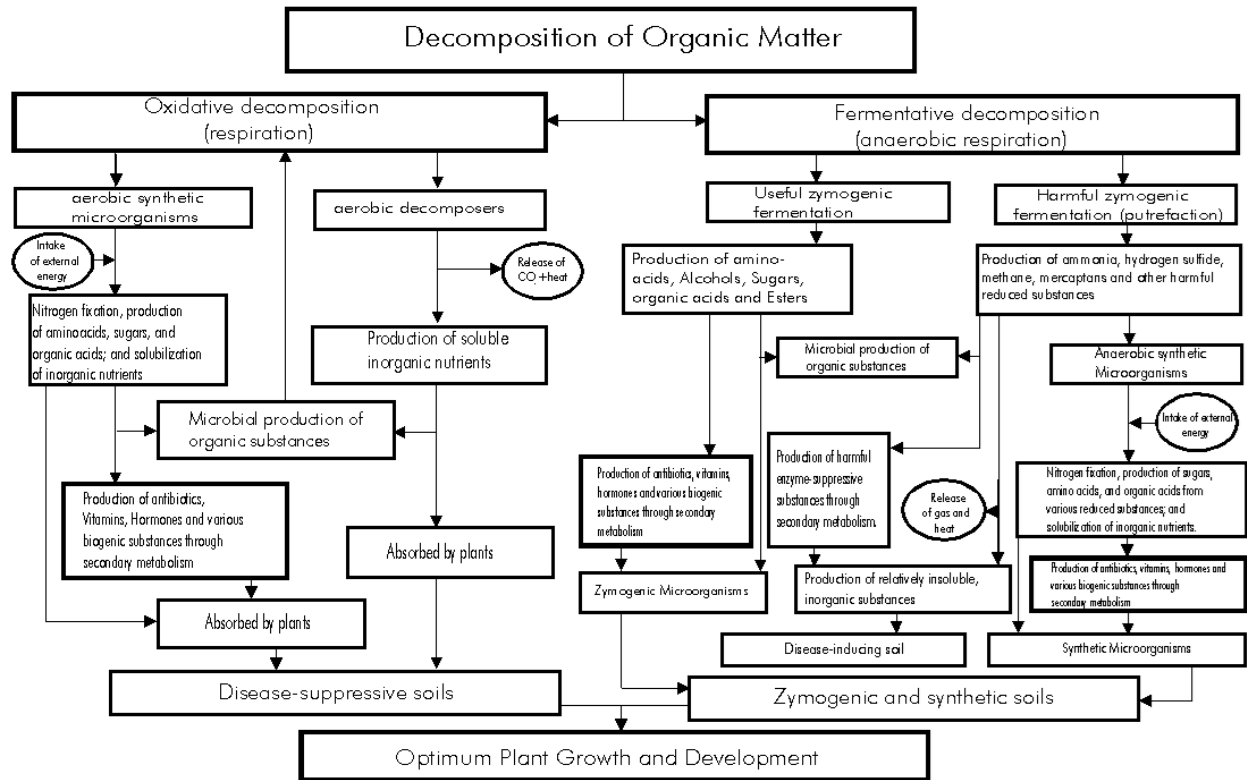
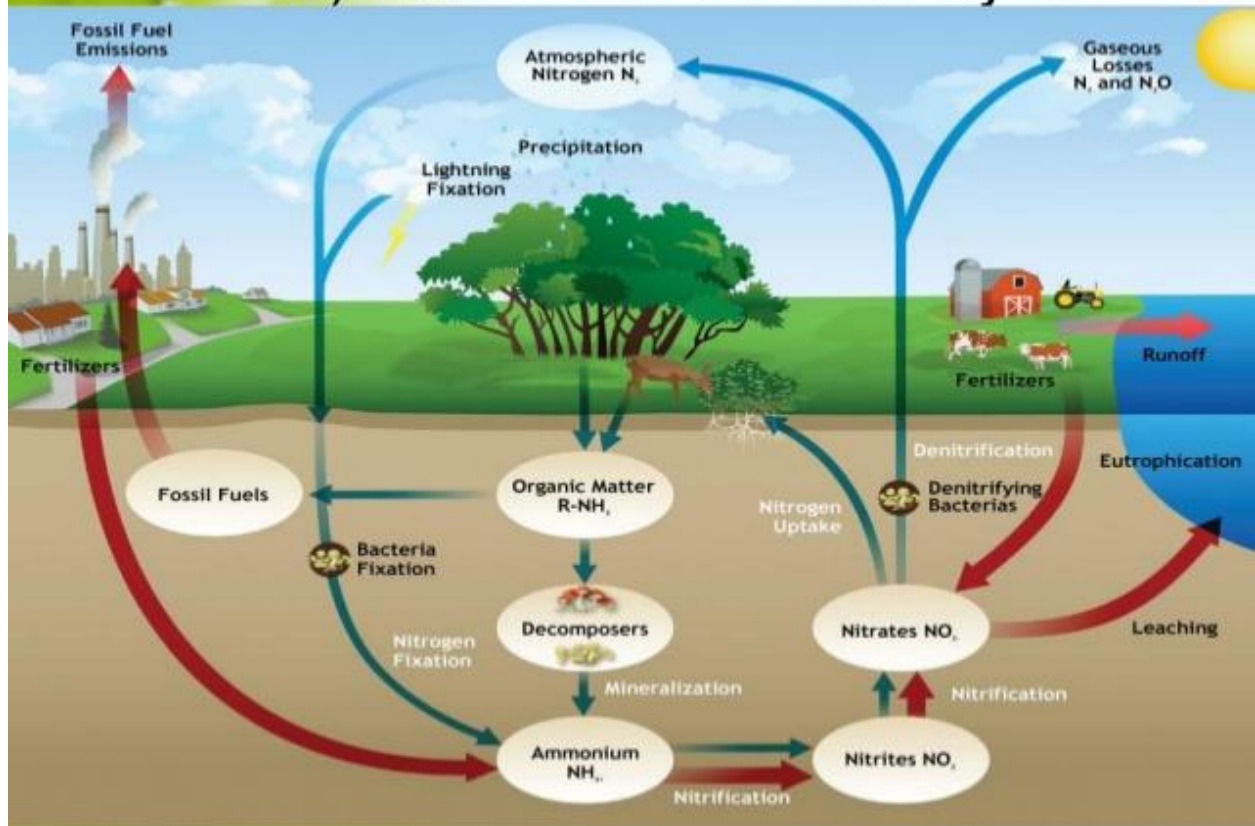


Fig 1 Flow chart of organic matter transformations by soil microorganisms and the development of soils that may be disease-inducing, zymogenic or synthetic (adapted from Prof. Dr. Teruo Higa).

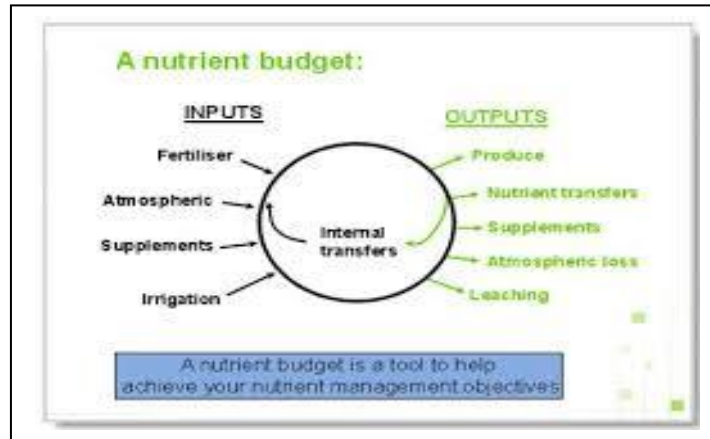


5) Basic Plant Nutrient Cycle



Nutrient budgeting

Nutrient budgets offer insight into the balance between crop inputs and outputs. In short, they compare nutrients you apply to the soil to nutrients taken up by crops. A nutrient budget takes into account all the nutrient inputs on a farm and all those removed from the land.



Importance

An accurate nutrient budget is an important tool to provide an early indication of potential problems arising from (i) a nutrient surplus (inputs>outputs), leading to an accumulation of nutrients and increased risk of loss or (ii) a deficit (outputs>inputs), depleting nutrient reserves and increasing the risk of deficiencies and reduced crop yields. They also provide regulatory authorities with a readily-determined, comparative indicator of environmental impact. Overall, nutrient budgets help ensure that farming practices are conducted in an efficient, economic, and environmentally sustainable manner.

Contents

A nutrient budget isn't as exact as a financial statement. An assortment of variables affects each tract of land. For example, some areas may have had too much manure applied over time or it may have been unevenly distributed, and previous flooding could affect results. Limits and assumptions should be incorporated when compiling a budget including the average nutrient removal coefficient values if they are not specific to a certain field field.

Soil test: This component is complementary to the budget and lets you know what nutrients are already available to crops and helps you plan input purchases. It is a critical best management practice (BMP) in the 4R strategy.^[3]

Yield history: By examining the historical yields of crops taken from specific fields, you can calculate nutrient removal over time. Yield history may also help better predict the amount of uptake that will occur with similar crops planted in the future.

Previous applications: Knowing what's been applied to the field in years past will offer insight into what may already be in the ground or what nutrients may no longer be present.

Water: Consider what kind of water has been applied to the field. Does irrigation water contain dissolved nutrients such as nitrogen (N), sulfur (S), or chloride (Cl)? If so, it should be counted as input.

What's around you?: Consider water sources that could run into your field. Is there a manufacturing facility nearby? What makes up these water sources can impact how you plant.

Introduction to soil fertility and productivity

Soil Fertility: It is defined as the inherent capacity of a soil to supply available nutrients to plants in an adequate amount and in suitable proportions to maintain growth and development. It is a measure of nutrient status of soil which decides growth and yield of crop.

Soil Productivity? Soil productivity means the crop producing capacity of a soil which is measured in terms of yield (bio-mass). Productivity is a very broad term and fertility is only one of the factors that determine the crop yields. Soil, climate, pests, disease, genetic potential of crop and man's management are the main factors governing land productivity, as measured by the yield of crop. To be productive, soil must contain all the 13 essential nutrients required by the plants.

The total quantity of nutrients is not only being sufficient but they should also be present in an easily “available” form and in “balanced” proportions. Over and above fertility, there are other factors deciding productivity.

“All the productive soils are fertile but not all fertile soils are productive”

Factors affecting Soil Productivity

The factors affecting soil productivity include all those which affect the physical, chemical and biological conditions of the soil environment in which plants grow. They include all the practices that affect fertility, the water and air relationships and the activity of the biological agents such as insects, pests, diseases and microorganisms.

I. Internal factors: may be called as genetic or hereditary factors which cannot be manipulated such as soil type, texture etc.

II. External factors: may be regulated to certain extent, They include

a. Climatic factors: like precipitation (rain fall), solar radiation, atmospheric gases (CO₂, NO₂, N₂O, O₂), wind velocity etc.

b. Edaphic or Soil factors: Soil moisture, soil air, soil temperature, soil mineral matter, inorganic and organic components, microorganisms, soil reaction.

c. Biotic factors:

i. Plants: have competitive and complementary nature, competition between weeds and crop plants, plants growing as parasites.

ii. Bacteria of symbionts, free living.

d. Animals: earth worms, small and large animals

e. Physiographic factors: geological strata (parent materials), topography (altitude, steepness of slope)

f. Anthropogenic factors: human factors including skill and efficiency of cultivation by man.

Major Types of Problematic Soils

The 'problem soil' herein means the soil that has agricultural problems due to the soil's unsuitable physical and chemical properties, or less suitable for cultivation, resulting in that crops are not able to grow and produce yields as normal. These soils always occur naturally, including saline soil, acid sulfate soil, sandy soil, organic soil, skeletal soil and shallow soil.

Acid Soils: The soils with pH less than 6.5 and which respond to liming may be considered as acidic soils.

(a) Reasons for Acidity:

- (i) Humus decomposition results in release of large amounts of acids. There by lowering the pH.
- (ii) Rainfall: In areas with more than 100 cm rainfall associated with high R.H., Ca, Mg is dissolved in water and leached out due to this base saturation of soil decreases.
- (iii) Application of elemental sulphur under goes reactions resulting in formation of H_2SO_4 .
- (iv) Continuous application of acid forming fertilizers like ammonium sulphates or ammonium chlorides results in depletion of Ca by CEC (cation exchange capacity) phenomenon.
- v) Parent Material: Generally rocks are considered as acidic, which contain large amount of silica (SiO_2) when this combined with water, acidity increases.

(b) Characteristics:

- (i) pH is less than 6.5
- (ii) These soils are open textured with high massive Structure.
- iii) Low in Ca, Mg with negligible amount of soluble salts.
- (iv) These soils appear as brown or reddish brown, sandy loams or sands.

(c) Injury to Crops:

(i) Direct Affects:

- (1) Plant root system does not grow normally due to toxic hydrogen ions.
- (2) Permeability of plant membranes are adversely affected due to soil acidity.

(3) Enzyme actions may be altered, since they are sensitive to pH changes.

(ii) Indirect Affects:

1) Deficiency of Ca and Mg occur by leaching.

(2) Al, Mn and Fe available in toxic amounts.

(3) All the micro nutrients except molybdenum are available. So 'Mo' deficiency has been identified in leguminous crops.

(4) Phosphorous gets immobilized and its availability is reduced.

(iii) Effect on Activity of Microorganisms:

(1) Most of the activities of beneficial organisms like Azotobacter and nodule forming bacteria of legumes are adversely affected as acidity increases.

(d) Crops Suitable for Cultivation in Acidic Soils

<i>pH Level</i>	<i>Acidic Soils</i>
4.5	: Citrus, Blue berries
5.0	: Tobacco, Apple, Grapes, Plum, Watermelon
5.5	: Cowpea, Soybean, Cotton, Wheat, Oat, Peas, Tomato, Sorghum.
6.0	: Peanut, Cabbage, Carrot, Onion, Radish, Spinach, Cauliflower.
6.5	: Alfalfa, Sugarbeet

(e) Amelioration:

(i) Lime as reclaiming agent: Lime is added to neutralize acidity and to increase the pH, so that the availability of nutrients will be increased.

(ii) Basic slag obtained from Iron and steel industry can be substituted for lime. It contains about 48-54 per cent of CaO and 3-4 per cent MgO.

(iii) Ammonium sulphate and Ammonium chloride should not be applied to acid soils but urea can be applied.

(iv) Calcium Ammonium Nitrate (CAN) is suitable to acidic soils.

(v) Any citrate soluble phosphate fertilizer is good source of phosphorous for acidic soils.

(vi) Eg. Dicalcium phosphate (DCP), Tricalcium phosphate (TCP) Potassium sulphate is a suitable source of 'K' for acidic soils. But MOP is better than K_2SO_4 because Cl^- of MOP replaces $-OH$ ions, their by release of $-OH$ ions tends to increase the pH.

2. Alkali Soils:

Alkali soils are formed due to concentration of exchangeable sodium and high pH. Because of high alkalinity resulting from sodium carbonate the surface soil is discoloured to black; hence the term black alkali is used.

(a) Reasons for Alkalinity:

The excessive irrigation of uplands containing Na salts results in the accumulation of salts in the valleys.

- (i) In arid and semi arid areas salt formed during weathering are not fully leached.
- (ii) In coastal areas if the soil contains carbonates the ingress of sea water leads to the formation of alkali soils due to formation of sodium carbonates.
- (iii) Irrigated soils with poor drainage.

(b) Characteristics:

- (i) Alkali soil has soil pH of more than 8.5
- (ii) EC is less than 4.0 dS/m
- (iii) ESP (exchangeable sodium per cent) is more than 15
- (iv) It has black colour that why it is also called as Black alkali

(c) Injury to Crops:

- (i) High exchangeable sodium decreases the availability of calcium, magnesium to plants.
- (ii) Dispersion of soil particles due to high exchangeable 'Na' leads to poor physical condition of soil, low permeability to water and air, tends to be sticky when wet and becomes hard on drying.
- (iii) Toxicity due to excess hydroxyl and carbonate ions.
- (iv) Growth of plant gets affected mainly due to nutritional imbalance.
- (v) Restricted root system and delay in flowering in sensitive varieties.
- (vi) Typical leaf burn in annuals and woody plants due to excess of chloride and sodium.

(vii) Bronzing of leaves in citrus.

(viii) It affects the solubility of zinc (Zn).

(d) Crops Suitable for Cultivation in Alkaline Soils:

(i) Barley, Sugar beet, Cotton, Sugarcane, Mustard, Rice, Maize, Red gram, Green gram, Sunflower, Linseed, Sesame, Bajra, Sorghum, Tomato, Cabbage, Cauliflower, Cucumber, Pumpkin, Bitter guard. Beetroot, Guava, Asparagus, Banana, Spinach, Coconut, Grape, Date palm, Pomegranate.

(e) Amelioration:

(i) The process of amelioration consists of two steps:

(1) To convert exchangeable sodium into water soluble form.

(2) To leach out the soluble sodium from the field. Amendments used for reclamation of Alkali soils.

(ii) Gypsum:

(1) It is slightly soluble in water. So it should be applied well in advance.

(2) For every 1 m.e. of exchangeable Na per 100 gm of soil, 1.7 tones of Gypsum/acre is to be added.

(iii) Use of Pyrites (FeS_2).

(iv) Sulphur present in pyrites causes decrease in pH of soil due to formation of H_2SO_4 .

(v) Application of sulphur.

(vi) Application of molasses.

(vii) Drainage channels must be arranged around the field.

(viii) Growing the green manure crops and incorporates in the field.

3. Saline Soils:

The saline soils contain toxic concentration of soluble salts in the root zone. Soluble salts consist of chlorides and sulphates of sodium, calcium, magnesium. Because of the white encrustation formed due to salts, the saline soils are also called white alkali soils.

(a) Reasons for Salinity:

In arid and semi arid areas salts formed during weathering are not fully leached. During the periods of higher rainfall the soluble salts are leached from the more permeable high laying areas to low laying areas and where ever the drainage is restricted, salts accumulate on the soil surface, as water evaporates.

(i) The excessive irrigation of uplands containing salts results in the accumulation of salts in the valleys.

(ii) In areas having salt layer at lower depths in the profile, seasonal irrigation may favour the upward movement of salts.

(iii) Salinity is also caused if the soils are irrigated with saline water.

(iv) In coastal areas the ingress of sea water induces salinity in the soil.

(b) Characteristics:

(i) Saline soil has soil pH of less than 8.5

(ii) EC is more than 4.0 dS/m

(iii) ESP (exchangeable sodium per cent) is less than 15

(iv) Dominated by sulphate and chloride ions and low in exchangeable sodium

(v) Flocculation due to excess soluble salts.

(vi) High osmotic pressure of soil solution

(vii) Presence of white crust

(viii) It has white colour that why it is also called as White alkali

(c) Injury to Crops:

(i) High osmotic pressure decreases the water availability to plants hence retardation of growth rate.

(ii) As a result of retarded growth rate, leaves and stems of affected plants are stunted.

(iii) Development of thicker layer of surface wax imparts bluish green tinge on leaves during to high EC germination per cent of seeds is reduced.

(d) Crops Suitable for Cultivation in Saline Soils:

(i) Barley, Sugar beet, Cotton, Sugarcane, Mustard, Rice, Maize, Red gram, Green gram, Sunflower, Linseed, Sesame, Bajra, Sorghum, Tomato, Cabbage, Cauliflower, Cucumber, Pumpkin, Bitter guard. Beetroot, Guava, Asparagus, Banana, Spinach, Coconut, Grape, Date palm, Pomegranate.

(e) Amelioration:

(i) The salts are to be leached below the root zone and not allowed to come up. However this practice is somewhat difficult in deep and fine textured soils containing more salts in the lower layers. Under these conditions, a provision of some kind of sub-surface drains becomes important.

(ii) The required area is to be made into smaller plots and each plot should be bounded to hold irrigation water.

(iii) Separate irrigation and drainage channels are to be provided for each plot.

(iv) Plots are to be flooded with good quality water up to 15 – 20 cms and puddled.

(v) Thus, soluble salts will be dissolved in the water.

(vi) The excess water with dissolved salts is to be removed into the drainage channels.

(vii) Flooding and drainage are to be repeated 5 or 6 times, till the soluble salts are leached from the soil to a safer limit

(viii) Green manure crops like Daincha can be grown up to flowering stage and incorporated into the soil. Paddy straw can also be used.

(ix) Super phosphate. Ammonium sulphate or Urea can be applied in the last puddle. MOP and Ammonium chlorides should not be used.

(x) Scrape the salt layer on the surface of the soil with spade.

(xi) Grow salt tolerant crops like sugar beet, tomato, beet root, barley etc. Before sowing, the seeds are to be treated by soaking the seeds in 0.1 per cent salt solution for 2 to 3 hours.

COMPARISON BETWEEN SALINE AND ALKALINE SOIL

<i>Particular</i>	<i>Saline soil</i>	<i>Alkaline soil</i>
Known as	Solan chalk	Solanetz
Soluble salt concentration	≥ 0.1 per cent	< 0.1 per cent
Colour	White coloured so also called white alkali	Black coloured so also called black alkali
Ions presence	Cl ⁻ and SO ₄ ²⁻ ions of Na ⁺	CO ₃ ²⁻ of Na ⁺

COMPARISON BETWEEN SALINE, SALINE ALKALINE AND ALKALINE SOIL

<i>Particular</i>	<i>EC (dSm) at 25°C</i>	<i>ESP (per cent)</i>	<i>pH</i>
Saline soil	> 4	< 15	< 8.5
Saline alkaline soil	> 4	> 15	< 8.5
Alkaline soil	< 4	> 15	8.5 – 10.0

Water Logging : Water logging refers to the saturation of soil with water. Soil may be regarded as water logged when the water table of the groundwater is too high to conveniently permit an anticipated activity, like agriculture.

Prevention of Water Logging

1. There are many following steps to control the water logging:
2. Canal Closures
3. Lowering Full Supply Level
4. Lining Of Canals and water courses
5. Provision Of Intercepting Drains
6. Provision Of Surface Drains
7. Pumping
8. Plantation
9. Crop Rotation

Soil Microorganisms

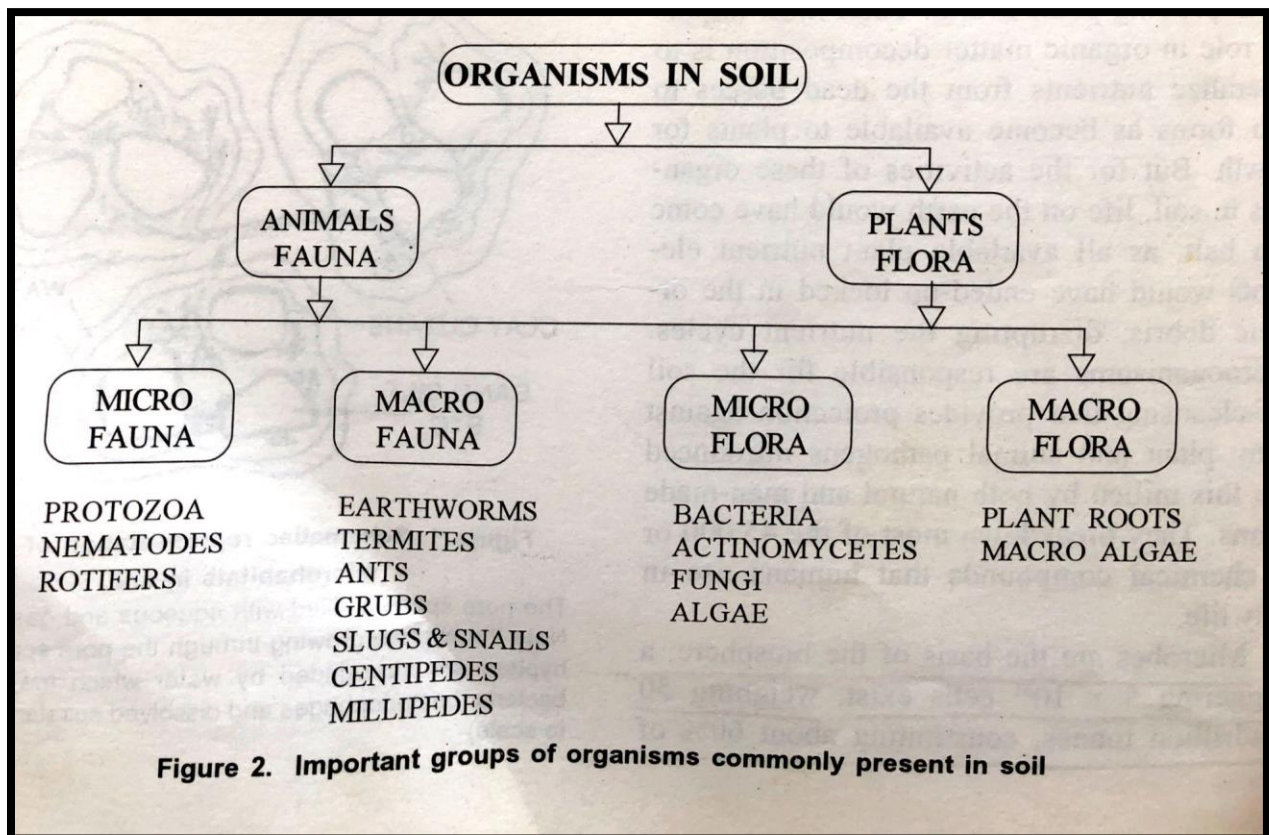
Soil biology is the study of **microbial** and **faunal** activity and **ecology** in **soil**. These organisms include **earthworms**, **nematodes**, **protozoa**, **fungi**, **bacteria**, Soil biology plays a vital role in determining many soil characteristics yet, being a relatively new science, much remains unknown about soil biology and its effect on soil **ecosystems**.

Distribution of various microorganisms in soil ecosystem

Organisms in Soil- Organisms presents in soil are classified into two main groups-

Soil Flora- Belonging to plant kingdom.

Soil Fauna- Belonging to animal kingdom



Classification of Microbes

A Based on the ability to grow in the presence or absence of molecular oxygen microbes are of two categories.

1 Aerobs- Azotobacter, Rhizobium

2 Anaerobs- Clostridium

Facultative aerobs- Those which generally grow and develop in the presence of oxygen but can also adopt themselves to grow under an oxygen depleted environment. Ex- Staphylococcus spp., Streptococcus spp., Escherichia coli

B Based on Temperature

Psychrophiles- Those which grow at temperature below 10⁰C

Mesophiles- Those which grow between 20⁰C to 40⁰C. e.g., E. coli, Salmonella spp., and Lactobacillus spp.

Thermophiles- Those which grow above 45⁰C.

C Based on the energy and carbon requirements for cell synthesis-

Heterotrophs- The heterotrophs derive their energy from oxidation of complex organic compounds which also serve as sources of carbon. Ex- Azotobacter, Rhizobium

Autotrophs- The autotrophs utilize carbon from CO₂. Ex Cynobacteria

Chemoautotrophs- Which drive their energy from oxidation of simple inorganic compounds.Ex - Nitrosomonas, Methanogens

Photoautotrophs- Which derive their energy from sunlight. Ex- BGA

Soil MicroFlora (Soil microorganism)- Soil microorganisms can be classified as bacteria, actinomycetes, fungi, algae and protozoa. Each of these groups has characteristics that define them and their functions in soil.

1 Bacteria- Bacteria are the smallest and most numerous of the organisms present in soil. They are single cell organisms and their size is approximately 1 micron in diameter and up to 10 micron in length. The bacteria in soil are of different shapes. Those with spherical cells are called cocci, rod- shaped cells are termed as bacilli and long spiral- shaped are termed as spirilla.

The different bacterial genera commonly occurring in diverse soils are : Pseudomonas, Arthrobacter, Clostridium, Bacillus, Achromobacter, Micrococcus and Agrobacterium. The genus Bacillus has largest representation in soils in terms of species.

2 Actinomycetes- Taxonomically actinomycetes are like bacteria which possess aerial hyphae like fungi. These organisms share characteristics of both bacteria(cell size, structure and mode of multiplication) and fungi (branching). They are next to bacteria in numbers and are fairly widely distributed in soils. They are more common in dry soils and in undisturbed pastures and grasslands. Like bacteria, they are more common in neutral to slightly alkaline soils. They are aerobic organisms. The species more commonly encountered in soils belong to the genera Streptomyces, Micro- monospora, Nocardia and Thermo-actinomyces.

3 Fungi- Fungi are filamentous organisms with much larger cell width than actinomycetes. The filaments are called hyphae and the network of hyphae collectively is termed mycelium. They are heterotrophs devoid of chlorophyll and are primarily responsible for organic matter decomposition. Soil fungi can grow in a wide range of soil pH, but their population is more under acidic condition. A majority of fungi are aerobic and prefer to grow at optimum soil moisture. Example- Pythium, Rhizopous, Mucor, Aspergillus, Penicillium , VAM Etc.

4 Alage- Soil alage are chlorophyll containing organism. They are autotrophic and therefore, their development is not restricted by organic carbon supply. Soil alage are classified on the basis of the colour (pigments) as:

1 Cyanophyta (blue green)

2 Chlorophyta (grass green)

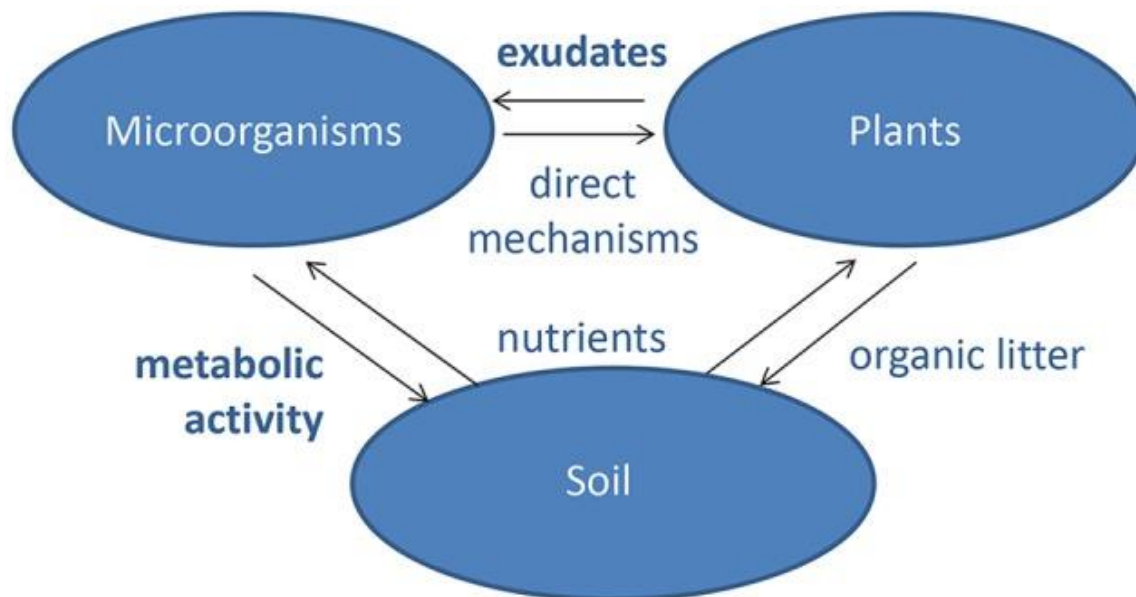
3 Xanthophyta (yellow green)

4 Bacilliriophyta (golden brown)

Blue green alage also known as Cyanobacteria are most important from the agricultural point of view because they fix atmospheric nitrogen. Some other examples- Anabaena, Nostoc etc.

5 Protozoa- Soil protozoa are single cell organisms belong to animal kingdom and larger in size than most microorganisms found in the soils.

Interactions



Interactions between plants, microbiota, and soil. Both plants and microorganisms obtain their nutrients from soil and change soil properties by organic litter deposition and metabolic activities, respectively. Microorganisms have a range of direct effects on plants through, e.g., manipulation of hormone signaling and protection against pathogens. Plants communicate with the microorganisms through metabolites exuded by the roots.

Role of microorganism in soil fertility

1 Microbes can make nutrients and minerals in the soil available to plants, produce hormones that spur growth, stimulate the plant immune system and trigger or

dampen stress responses. In general a more diverse soil microbiome results in fewer plant diseases and higher yield.

2 The group of bacteria called rhizobia live inside the roots of legumes and fix nitrogen from the air into a biologically useful form.

3 Mycorrhizae or root fungi form a dense network of thin filaments that reach far into the soil, acting as extensions of the plant roots they live on or in. These fungi facilitate the uptake of water and a wide range of nutrients.

4 *Stenotrophomonas rhizophila* increases drought tolerance in crops such as sugar beets and maize. The microbe excretes molecules that help plants withstand stress, including osmoprotectants, which prevent the catastrophic outflux of water from plants in salty environments.

5 Soil microorganisms are very important as almost every chemical transformation taking place in soil involves active contributions from soil microorganisms.

6 Soil microorganisms are responsible for the decomposition of the organic matter entering the soil (e.g. plant litter) and therefore in the recycling of nutrients in soil.

7 Soil microorganisms produce compounds that stimulate the natural defense mechanisms of the plant and improve its resistance to pathogens. Collectively, these soil microorganisms have been termed 'biopesticides' and represent an emerging and important alternative (i.e. biological control) to the use of chemical pesticides for the protection of crops against certain pathogens and pests.

Rhizosphere and Phyllosphere

The rhizosphere is the narrow region of soil that is directly influenced by root secretions and associated soil microorganisms. The rhizosphere contains many bacteria and other microorganisms that feed on sloughed-off plant cells, termed rhizodeposition, and the proteins and sugars released by roots.

The active root zone of the plant contact with the soil is termed as 'rhizosphere' which play an important role in maintaining of plant-microbe relationship.

The microbial population of rhizosphere has an important influence on the growth of the plant. The interaction of plant root and rhizosphere microorganisms are based largely on interactive modification of the chemical soil environment by processes such as, water up take by plant system , release of organic chemicals to the soil by plant roots, microbial production of plant factors and microbial mediated availability of mineral nutrients.

Microbial population in the rhizosphere soil may benefit to the plant various ways, including removal of H₂S, toxic to the roots, increased solubilization of mineral nutrients, synthesis of vitamin, amino acids, auxins and gibberellins which stimulate the plant growth and antagonism with potential plant pathogen through competition and development of a mensal relationships based on production of antibiotics.

The Phyllosphere: The stem, leaves and fruits of a plant provided suitable habitats for some microbial populations such as, heterotrophic and cyanobacteria, fungi, lichens and some algae which are occurring in the aerial plant surface. Such type of growing plants are called 'epiphytes'. The habitat in the leaf surface is known as 'phyllosphere' to denote leaf surface environment. The name was coined by Last (1955) and Ruinen (1956) independently. The term phyllosphere and phylloplane are interchangeably used in literature. Phylloplane is a natural habitat on leaf surface which support heterogeneous population both pathogen and non-pathogens. The phylloplane microbes cover a wide variety of microorganisms including yeast, filamentous fungi, bacteria, actinomycetes, blue green algae etc. The phylloplane mycoflora is of special interest from various view point because some of them have antagonistic action against fungal pathogen, degrade plant surface wax and cuticles and produce plant hormones as well as activate plants to produce phytoalexins.