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Introduction

Soil- Soil comes from a latin word *Solum* which means earthy material in which plants grow. Soil may be defined as "the uppermost layer of the earth's crust, which contains the organic as well as mineral matter necessary for the growth of plants." Muddy bottom of ponds and lakes, porous rock surfaces, peats etc. are all soils.
The study of soil is called as Soil science or Pedology or Edaphology.

Formation (origin) of soil

Soil is derived from parent rock and whole process of soil formation is divided into two stages-

(1) Weathering- breakdown of bigger rocks into fine, smaller mineral particles called as regolith

(2) Pedogenesis-modification of mineral particles into mature soil through the interaction between biological, topographic and climatic effects.

Practically no definite line can be drawn where weathering process terminates and pedogenesis starts. In fact, both these processes run simultaneously.

(1) Weathering- In this process, the massive consolidated rocks are broken down into smaller particles and eventually into the individual minerals of which they are composed of.

It is distinguished into three types depending on the agencies which bring about weathering-

(i) Physical weathering

(ii) Chemical weathering

(iii) Biological/ Biogeochemical weathering

(i) Physical weathering- It is brought about by a number of physical factors namely,
(a) Temperature;
(b) Water and
(c) Wind

(a) Temperature-It causes breakdown of rocks in the following ways:

➔ Differential expansion and contraction of minerals- Minerals of rocks expand at high temperature during the day and contract at low temperature at night at different degrees and set up internal tension resulting in crack formation in rocks and thus rocks weather into finer and finer particles in course of time.

➔ Exfoliation- This is not common in all types of rocks. Here the upper layer of rock expand and contract faster than those in the deeper regions with change in temperature. This brings about separation and disintegration of layers of rocks.

➔ Frost action- Sometimes the temperature of rocks reaches below freezing point which cases freezing of water present in the crevices and the rock joint. In freezing, water expands to about 9% of its original volume and exerts a pressure of approximately 150 tons/ square feet which is more than enough to break the rocks.

(b) Water- It causes breakdown of the rocks in the following ways:

➔ Rain- Natural water falling in the form of rain or hail storm on rock surfaces with beating effect bring about abrasion of massive rocks into smaller particles in due course of time.

➔ Running water- Rapidly flowing water like that of streams etc. gradually grinds heavy rock masses at the bottom of stream into finer particles.

➔ Water action- Along sea shore, the water waves striking with great force on rock surface break and grind the latter into pieces.

➔ Glaciation- At mountain tops, ice formation takes place in winter season which starts melting in summer. These glaciers (huge masses of ice and snow) while falling cause physical erosion of rocks through grinding process.

➔ Solution- Soluble components of rocks such as calcium, chlorides, sulphates etc. are easily removes by water thus decreasing the compactness of the rocks.

➔ Wetting and drying of the mineral particles- The layers of rock are disrupted by this process of wetting and drying of mineral particles making the rock less compact.

(c) Wind- It causes breakdown of the rocks in the following way:

➔ Sand blast- In arid, desert conditions, the rocks are disrupted by rapid stormy wind carrying suspended sand particles.

(ii) Chemical weathering- It brings about disappearance of original rock minerals either completely or partly and secondary products may be formed from the parent material. This process is also known as chemical transformation. Presence of moisture and air is essential in chemical weathering, hence it is not so effective in desert.
It includes the followings-
(a) Hydration

(b) Hydrolysis

(c) Oxidation-reduction

(d) Carbonation

(e) Chelation

(a) <u>Hydration-</u> In this process, water molecules become chemically attached to particular rock material resulting in increase in volume of the parental material and the hydrated material becomes soft due to swelling and thus more readily weatherable.

For example

$$2Fe_2O_3 + 3H_2O \text{ ----------} \rightarrow 2Fe_2O_3.3H_2O$$

(Hematite) (Limonite)

(b) <u>Hydrolysis-</u> It is an exchange of constituent parts between water and rock minerals resulting in the formation of elements that can be easily washed out giving rise to simpler mineral matter.

For example

Alumino silicates of rock breakdown and elements such as Potassium and surplus Silicon are washed out giving rise to simpler mineral matter like clay Alumino-Silicates.

(c) <u>Oxidation-reduction-</u> Some oxidation reduction chemical reactions, such as reversible change of Ferric ion (Fe^{+++}) to Ferrous ion (Fe^{++}) cause disruption of rocks because Ferrous ion is more soluble than Ferric ion.

$$2Fe_2O_3 \xleftarrow[\text{Reduction}]{\text{Oxidation}} 4FeO + O_2$$

Ferric oxide Ferrous oxide

Reduction takes place in deep zone where O_2 is not available.

(d) <u>Carbonation-</u> It occurs simultaneously with hydrolysis. Here, carbon dioxide (produced in the atmosphere and those during the metabolism of microorganisms) unites with water to produce carbonic acid (weak acid) which reacts with hydroxides of soil forming carbonates and bicarbonates.

$$CO_2 + H_2O \text{ ----------} \rightarrow H_2CO_3$$

Carbonic acid

$Ca(OH)_2 + CO_2 \text{ ----------} \rightarrow CaCO_3 + H_2O \text{ ------} + CO_2 \text{--------} \rightarrow Ca(HCO_3)_2$

Change of $CaCO_3$ to $Ca(HCO_3)_2$ leads to solution loss of limestone or in other words disruption of $CaCO_3$ cemented rock occurs because bicarbonate is more soluble than the carbonate. Sodium, Potassium, Calcium and Magnesium are easily removed from the rocks in dissolved state.

(iii) **Biological/ Biogeochemical weathering**- It brings about weathering of the rocks in the following way-

(a) **Chelation-**Some chemical exudates produced through biochemical activities of microorganisms like bacteria and also from lichen etc. are able to dissolve out mineral components of the rocks resulting in gradual weathering of rocks. The metals dissolved with organic products of microbial activity are known as 'chelates'.

(2) **Pedogenesis-** Simultaneously with weathering process, pedogenesis or soil forming process also runs which leads weathered materials to develop into mature soil with well differentiated soil profile and biological system.

Whereas in weathering, mostly physical and chemical factors are involved, pedogenesis is largely a biological phenomenon. Lichens are able to extract nutrients from bare rocks. Also, lichen, fungi and bacteria present on rock surfaces retain water for long periods during which chemical processes can proceed. Algal partner of lichen, through photosynthesis, increase the amount of available organic matter at rock surfaces. The living organisms including bacteria, fungi, algae, lichens, micro-arthropods, mollusks etc. secrete organic acids, enzymes, carbon dioxide etc. and also add organic matter after their death. Due to all these, the crust of weathered rock debris is converted into true soil consisting of mineral matter, various organic compounds, dead organic matter, living organisms etc. Rock weathering is, therefore, for a short time a physico-chemical process but soon it becomes biogenic.

Depending upon the its origin, the soil is broadly categorized into two groups, namely-

1. Residual soil- when the soil is found at the place of its formation.

2. Transported soil- when the soil is transported from the place of its formation. It is of the following types depending on the agents by which they are transported, namely-

   (a) Colluvial soil- transported by gravity

   (b) Alluvial soil- transported by running water

   (c) Glacial soil- transported by glaciers

   (d) Eolian soil- transported by wind

Factors affecting formation of soil

Joffe (1936) divided the factors affecting soil formation as follows:

(I) Passive factors

(i) Parental material- The physical constituents of the soil influences the soil aeration, texture, leaching rate whereas its chemical composition influences the chemical characteristics of the soil. These all have major role in the breakdown of the parental rock.

(ii) Topography- It determines drainage condition and water retention condition in the soil. Very steep slopes do not promote pedogenesis, because decomposition of parental materials is affected by downwardly flowing water. Even if soil is formed, water content in such soil is very poor.

(iii) Time- Length of the time required for soil formation depends upon many interrelated factors such as climate, nature of parent materials etc.

Soil materials on moderate slopes promote deeper profile development and more luxuriant vegetation than in soil on steep slopes.

Time, therefore, is not always an indicator of the exact age of a soil or the stage of a soil's development.

Active factors

(i) Rainfall and humidity- Heavy rainfall and high relative humidity determine depth of water table, and favour soil formation.

(ii) Temperature- It influences physico-chemical processes and control rate of organic turnover in soil. Horizons tend to develop faster under cool and humid forest condition.

(iii) Wind- Severe erosion of material by wind affects pedogenesis adversely.

(iv) Biosphere effect- Living organisms are very important in pedogenesis as they speed up and modify the physico-chemical processes. They affect the soil formation in the following ways:

(a) Some types of microorganisms promote acid conditions and change the chemistry of the soil which in turn influences the type of soil forming processes that take

place. Microorganisms decompose organic materials and return the products of decomposition to the soil.

(b) Larger animals such as earthworms and burrowing animals upturn deep soil and change its physical characteristics. They generally make the soil more permeable to air and water. Their waste products cause aggregation of soil particles and improve soil structure.

(c) Of all the animals, man can have the most beneficial or most detrimental impact on the soil forming processes. Man's activities such as manuring, ploughing, irrigation, cropping system, reclamation etc affect the physical and chemical properties of the soil to a great extent.

(d) Vegetation influences pedogenesis through the amount of organic matter which it adds to the soil and by checking soil erosion.

Composition of soil

Soil is a complex consisting of a group of mineral particles and biological system of living organisms.

Composition of soil-

1. Mineral particles
2. Humus
3. Soil atmosphere
4. Soil water
5. Soil micro-organisms

1. **Mineral particles-** These are derived from the parental rock and are found in particles of varying sizes, from clay (0.0002 mm or less in diameter) to large pebbles and gravels (more than 2 mm in diameter). These constitute about 90% of total weight of soil and are composed of oxygen, silicon, iron, aluminium, nitrogen, potassium, phosphorus, calcium, magnesium, carbon, hydrogen etc. In soil, nitrogen comes from atmosphere in the form of nitrogen salts.
2. **Humus** (dead organic matter)- When plants and animals die, decomposition by microorganisms takes place which breaks the organic complex into elemental forms which are returned back to the nature. When the decomposition is incomplete, then a dark coloured organic complex called as humus is formed which is composed of residual organic matter that is not readily decomposed by soil microorganisms. The process of humus formation is called as humification.

   Humus is a dynamic product and is constantly changing due to its oxidation, reduction and hydrolysis; and thus has no definite chemical composition. Still, it is found to be composed of carbohydrate, phosphoric acid, some organic acid, fats, resins, urea etc. Very little

decomposed dead organic matter like the tree litter also contains some inorganic substances like potash, manganese, magnesium, copper, aluminium, calcium, sodium, potassium etc. Humus is not soluble in water. Humus quantity is greater in top layers of soil.
Humus is found in three stages of degradation which are as follows-

(a) Top layered dead organic parts showing low degree of decomposition form litter.

(b) Below litter, a layer of partially decomposed organic substances forming the duff layer.
(c) Below duff layer, completely decomposed organic substances forming the leaf moulds.
Sometimes, under anaerobic conditions, the dead remains are not acted upon by the microorganisms. Accumulation of such undecomposed organic remains is termed as peat.

Role of humus

(i) It makes the soil fertile.
(ii) It provides nutrients to plants and microorganisms.
(iii) On complete decomposition, it forms several organic acids which serve as solvents for soil materials and thus, increases the availability of minerals in dissolved state to the plants.
(iv) Because it is porous, it has high capacity for retaining water.
(v) It makes the soil porous, thus increases aeration and percolation (to move gradually through a surface having small holes or spaces) which makes the soil more suitable for plant growth.
(vi) It also binds soil particles, thus checks soil erosion.
(vii) It increases rate of absorption in plants.

3. Soil atmosphere- Gases found in soil profile form the soil atmosphere. Spaces in between the mineral particles are occupied by various liquids and gases mainly oxygen, carbon dioxide and nitrogen. O_2 is less and CO_2 concentration is more in soil as compared to the external atmosphere. This is due to the reason that O_2 of soil is absorbed by plant roots and soil microorganisms in respiration and CO_2 is given out which accumulates in spaces in between the soil particles. Water logged soils are highly deficient in O_2. The amount of CO_2 increases and O_2 content decreases with increase in depth of soil due to decomposition of accumulated organic matter and abundance of plant roots which absorb O_2.
If the soil is deficient in O_2, rate of microbial activities are slowed down which may result in several undesirable processes such as evolution of methane, accumulation of sulphides, ferrous, manganous ions and organic inhibitors which may be injurious to the plants.
The soil atmosphere is affected by temperature, atmospheric pressure, wind and rainfall. Temperature and pressure cause expansion and contraction of soil air. Wind helps the soil im sucking the air and rain water displaces the soil air.

4. Soil water- Plants absorb a small quantity of rain water and dew directly from their surfaces, but most of the water absorbed by them comes from soil. Principal source of soil water is rain. Soil water plays important role in the growth of the plants. It is a good solvent for minerals of

soil and makes the concentration of the nutrients low, so that they are easily absorbed by the plants. Besides, it helps in photosynthesis and in maintaining the turgidity of plant. It regulates physical, chemical and biological activities in soil. Soil water maintains soil texture, arrangement and compactness of soil particles.

The water holding capacity of soil depends on the size of the mineral particles of which it is made, their shape and number of pore spaces. For example- sands which are coarse textured with larger particles can hold water loosely due to bigger pore spaces and hence, the water generally runs down rapidly reaching to deeper layers of the soil. Thus sandy soils are well drained. Such soils are called as physically dry soil. Clay soils with much humus can retain much water. Silts also can retain much water. Loams (mixture of sand and silt and/ or clay) are considered as best soils for plant growth as they are very fertile, rich in nutrients have proper aeration and are capable of holding fairly large amount of water.

In some soils as those of halophytic condition, although water is present in abundance, but due to high degree of salinity, it is not easily absorbed by the plants. Such soils are referred to as physiologically dry soils.

Water is held in the soil in five forms or states, namely-

- ***(a)*** **Gravitational water-** After complete saturation of soil, the surplus water displaces air of the soil and moves downwards under gravitation influence. This excess water is called gravitational water. When the gravitational water reaches to the level of parental rock, it is called ground water, the upper surface of which is the water table.
- ***(b)*** **Capillary Water-** The amount of water present around the soil particles at saturation stage (when the gravitational water has drained away) is called the capillary water. It is held by surface tension and attraction force of water molecules as thin film around soil particles in capillary spaces. Amount of water present in the capillaries determines the capillary capacity or the field capacity. This is the most important form of water to the plants.
- ***(c)*** **Hygroscopic water-** This is the water adsorbed on the soil particles. Soil is surrounded by a film of molecular layer of water that cannot be easily removed by the plants. The water is held tightly around the soil particles as a result of cohesive force acting between the water molecules and adhesive force acting between the water molecules and the soil particles.
- ***(d)*** **Combined water-** It is the water present in the soil in the form of chemical compound held by chemical forces of molecules. eg. $CuSO_4.5H_2O$. This form of water can also be not utilized by the plants.
- ***(e)*** **Water vapour-** This is the water present in the soil atmosphere in vapour form and cannot be utilized by the plants.

5. Soil micro-organisms- In addition to its solid, liquid and gaseous components, each soil has its own distinctive fauna and flora which make the biological system of the soil complex.

Important groups of soil organisms are-

Soil fauna- include protozoa, nematodes, insects and mites, rodents and earthworms, burrowing vertebrates etc.

Soil flora- include bacteria (in neutral soil), soil fungi (in acidic soil), soil actinomycetes (prefer saline soil), algae, roots, rhizoids and rhizomes of higher plants etc.

It is estimated that in soil micro flora, bacteria form 90% of total microbe population, actinomycetes 9% and fungi and algae together 1%. The greatest amount of microbes (approx. 10, 00,000/ cm^3) is found in the top layer of the soil at a depth of 5 to 15 cm.

Role of soil organisms

(i) Nitrogen fixation- Many bacteria like *Rhizobium* (symbiotic), *Azotobacter* (aerobic, asymbiotic), *Clostridium pasteurianum* (anaerobic, asymbiotic), blue green algae like *Nostoc, Anabaena, Oscillatoria* etc. fix atmospheric nitrogen and increase soil fertility.

(ii) Production of growth hormones- Many soil organisms including bacteria and fungi (*Fusarium, Gibberella fujikuroi* etc.) produce growth hormones like IAA (Indole Acetic Acid), Gibberellins, Gibberellic acid and thus affect root growth.

(iii) Antibiosis- Some soil microorganisms produce metabolic products which inhibit the growth or cause killing of other microorganisms. This phenomenon is called as antibiosis.

(iv) Injury to plants(soil borne diseases)-Some soil microorganisms become parasites of higher plants and cause diseases like root rot, seedling blight, damping off etc. resulting in considerable damage.

(v) Production of toxins- In absence of O_2, some soil microorganisms secrete chemicals like aldehydes, organic acids etc. which show toxic effect on many plants. For example *Fusarium lini* secretes HCN, a deadly poisonous substance and causes wilt of flax. Likewise, *Fusarium udum* secretes fusaric acid which causes wilt of arhar.

(vi) Soil mixing- Many organisms by their mechanical activities help in mixing soil. Roots of plants make compact soil loose. Many rodents, earthworms etc. turn over the soil and mix them. It also improves aeration of the soil. Besides, the excreta of the soil organisms increases fertility of the soil.

(vii) Improvement in aggregation of soil particles- Soil microorganisms like bacteria and blue green algae produce mucilagenous substance which bind soil particles into larger aggregates and checks soil erosion.

(viii) Decomposition of dead organic matter- Most important role of soil microorganisms like bacteria and fungi is decomposition of dead organic matter, changing it to humus and finally to minerals which is returned back to soil.

Decomposition of dead organic matter primarily help in feeding and growth process of these microorganisms and secondly, increases nutrient contents of the soil, thus making the soil fertile.

Soil Profile

Fully developed soil can be seen as having a number of layers- horizons, superimposed one above the other. This sequence of different horizons of a soil is known as soil profile and is different for different soil types i.e. soils are described and identified bt reference to their profiles.

Pedon- "smallest three dimension volume of soil needed to give full representation of horizontal variability of soil"

Soil horizon-"a layer which is approximately parallel to the soil surface and that has properties produced by soil forming processes but that is unlike those of adjoining layers"

Soil profile consists of the following five main horizons, though it is not always true that all these horizons are always present in each profile.

(I) The 'O' horizon- Organic horizon forming above the surface of mineral matrix, composed of fresh or partially decomposed organic matter, well developed in forest and may be completely absent in grassland.

It is divided into two sub layers-

(i) $O_1(A_{00})$ region- It is the uppermost layer consisting of freshly fallen dead organic matter (dead leaves, branches, flowers, fruits, dead parts of animals etc.), does not show evident breakdown.

(ii) O_2 (A_0) region- It is below O_1, here decomposition has begun and organic matter is found in different stages of decomposition. The microorganisms (bacteria, fungi, actinomycetes) are frequently found. Upper layer has initial stage of decomposition and lower layer has fairly decomposed matter, the duff layer.

(II) The 'A' horizon- These are mineral horizons at or adjacent to the surface, rich in organic matter, show downward loss or leaching (eluviations) of soluble salts, iron, aluminium etc., rich in resistant minerals like silica etc.

It is divided into two sub layers-

(i) A_1 region- It is dark and rich in organic matter mixed with mineral matter- known as humic/ melanized region. In forest, this region is less deeper than those of grassland.

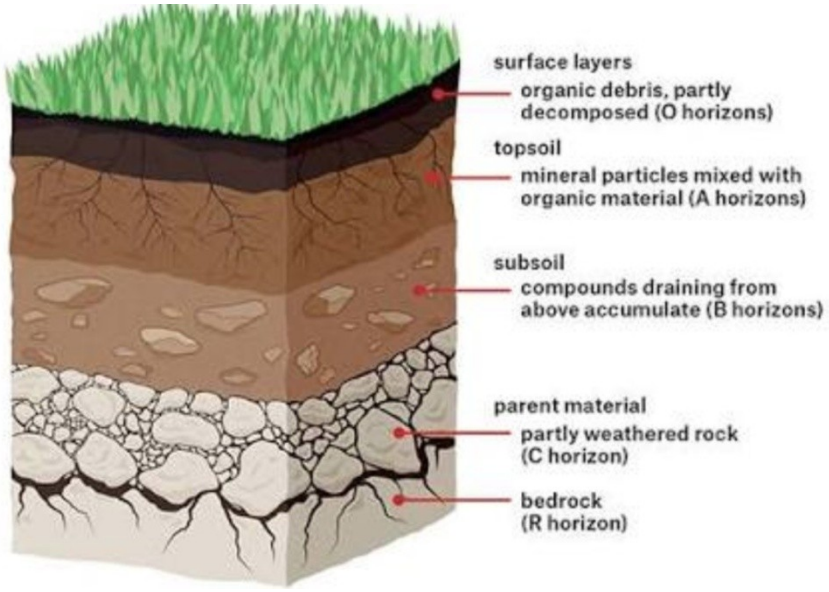
(ii) A_2 region- It is light coloured with large sized mineral particles as sand and little amount of organic matter. In areas of high rainfall, the mineral elements and organic chemicals are rapidly lost downwards in this region, making it light colourded- known as podosolic or eluvial zone or zone of leaching.

(III) <u>The 'B' horizon-</u> (sub soil) It is dark coloured, coarse textured due to presence of silica-rich clay, organic compounds, hydrated oxides of aluminium, iron etc. The chemicals are leached from A_2 region to this region (illuviation) and this zone is known as <u>illuvial zone.</u> It is poorly developed in dry areas.

A_1, A_2 and B horizons are collectively known as mineral soil or <u>*solum*</u>.

(IV) <u>The 'C' horizon-</u> (regolith) It is below B horizon and above parental rock, consisting of incompletely weathered large masses of rocks.

(V) <u>The 'R' horizon-</u> This is the parent, unweathered bedrock, upon which gravitational water is collected.



Hypothetical diagram of the soil profile to show principal horizons

<u>Importance of soil</u>

Soils are essential for life. They perform many functions which make them important to plants and animals including human beings.

Important functions of soils are as follows-

<u>Medium for plant growth-</u>

- Soils support roots and keep them upright for growth.

- Soils provide essential minerals and nutrients to the plants.
- Soils provide air for gaseous exchange between root and atmosphere.
- Soils protect plants from erosion and other destructive physical activities.
- Soils hold water which acts as solvnt for the minerals to make them readily available to the plants. In fact, most of the water absorbed by the plants for their metabolic activities is provided by the soil.

Habitat for many insects, microbes and other organisms-

- Many insects, microbes and other burrowing animals live in soils and depend on soils for food and air.
- The soils provide a home to many organisms such as insects to lay and hatch eggs, and rodents to give birth to new offspring.

A filtration system for surface water-

After rainfall and snowmelts, water flows on the earth's surface to water bodies, but much of it gets infiltrated into the ground. As it continues its way downwards through the many layers in the ground, it is filtered from dust, chemicals and other contaminants. This is why the underground water is one of the purest sources of water.

Carbon store and maintenance of atmospheric gases-

Soils help to regulate atmospheric CO_2 by acting as a carbon store. During humification, some of the organic matter is not completely decomposed, resulting in accumulation of carbon rich organic matter in the soil. Besides, nitrogen, phosphorus and many other nutrients are stored, transformed and cycled in the soil.

Plays vital role in human's life-

Soil provides plants with foothold for their roots and holds the necessary nutrients for plants to grow properly which in turn provide the basic necessities of human beings including food, cloth, shelter and medicines. Besides, the soils provide man with some essential construction and manufacturing materials like the houses are built with the bricks made from clay, even the coffee mug is baked soil. Another use of soil is in the form of mud mask (multani mitti) to cleanse the skin pores. When it comes to human health, almost all of the antibiotics we take to help fight infection are obtained from soil microbes.