

T. Y. B. Sc. Chemistry
Paper-VI
Chapter-1
Soil Chemistry

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Role of agriculture chemistry

- Chemistry deals with compounds, both organic and inorganic, and agriculture deals with the production of organic products using both organic and inorganic inputs. Thus, Chemistry forms an integral part of agriculture from molecular to organ level. It plays a role from the basics of photosynthesis to the utilization of agricultural produce.

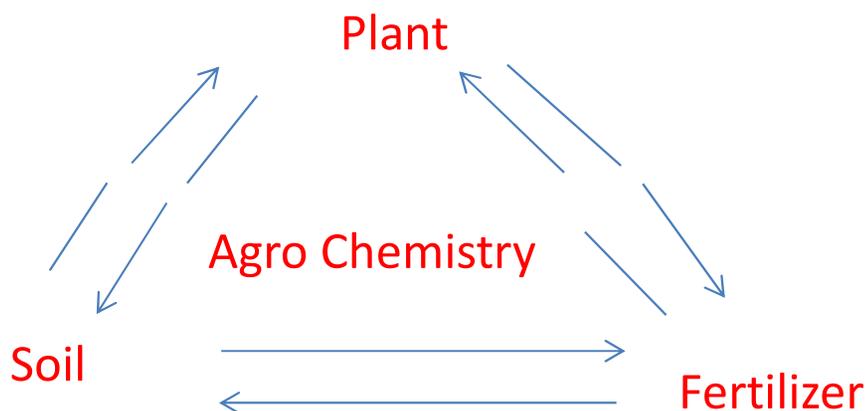
Agriculture chemistry play role in Following processes

- **Photosynthesis:** This natural process provides the basic building block for all the agricultural products. The overall process is best shown by the net equation. $6\text{CO}_2 + 6\text{H}_2\text{O} \Rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$
- **Fertilizers:** Fertilizer is any organic or inorganic material of natural or synthetic origin that is added to a soil to supply one or more plant nutrients essential to the growth of plants. A recent assessment found that about 40 to 60% of crop yields are attributable to commercial fertilizer use
- **Pesticides and Insecticides:** In order to minimize the damage of the crops by pests a large variety of chemicals known as pesticides are used. Subclasses of this are herbicides, insecticides, fungicides, rodenticides, pediculicides, and biocides depending on its target. With active research in this field safer and greener pesticides are being developed
- **Plastic pipes for improved irrigation :** Plastic was derived from chemistry and this is widely used in agriculture. This has increased irrigation massively which results in a better environment for the crops to prosper in.

- **Storage and preservation of agriculture produce:** Sulfur dioxide is used to keep grain fresh and useable for a longer period of time. Food preservatives like sodium benzoate and salicylic acid are used for longer shelf life. New generation refrigerants have been developed. Chemicals are added to promote the ripening of fruits or the germination of seeds.
- **Food Processing:** Development of Saccharin and sweeteners, Vitamins and minerals. Consumers have benefited from new technologies that have enhanced the flavor, appearance, availability, and nutritional value of their food.
- **Chemicals from agriculture waste:** Advancement in Chemistry has resulted in development of technologies to produce a variety of chemicals from agricultural waste. Production of alcohol from bagasse which is used as the feedstock for chemicals is good example,

Scope and importance of agricultural chemistry

- Agricultural chemistry is the study of chemistry and biochemistry in their relation to agriculture, especially agricultural production, the utilization of agricultural products, and environmental matters.
- The three main objects of agriculture chemistry are-
 1. Plant
 2. Soil
 3. Fertilizer
- They are inter-related to each other. Their inter relation is given by Russian scientist Pryanishnikov, which is known as **Pryanishnikov triangle**.



Importance of Agricultural chemistry

- Agro chemistry is closely related to the physiology of plants concern with the functions of green plants and the vital activities of plant organisms.
- Knowledge of plant organism, properties underlying the science of agro chemistry.
- Cultivation of plants and the desire to maximize their yields.
- The environmental factors are studied by pedology, metrology, and agro physics sciences which agro chemistry is closely related.
- Agro chemists resort to finding in such disciplines as the genetics and breeding of farm crops, agronomy, agricultural microbiology and biochemistry.
- It is difficult to define boundaries between agro chemistry and plant physiology and biochemistry of plants.

Soil and Components

- Soil may be defined as the upper layer of earth in which plants grow, a black or dark brown material typically consisting of a mixture of organic remains, clay, and rock particles.

OR

- **Soil** is a mixture of organic matter, minerals, gases, liquids and organisms that together support life. Earth's body of soil, called the pedosphere, has four important functions:
 - as a medium for plant growth
 - as a means of water storage, supply and purification
 - as a modifier of Earth's atmosphere
 - as a habitat for organisms

- The pedosphere interfaces with the lithosphere, the hydrosphere, the atmosphere and the biosphere.
- Soil science has two basic branches of study: edaphology and pedology.
- Edaphology studies the influence of soils on living things.
- Pedology focuses on the formation, description (morphology), and classification of soils in their natural environment
- Soil Scientists are called Pedologists who use term polypedons for the bodies of individual kinds of soil in a geographic area.
- Soil profile is a term used to describe the composition of soil.
- A pedon is the three dimensional sampling unit of size of about 1 to 10m² used for examination and study of the soil in the field.
- A Pedologists studies, examines and classifies soil as they occur in natural environment.
- Edaphology is the study of the soil from stand-point of higher plants. Edaphologists considers various properties of soil in relation to crop production.

Soil Components

- There are five basic components of soil that are
- Mineral
- Organic Matter
- Water
- Air
- Microorganisms

Mineral

- The largest component of soil is the mineral portion, which makes up approximately 45% to 49% of the volume. Soil minerals are derived from two principal mineral types. **Primary minerals**, such as those found in sand and silt, are those soil materials that are similar to the parent material from which they formed. They are often round or irregular in shape. **Secondary minerals**, on the other hand, result from the weathering of the primary minerals, which releases important ions and forms more stable mineral forms such as silicate clay. Clays have a large surface area, which is important for soil chemistry and water-holding capacity. Additionally, negative and neutral charges found around soil minerals influences the soil's ability to retain important nutrients, such as cations, contributing to a soils cation exchange capacity (CEC)

Organic matter

- Organic matter is the next basic component that is found in soils at levels of approximately 1% to 5%. Organic matter is derived from dead plants and animals and as such has a high capacity to hold onto and/or provide the essential elements and water for plant growth. Soils that are high in organic matter also have a high CEC and are, therefore, generally some of the most productive for plant growth. Organic matter also has a very high "plant available" water-holding capacity, which can enhance the growth potential of soils with poor water-holding capacity such as sand. Thus, the percent of decomposed organic matter in or on soils is often used as an indicator of a productive and fertile soil. Over time, however, prolonged decomposition of organic materials can lead it to become unavailable for plant use, creating what are known as recalcitrant carbon stores in soils

Water

- Water can make up approximately 2% to 50% of the soil volume. Water is important for transporting nutrients to growing plants and soil organisms and for facilitating both biological and chemical decomposition. Soil water availability is the capacity of a particular soil to hold water that is available for plant use.
- The capacity of a soil to hold water is largely dependent on soil texture. The more small particles in soils, the more water the soil can retain. Thus, clay soils having the greatest water-holding capacity and sands the least. Additionally, organic matter also influences the water-holding capacity of soils because of organic matter's high affinity for water. The higher the percentage of organic material in soil, the higher the soil's water-holding capacity.
- The point where water is held microscopically with too much energy for a plant to extract is called the “wilting coefficient” or “permanent wilting point.” When water is bound so tightly to soil particles, it is not available for most plants to extract, which limits the amount of water available for plant use.

Soil Atmosphere

- Soil air is the next basic component of soil. Because air can occupy the same spaces as water, it can make up approximately 2% to 50% of the soil volume. Oxygen is essential for root and microbe respiration, which helps support plant growth. Carbon dioxide and nitrogen also are important for belowground plant functions such as for nitrogen-fixing bacteria. If soils remain waterlogged (where gas is displaced by excess water), it can prevent root gas exchange leading to plant death, which is a common concern after floods.

Microorganisms

- Microorganisms are the final basic element of soils, and they are found in the soil in very high numbers but make up much less than 1% of the soil volume. A common estimate is that one thimble full of topsoil may hold more than 20,000 microbial organisms. The largest of these organisms are earthworms and nematodes and the smallest are bacteria, actinomycetes, algae, and fungi. Microorganisms are the primary decomposers of raw organic matter. Decomposers consume organic matter, water, and air to recycle raw organic matter into humus, which is rich in readily available plant nutrients.
- Other specialized microorganisms such as nitrogen-fixing bacteria have symbiotic relationships with plants that allow plants to extract this essential nutrient. Such "nitrogen-fixing" plants are a major source of soil nitrogen and are essential for soil development over time. Mycorrhizae are fungal complexes that form mutualistic relationships with plant roots. The fungus grows into a plant's root, where the plant provides the fungus with sugar and, in return, the fungus provides the plant root with water and access to nutrients in the soil through its intricate web of hyphae spread throughout the soil matrix.

- Activities of microorganisms are influenced by
- Moisture
- Temperature
- Light
- Reaction
- Air
- Food
- Energy supply.

Processes Carried by Soil Microorganisms

- Decompose dead organic matter.
- Mix soil and help in nitrogen fixation
- Increase plant nutrients.
- Produce toxins, growth stimulating substances.
- Improve soil aeration and soil binding.
- Cause injury to plants.

Humus and its function

- Humus is the dark organic matter that forms in soil when dead plant and animal matter decays.
- It makes the soil fertile and provides nutrients to plants and microorganisms.
- It has high capacity of retaining water because of its porous nature.
- On complete decomposition, it forms several organic acids, which help to dissolve minerals.
- It reduces surface run off and erosion.
- It provides exchangeable and available cations to plants whenever required.
- It is a source of energy for the growth of micro-organisms.
- It possesses power of adhesion and cohesion.
- It has a high ion adsorbing capacity.
- It is insoluble in water. It behaves like weak acid.

Soil Water

- Gravitational water or free water: The water in the large pores that moves freely under the influence of gravity.
- Capillary water: Available form of water that held against gravity. Held in fluid state. It moves more slowly than free water. It moves in any direction but always in direction of greatest tension.
- Hygroscopic water: It is in non liquid state and is immobile in nature. Non-available water to th

- Gravity lets water move downward. It depends on the size and continuity of the pore spaces. Percolation is retarded by ploughpan or claypan (next slide).
- Adhesive and cohesive forces lets water moves in small pores by capillarity. Affected by soil texture. Movement is from thick films to thin films i.e. low tension to high tension.
- Heat vapourizes and diffuse through the air. As water is evaporated from the surface, it is replaced by rise in the capillary water. This continues until few inches of surface soil become dry and capillary is broken. Water then leaves the soil only by vaporising.

- Adhesive forces
- Cohesive forces
- Not much work or energy is required to remove water from a soil near saturation.
- As more and more water is removed, more and more energy is required.
- The tenacity with which water is retained in the soil and the force that must be exerted to remove water from the soil is referred to as soil moisture tension

Available water

- Total amount of water between field capacity and permanent wilting point.
- Soil moisture tension, osmotic pressure and temperature are important determinants of available water.
- Low soil temperature decreases availability

Water intake

- The movement of irrigation water from the surface into and through the soil is called water intake.
- It is the expression of several factors.
- Infiltration
- Percolation

Physical properties of soil

- Soil texture
- Soil structure
- Soil color
- Soil temp
- Soil density
- Porosity of soil.

Soil texture

- **Soil texture** refers to the proportion of sand, silt and clay sized particles that make up the mineral fraction of the **soil**.
- For example, light **soil** refers to a **soil** high in sand relative to clay, while heavy **soils** are made up largely of clay

Soil structure

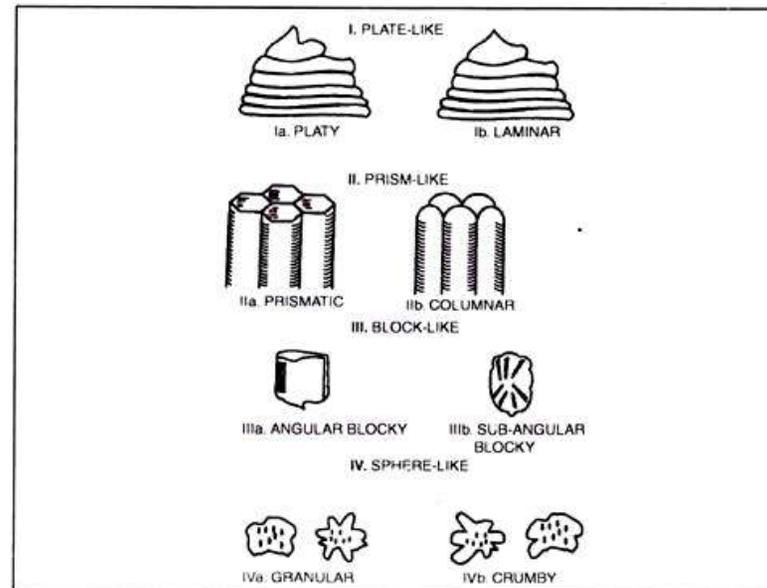
- The arrangement of soil particles and their aggregate into certain defined patterns is called structure.
- The primary soil particles sand, silt and clay usually occur grouped together in the form of aggregates.
- Natural aggregates are called peds, whereas clod is an artificially formed soil mass.

Types of Soil Structure

- **There are four principal forms of soil structure:**
- **Plate-like**
- **Prism-like**
- **Block-like**
- **Spheroidal (Sphere-like)**

Plate-like

- In this structural type of aggregates are arranged in relatively thin horizontal plates. The horizontal dimensions are much more developed than the vertical. When the units are thick, they are called platy, and when thin, laminar.



- Platy structure is most noticeable in the surface layers of virgin soils but may be present in the sub-soil. Although most structural features are usually a product of soil forming forces, the platy type is often inherited from the parent material, especially those laid down by water.

Prism-like

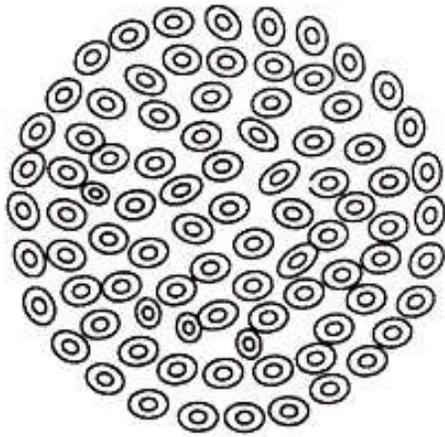
- The vertical axis is more developed than horizontal, giving a pillar-like shape. When the top of such a ped is rounded, the structure is termed as columnar, and when flat, prismatic. They commonly occur in sub-soil horizons in arid and semi-arid regions.

Block-like

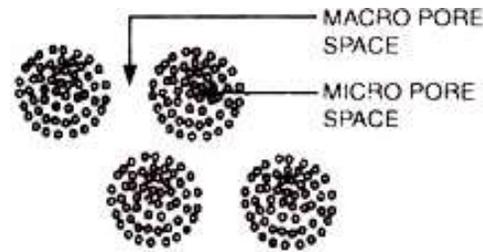
- All these dimensions are about the same size and the peds are cube-like with flat or rounded faces. When the faces are flat and the edges sharp angular, the structure is named as angular blocky. When the faces and edges are mainly rounded it is called sub angular blocky. These types usually are confined to the sub-soil and characteristics have much to do with soil drainage, aeration and root penetration.

Spheroidal (Sphere-like)

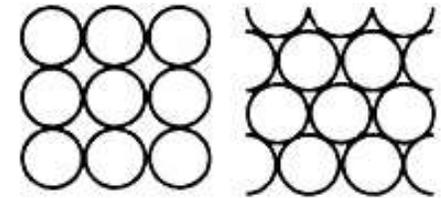
- All rounded aggregates (peds) may be placed in this category, although the term more properly refers to those not over 0.5 inch in diameter. Those rounded complexes usually lie loosely and separately
- When wetted, the intervening spaces generally are not closed so readily by swelling as may be the 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, the term used is crumby.



Example of sphere like soil structure



Arrangement of soil particles in sphere like soil structure

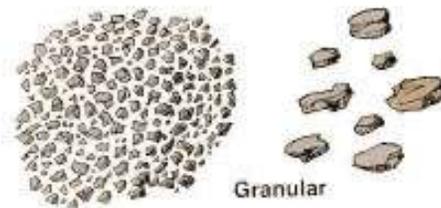


Arrangement of soil particles in two ways

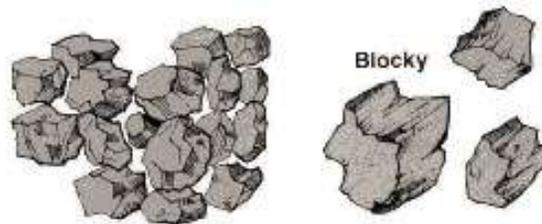
Classes and types of soil structure

- By definition, **class** of structure describes the **average size of individual aggregates**. Usually, five distinct classes may be recognized in relation to the type of soil structure from which they come. They are:
 - **Very fine or very thin;**
 - **Fine or thin;**
 - **Medium;**
 - **Coarse or thick;**
 - **Very coarse or very thick.**

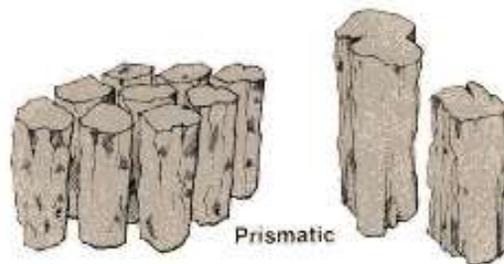
- **Granular and crumb structures** are individual particles of sand, silt and clay grouped together in small, nearly spherical grains. Water circulates very easily through such soils. They are commonly found in the A-horizon of the soil profile.



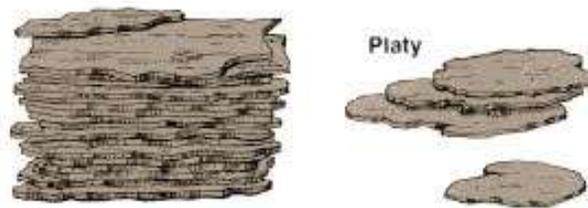
- **Blocky and subangular blocky structures** are soil particles that cling together in nearly square or angular blocks having more or less sharp edges. Relatively large blocks indicate that the soil resists penetration and movement of water. They are commonly found in the B-horizon where clay has accumulated.



- **Prismatic and columnar structures** are soil particles which have formed into vertical columns or pillars separated by miniature, but definite, vertical cracks. Water circulates with greater difficulty and drainage is poor. They are commonly found in the B-horizon where clay has accumulated



- **Platy structure** is made up of soil particles aggregated in thin plates or sheets piled horizontally on one another. Plates often overlap, greatly impairing water circulation. It is commonly found in forest soils, in part of the A- horizon, and in **claypan** soils.



Importance of Soil Structure

- Soil structure influences the amount and nature of porosity.
- Structure controls the amount of water and air present in the soil. Not only the amount of water and air dependent on soil structure, but their movement and circulation are also controlled by soil structure.
- It affects tillage practices.
- Structure controls runoff and erosion.
- Platy structure normally hinders 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.

Factors Affecting Soil Structure

- **Climate:** Climate has considerable influence on the degree of aggregation as well as on the type of structure. In arid region, there is very little aggregation of primary particles. In semi- arid regions, the degree of aggregation is greater than arid regions.
- **Organic matter:** Organic matter improves the structure of a sandy soil as well as of a clay soil. In a case of sandy soil, the sticky and slimy material produced by the decomposing organic matter and the associated microorganism cement the sand particles to form aggregates. In the case of clayey soil, it modifies the properties of clay by reducing its cohesive power. This helps making clay more crumbly.
- **Tillage:** Cultivation implements break down of large clods into smaller fragments and aggregates. For obtaining good granular and crumbly structure, an 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.
- **Plant roots:** Large number of granules remain attached to roots and root hairs which help to develop crumb structure. Plant root secretions may also act as cementing agents in binding the soil particles. The plant roots, on decay, may also bring about granulation due to the production of sticky substances.

- **Soil organism:** 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.
- **Fertilizers:** Fertilizer like Sodium nitrate destroys granulation by reducing the stability of aggregates. Few fertilizers, for example, Calcium Ammonium nitrate, help in development of good structures.
- **Wetting and drying:** When a dry soil is wetted, the soil colloids swell on absorbing water. On drying, shrinkage produced strains in the soil mass give rise to cracks which break it up into clods and granules of various sizes.

Effects of Soil Structure on Other Physical Properties of Soil

- **Porosity:** Porosity of a soil is easily changed. In plate-like structure pore spaces are less whereas in crumby structure pore spaces are more.
- **Temperature:** Crumby structure provides good aeration and percolation in the 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 chiefly influences pore spaces. Platy structure with less total pore spaces has high bulk density whereas 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 colours of soil are generally due to poor drainage of soil. Platy structure normally hinders free drainage.

Stability of Soil Structure

- Stability of soil aggregates related to their break down their capacity to withstand disruption.
- Crumbs formation cannot remain stable indefinitely due to beating effect of rain, the pulverizing effects of cultivation operations, the slaking effects of rain and irrigation water and the grinding effects of dust laden blowing winds.
- In cultivated lands, the disintegration of crumbs is brought about (1) by removal of the cementing material or (2) by the shattering effect of the occluded air as the soil aggregates are wetted or slaked or (3) by mechanical pulverization.
- Stability of soil structure is influenced by the kind ions countering the negative charge of clays. Ca^{2+} , Mg^{2+} , Al^{3+} stabilize the soil structure. Na^{+} monovalent ion provides relatively weak bonding forces between particles.
- Soil high in Na^{+} are often poorly aerated because of lack of charge, structure related pore spaces. The physical state of these soil can be improved in Na^{+} is replaced by Ca^{2+}
- Stability of soil structure also depends on the organic matter.

Soil Colour

- Soil color is produced by the minerals present and by the organic matter content. Yellow or red soil indicates the presence of oxidized ferric iron oxides. Dark brown or black color in soil indicates that the soil has a high organic matter content. Wet soil will appear darker than dry soil. However, the presence of water also affects soil color by affecting the oxidation rate. Soil that has a high water content will have less air in the soil, specifically less oxygen. In well drained (and therefore oxygen rich soils) red and brown colors caused by oxidation are more common, as opposed to in wet (low oxygen) soils where the soil usually appears grey or greenish due to the presence of reduced (ferrous) iron oxide. The presence of other minerals can also affect soil color. Manganese oxide causes a black color, glauconite makes the soil green, and calcite can make soil in arid regions appear white.

- Organic matter tends to make the soil color darker. Humus, the final stage of organic matter breakdown is black. Throughout the stages of organic matter breakdown the colour imparted to the soil varies from browns to black. Sodium content influences the depth of colour of organic matter and therefore the soil. Sodium causes the organic matter (humus) to disperse more readily and spread over the soil particles, making the soil look darker (blacker). Soils which accumulate charcoal exhibit a black color.
- The colour of soil helps Pedologists to estimate the amount of air, water, organic material and certain elements in the soil.
- Soil colour influences greatly the soil temperature.

Soil Temperature & its importance

- Soil temperature is simply the measurement of the warmth in the soil. Ideal soil temperatures for planting most plants are 65 to 75° F. (18°C to 24° C).
- Temperature begins to affect soil characteristics from the stage of weathering of its parent rock. Temperature fluctuates frequently enough to crack and exfoliate hard rocks which are finally disintegrated enough to facilitate chemical weathering to take place.
- Increase in temperature accelerates chemical weathering of primary minerals in presence of adequate amount of moisture. Soil micro-organisms are able to function within a wide range of soil temperature i.e. from 25°C to 30°C. They decompose organic matter.

- The higher the temperature, more rapid is the decomposition of organic matter to release the nutrient especially nitrogen contained in it in the soluble form which are either absorbed by plant roots or lost by leaching. Hence soil organic matter content depends on mean annual soil temperature.
- So temperate region soils contain more organic matter than tropical region soils. The intensity of other microbial process taking place in the soil depends on soil temperature. For example nitrification takes place best at a temperature varying from about 27°C to 32°C.
- The soil must be warm and moist enough for the seeds to germinate. Seeds of different crops germinate at different temperature e.g. maize begins to germinate at a temperature varying from 7°C to 10°C, The soil temperature should be 10°C to 29°C and 4°C to 10°C for maximum germination and growth of maize and wheat and peas respectively.

- Potato tubers sprout best and potato crop grows best at 16°C to 21°C. The optimum temperature for emergence of cabbage and pinch seeds vary from 8°C to 11°C, that for emergence of beets and cauliflower seeds varies from 11° to 18°C.
- If the temperature of the soil is very low then seeds either do not germinate or germinate very feebly. Seeds may be injured in very hot soil.
- Temperature affects the rate of entry of water in the seed. It therefore controls the germination of seeds when it affects the development of plumule and the radicle when plant grows, photosynthesis and respiration are influenced by temperature of the soil which also influences the growth of roots and absorption of nutrients by them. Most of the warm season i.e. kharif crops grow best at a temperature of about 25°C.
- Cold soils tend to retard the absorption of phosphate by plant roots from it. This may be remedied by draining them. Drainage tends to warm these soils up.

- Alternate freezing and thawing of soils results in the lifting up of roots of plant. This phenomenon is known as heaving of soils. Roots get broken by this phenomenon.
- However alternate freezing and thawing of soil improves the structure of cloddy soil if it contains moderate amount of moisture but destroy the soil structure if the soil contains excessive moisture.
- Anhydrous ammonia should be applied at a depth of 10 cm when the soil is at 10°C or less at 10 cm depth because ammonium ions are very slowly converted to nitrate below 10°C. So leaching loss of nitrate is less.

Factors Affecting Soil Temperature

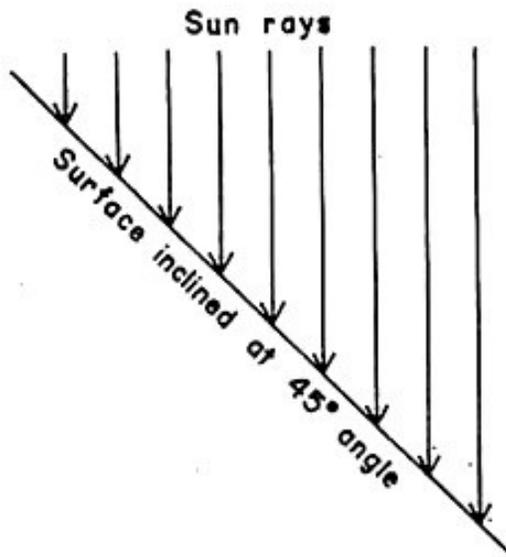
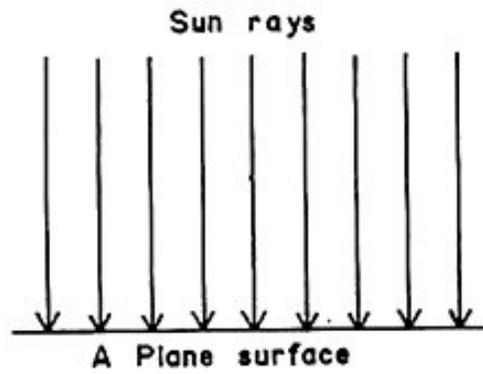
- **(i) Nature of the soil:**

Inorganic vs. Organic:

- As the average specific heat of dry inorganic soil is about 0.22 cal/gm. and that of humus is about 0.44 cal/gm. so dry inorganic soil would warm up quicker and also would cool down quicker than the dry organic soil.
- This means that organic soils, once they have been warmed up, will remain warm for longer period, than inorganic soils. Hence organic soils remain warmer in winter and cooler in summer than the inorganic soils because the former warms up slowly in summer and cools down slowly in winter in comparison to the latter.
- **(ii) Soil moisture content:**
- As the specific heat of water is 1 cal/gm and the average specific heat of dry inorganic soil is 0.22 cal/gm., so the specific heat of the soil increases with the increase in its moisture content as shown below:

- Suppose the soil contains 20 per cent moisture on weight basis. This means that 100gms of a dry mineral soil has absorbed 20gms of water.
- Heat required to raise the temperature of 100gms of dry inorganic soil by 1°C is $0.22 \times 100 = 22$ calories.
- Heat required to raise the temperature of 20gms of water by 1°C is 20 calories.
- Therefore the heat required to raise the temperature of $100 + 20 = 120$ gms of moist soil by 1°C is $22 + 20 = 42$ calories
- Therefore the heat required to raise the temperature of 1gm of moist soil will be $42/120 = 0.35$ calories.
- Therefore the specific heat of the inorganic soil has increased from 0.22cal/gm. to 0.35cal / gm. when the soil moisture content has increased from 0 to 20 per cent.
- Hence moist soil remains cool in summer and warm in winter because it warms up slowly in summer and cools down slowly in winter.
- As water evaporates especially in summer from moist soil, so it loses heat and cools down. Hence moist soil remains cooler than dry soil in summer.

- **(iii) Soil texture:**
- The specific heat of pure quartz is 0.17cal/gm. and that of pure kaolinite is 0.24gms /cal. clayey soils contain more humus and more moisture, so the specific heat of average clayey soil is more than that of the sandy soil.
- Therefore sandy soils would warm up quicker in summer and cool down quicker in winter than clayey soils. In other words, clayey soils remain cooler in summer and warmer in winter than sandy soils because the former warms up more slowly in summer and cools down more slowly in winter than the latter.
- **(iv) Slope of the land or Topography:**
- The angle at which the sun rays meet the land surface, affect the amount of solar radiation reaching the unit area of the land surface. If the same solar radiation reaches the plane surface of the land, and the land surface inclined at an angle against the horizon line, then it would meet more area of the land in the latter case than Sun rays in the former case as illustrated in Fig.
- So the amount of solar radiation received by the unit area of the land surface would be more on plane land surface than on the inclined land surface. Hence the soil would warm up quicker in the former case than in the latter case.



Effect of land slope on solar radiation reaching the unit area of the surface of the land.

- **(v) Vegetative cover of the land surface:** Bare soil absorbs heat and becomes very hot during summer very quickly and becomes very cold during the winter. This will not happen, if the surface of the land is kept covered with organic matter which would insulate the soil. So the soil will neither become too hot nor too cold.
- **(vi) Soil Depth:** Heat is conducted very slowly from the surface to the subsurface and back. So the temperature of the subsurface soil remains lower in summer and higher in winter than the surface soil.
- **(vii) Soil colour:** Suppose a black coloured soil and a white coloured soil are located side by side and both the soils are absolutely dry and do not contain any humus. As black coloured substance absorbs heat and a white coloured soil reflects heat incident on them, so under these circumstances only, the black coloured soil would be warmer than the white coloured soil.
- However usually a black/darker coloured soil contains more clay and therefore more humus and moisture than a white/light coloured soil, so the former may not be warmer than the latter.

- **Heat Balance of Soils:** The heat balance of a soil refers to the gains and losses of heat energy. Some portion of the incoming radiation is reflected back to the atmosphere while some portion of it is absorbed by the soil surface. A dark coloured soil may absorb 80 % of the incoming solar radiation while a light coloured sand may absorb 30 % of it. The albedo is the amount of reflected solar radiation.
- Albedo of soil and water are less than 10 % and about 20 % respectively. More than half of the incoming solar radiation is reflected from the snow whose albedo is more than 50 per cent.
- Some part of the solar radiation is expended for evaporating water, some other part of it is expended for heating the soil and some part of it is expended for heating the air while the remaining part of it is reradiated from the surface of the earth. A gain of heat to the soil and its losses from the soil balances each other in the long run.
- **Daily and Seasonal Variation in Soil Temperature:**
- During the day the soil temperature is maximum between noon and 2.00 p.m. and minimum during the night and morning. The average monthly temperature is usually highest in June and minimum in December and January. The variation in soil temperature decreases as the soil depth increases. Soil which remains covered with vegetation has undergone less variation in temperature than bare unprotected soil.

- **Control of Soil Temperature:**

- In a cold climate, the soil may be kept warmer by keeping it covered with some organic matter called mulches and draining the soil. Mulches also keep the surface of the land cool during the hot summer season.
- Organic matter mulches increase the infiltration of water in the soil; so the soil remains moist and therefore takes longer time to warm up in summer and to cool down in winter. Light coloured organic matter mulch also reflects some solar radiation incident on the land surface.
- The surface of the soil may be kept covered by dark coloured plastic mulches which would absorb more incoming solar radiation, prevent the soil from radiating heat and reduce the evaporation of water from the soil. The soil may thus be kept warm by keeping it covered with dark coloured plastic mulches during the winter.

Soil Density

- Density of soil is defined as mass per unit volume.
- Average density of soil is 2.65 gm/mL.
- It varies with degree of weathering.
- It is expressed in two terms: a) Particle density b) bulk density
- Particle density: It is average density of soil particles not including fluid space or pore space and usually expressed in gm/mL. The weight of the soil is usually expressed as specific gravity. True or absolute specific gravity represents the average specific gravity of the soil particles only. Apparent specific gravity is the specific gravity of the soil particles plus pore space.

- Specific gravity of soil particles =
$$\frac{\text{Particle density}}{\text{Density of water}}$$

- Bulk density: Dry weight of unit volume of soil inclusive of pore spaces is called bulk density.
- It changes with changes with change in total pore space of soil.
- It give the knowledge of porosity of soil.
- Texture and structure of a soil , its total pore space and organic matter contents are related to bulk density.
- It helps in better cultivation of crop.

Porosity of Soils

- It is the percentage pore space, by volume, in soil. It can be calculated from its absolute and apparent specific gravity by the formula:

$$\% \text{ Pore space} = 100 - \frac{[\text{apparent sp.gr.}]}{[\text{absolute sp. gr.}]} \times 100$$

- It gives an idea of the total pore space present on a soil or the percentage of soil volume that is not occupied by soil particles.
- Porosity of soil decreases in the particle size in the pore spaces and depth of soil.
- The pore spaces are responsible for better plant growth because they contain enough air and moisture.
- The percentage of solids in soil can be calculated by comparing bulk density and particle density multiplied by 100.
- Pore spaces is greatest soon after ploughing but diminishes steadily as the soil settles down.

Surface Soil

- Surface soil is defined as the immediate uppermost loose layer of the earth consisting of organic matter and soil organisms suitable for plant growth. It is generally called furrow slice soil layer (0-15 cm depth) and fertile soil.
- It is completely weathered.
- Surface soil is dominated by finer particles like silicate clays.
- Surface soil is porous and friable.
- Aeration status of surface soil is good and exchange of gasses between atmosphere and soil air takes place.
- The number and activity of soil microorganisms is very high.
- Relatively higher organic matter content due to presence of higher biomass on the soil surface.
- Due to presence of high organic matter content the colour of surface soil is deep brown or dark.
- It is fertile. Most of the essential plant nutrients are present.
- Surface soil has no hard pan.
- It has good physical management condition because of surface soil.
- Cation exchange capacity is very high.

SubSoil

- Sub-soil is defined as the compact soil below the furrow slice (0-15 cm depth) soil layer which cannot be cultivated by tillage operation. It is generally poor in nutrient status and organic matter and hence it is less fertile than that of surface soil.
- Sometimes in the sub-soil there is a formation of hard pan that cannot allow water to move down below the hard layer formed either due to accumulation of clay particle or formation of insoluble CaCO_3 layer resulting stagnation of water on the soil surface that affects plant growth.
- It is partially weathered.
- Sub-soil is dominated by quartz particles and other coarse fragments of minerals.
- The sub-soil is more massive and compact.
- Aeration status of sub-soil is very poor and hence exchange of gases is very much limited.
- The microbial population and their activity are very low.
- Due to lack in plant and animal residues in the sub-soil, the amount of organic matter is very low.

- The colour of sub-soil is light and sometimes may be light yellowish colour depending on the nature and kinds of un-weathered materials.
- It is less fertile; very few essential plant nutrients are present.
- Sub-soil sometimes has hard pan.
- It has poor physical condition.
- Cation exchange capacity is low.

Functions of Soil

- Soil performs three fold functions viz. (1) Chemical (2) Physical and (3) Biological
- **Chemical functions:** Chemically soil is a store house of nutrients due to presence of a large number of compounds of both organic and inorganic origin. Inorganic compounds supply nutrients like sodium, calcium, potassium, sulphur etc. while organic compounds mainly supply nitrogen, hydrogen which is taken by plants from water, oxygen partly from water and partly from soil air, while carbon is taken from carbon dioxide of the atmospheric air.
- **Physical functions:** Soil acts as a mechanical support for growing plants. The plant is able to stand erect because of the hold exerted by the soil on plant roots. The roots are reunified and they are anchored in soil mass. The soil acts as reservoir of water and air. Plants absorb water through their roots from the reservoir and the roots breathe in oxygen from the air stored in soil mass. The soil stores the sun's heat and supplies it to the growing plant.

- **Biological Functions:** Soil is a habitat of very large number of organisms like worms, insects, fungi and bacteria.
- Worms like nematodes and earthworms aerate the soil, disintegrate and mix its constituents by passing large quantities of soil through their body which is ejected as worm casts.
- The ejected material is in a more pulverized condition and is more fertile than original soil.
- Earthworms transfer soil from lower layer to the surface.
- The burrows made by other organisms like insects, rats, moles, facilitate the entry of air and water into lower layers thus helping aeration and drainage.
- Microorganisms like protozoa, algae, fungi act as scavengers in removing dead plants and animals from the surface soil.
- They decompose dead plants and animals and convert the complex compounds like proteins, cellulose into simple substances like nitrates, carbon dioxide which serve as plant nutrients.

Soil Reaction

- Soil shows three types reaction
 - a. Acidic-pH from 0 to 7
 - b. Alkaline- pH from 7 to 14
 - c. Normal- pH from 6.0 to 8.5
 - d. Neutral – pH 7

Importance of soil reactions

- It influences crop growth both directly and indirectly. Many plants grow well in neutral soil. The availability of plant nutrients depends on the prevailing soil reaction. Fe, Mn, Zn, Cu, are available in acidic soil. Availability of phosphates also depends on the soil reactions.
- It also influences soil structure. The cations present in soil control the aggregation of colloidal clay.
- The activity of micro organisms, which help in plant growth and crop production also depends on soil reaction. Most micro organism are active in neutral or slightly alkaline soil.
- The need of fertilizers depends on soil reaction.
- It affects the quality of crop by influencing the soil borne diseases.
- The rate of release of plant nutrients by weathering of rocks, soil solutions ion exchange depends on soil reaction.
- It helps to predict plant nutrient deficiencies at various pH values.
- It affects the physical condition of soil. The soil pH value above 8.5 indicates the presence of considerable amount of Na and a dispersed soil colloid

Factors controlling soil reaction

- The factors influencing soil reaction are:
 1. Nature
 2. Concentration
 3. Type of colloidal material
 4. Nature of exchangeable cation
 5. Parent Material
 6. Climate
 7. Culture practices
 8. Soil/water ratio
 9. Oxidation-Reduction State of Soil
 10. Percentage Base Saturation and Kind of Adsorbed Base
 11. Native vegetation

- **Nature of Soil Colloids:** The colloidal particles of soil (clay and humus) influence soil reaction to a great extent. When hydrogen (H^+) ion forms the predominant adsorbed cations on soil colloids (clay and humus) the soil reaction becomes acidic.
- **Soil Solution:** The soil solution comes a number of salts dissolved in water. The cations of the salts inter-mingle or mix together with those of the diffuse double layer of the clay colloidal particles and increase the concentration.
- In other words, the concentration of cations in the bulk of the solution is more or less the same as that near the particle surfaces.
- For a base unsaturated soil, a large number of hydrogen ions (H^+) dissociating into the solution. This increases the acidity of the soil solution or lowers its pH.
- Under field conditions, the concentration of salts varies with the moisture content of the soil. The more dilute solution, the higher the pH value. Hence the pH tends to decrease as the soil gets progressively dry.

- Soil reaction is also influenced by the presence of CO_2 in soil air liberated from plant roots, micro-organisms and decomposition of organic matter. As the concentration of CO_2 increases, the soil pH falls or decreases.
- **Climate:** Rainfall plays an important role in determining the soil reaction. In general, soil formed in regions of high rainfall are acidic (low pH value) while those formed in low rainfall regions are alkaline (pH value high).
- **Soil Management:** Cultural operations in general tend to increase soil acidity. They make an acid soil more acidic and an alkaline soil less alkaline. As a result of constant cultivation, basic cations are lost from the soil through leaching and crop removal. Besides, the continual use of fertilizers is also responsible for the changes in soil reaction. Acidic fertilizers like ammonium sulphate make the soil acidic, while basic fertilizers like sodium nitrate (NaNO_3) make the soil more alkaline in reaction.

- **Oxidation-Reduction State of Soil:** The ions of certain substance present in the soil change their valency depending upon the oxidizing or reducing conditions prevailing in the soil. Iron (Fe) and manganese (Mn) ions change their valency with the change in aeration.
- Under aerobic conditions these ions (Fe and Mn) are present in their oxidised state as their higher valence (Fe^{3+} and Mn^{4+}), whereas under anaerobic or reduced conditions their valencies are reduced to ferrous (Fe^{2+}) and manganous (Mn^{2+}) state.
- This brings about a change in soil reaction and the pH is increased. Under similar reduced conditions, sulphur is usually present as sulphide (S^{2-}). Upon aeration sulphur is converted to its oxidized sulphate (SO_4^{2-}) and is available to plant. This also increases the soil acidity and lowers the soil pH.
- **Percentage Base Saturation and Kind of Adsorbed Base:** Soils having low percentage base saturation show acidic reaction. Sodium saturated soils have much higher pH values than those dominated by calcium and magnesium.

- **Native vegetation:** Soils often become more acid when crops are harvested because of removal of bases. Type of crop determines the relative amounts of removal. For example, legumes generally contain higher levels of bases than do grasses. Calcium and Mg contents also vary according to the portion (s) of the plant harvested. Many legumes release H^+ ions into their rhizosphere when actively fixing atmospheric N_2 . The acidity generated can vary from 0.2 to 0.7 pH units per mole of fixed N.
- **Parent materials:** Soils developed from parent material of basic rocks generally have higher pH than those formed from acid rocks (e.g. granite). The influence of parent material is not very important as it is completely masked by the climatic conditions under which the soil is developed.
Precipitation: As water from rainfall passes through the soil, basic nutrients such as calcium (Ca) and magnesium (Mg) are leached. They are replaced by acidic elements including Al, H and manganese (Mn). Therefore, soils formed under high rainfall conditions are more acid than those formed under arid conditions.

Soil Solution

- Mixture of soil moisture with solids and gases is called soil solution.
- Soil solution is of two types: 1) Inner 2) Outer
- Inner soil solution: It is the mixture of fine particles and moisture. The concentration and composition of solute is in equilibrium with the solid phase of soil.
- Outer soil solution: It is the liquid in large capillary spaces having different concentration than solute particles.

Composition of soil solution

- Soil contains number of salts in solution, which are present both in ionic and molecular forms. In cultivated soils, the solution is dilute so they appear in ionic state while during dry spell they appear in molecular forms.
- Of all the cations Na^+ , Mg^{2+} , Ca^{2+} and K^+ are present to the greatest extent.
- In normal soil Ca^{2+} predominates while in saline form excess of Na^+ is present.
- In acid soil H^+ ion is present in large amount.
- Anions among bicarbonates, sulphate and chloride ions are present in excess. In alkaline solution hydroxide ion present in large quantity.

Factors affecting the composition of Soil Solution

- Type of soil
- Moisture content
- Action of growing plants
- Action of soil microorganisms
- Adsorption of colloidal complex
- Leaching effect
- Season
- Cultivation

- The amount of nitrate is highest when the crop is sown and lowest after it is harvested.
- Phosphate ions concentration remains fairly constant in soil.
- Soils formed in arid regions or under restricted drainage usually have more concentrated soil solution than those formed in temperate and most tropical regions or those having free drainage.
- The concentration as well as composition of soil solution is changed by growing plants.
- Soil micro-organisms help to increase concentration of soil solution.
- It is also changed by the rate which colloidal complex absorb ions from soil.
- Nature of soil solution is also affected by continuous leaching of certain ions that are not adsorbed by colloids or if they are present in excess in soil.
- Season variations, especially temperature and rainfall change the concentration of soil solution. Concentration of soil solution varies directly as temperature and inversely as rainfall.

- Cultural operations increase the solubility of soil constituents and hence the concentration of soil solution.
- Its concentration and composition is also changed by addition of manures, fertilizers and soil amendments.

Soil solution and Soil productivity

- The main function of soil is to supply mineral nutrients to the growing plants.
- The crop producing capacity of soil is linked with its nutrients supplying power.
- Normal good soil contains more concentrated soil solution than poor soil.
- The crop production is also influenced by the nature and proportion of the various ions constituting the salts present in the soil solution.
- Soil fertility depends upon the proportion of Ca^{2+} and Na^{+} ions.
- Fertile soils usually have a $\text{Ca}^{2+} : \text{Na}^{+} > 1$.
- Wherever the proportion of Na^{+} ions increases to reduce the ratio to less than one, the soil becomes less productive and in extreme cases barren.
- A soil supplying a greater amount of nitrate and phosphate ions during the crop growing period is usually more productive.

Factors Controlling Soil Reaction

- Nature
- Concentration
- Type of colloidal material
- Nature of exchangeable cation
- Parent material
- Climate
- Culture practices
- Soil/water ratio

Reserve and active acidity

- Acid clay contains excess of H^+ ions. Concentrations of H^+ ions in diffused double layer is greater than in true solution.
- The H^+ ions present in the diffuse layer is known as reserve exchangeable or potential acidity.
- The H^+ ions present in soil solution give rise to active acidity.
- Both the H^+ ions are in dynamic equilibrium.
- In case of depletion of H^+ ions from soil, the reserve H^+ ions come forward and maintain the acidity of soil and thus maintain the pH.
- A definite change in pH will only take place if all the available H^+ ions are completely neutralised and ^-OH ions begin to appear in solution.

Buffer Action

- The pH of an acid clay does not change on addition of an alkali or alkaline solution because of the dissociation of H^+ ions from the colloidal surface into soil solution. The resistance offered by the colloidal particles to the change in reaction is called Buffer action.
- This action is effective only within certain pH range.
- The range depends on the type of acid or base present.
- As soon as the acid or base buffer is neutralised, the buffer action disappears.

Buffer Capacity

- A number of substances especially weak acids, both mineral and organic and their salts possess buffer action as their power of dissociation is very poor.
- H_2CO_3 , H_3BO_3 , H_3PO_4 , acetic acid, citric acid are the weak acids which are generally present in the soil aqueous form and liberate very little amount of free H^+ ions.
- Clay minerals which are complex aluminosilicic acid are also weak acid.
- The colloidal complex of these substances act as a powerful buffer in soil and does not allow rapid and sudden change in soil reaction.
- The buffer capacity of soil lies in the reserve or adsorbed H_2 or cation content of the colloidal complex and it varies with its cation exchange capacity.

Importance of Buffer Action in Agriculture

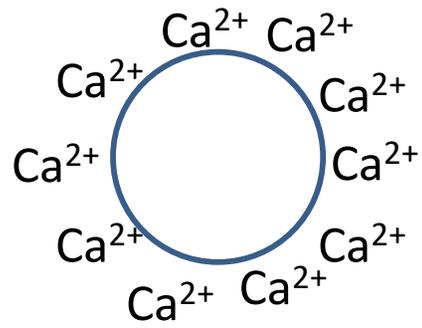
1. It regulates the activities of soil influenced by soil reaction.
2. The buffering action keeps the availability of plant nutrients at its optimum.
3. It stabilises the pH of soil.

Ion Exchange

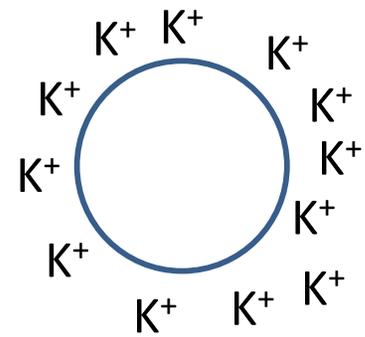
- The most of the activity of soil resides in the colloidal complex which is formed by fine particles of clay and humus.
- Complex colloidal has tendency to exchange ions when it comes in contact with an electrolyte.
- Both cations and anions take part in this exchange.
- It helps in retention and liberation of plant nutrients such as Ca, Mg, K, P.
- It controls soil structure and crumb formation by providing colloidal clay with the right type of adsorbed cation.
- It imparts stable structure to soil and controls vital role in reclamation of acid and alkaline soils.
- It also influences the effect of fertilisers and fertilisers practices.

Cation Exchange

- When an ordinary soil is brought in contact with an electrolyte solution like KCl a part of potassium is adsorbed by the soil and an equivalent quantity of cations adsorbed by soil colloids is liberated in the solution. During the reaction equivalent quantities of cations are exchanged and the reaction is localised at the surface of the colloidal particles. This process is known as Cation Exchange or Base exchange and the cations are called exchangeable or replaceable cations or bases.
- It is a reversible reaction.



Ca-clay



K-clay

Exchange of cations

Mechanism of cation exchange

- It is based on electro kinetic theory of ion exchange.
- According to this theory, the adsorbed cations forming the outer shell of the ionic double layer are supposed to be in a state of oscillation, when suspended in water, forming a diffuse double layer.
- Due to these oscillations some of the cations move away from the surface of the micelle.
- In the presence of the solution of an electrolyte, a cation of the added electrolyte slips in between the inner negative layer and outer oscillating positive ion.

- The electrolyte cation is now adsorbed on the micelle and surface of cation remains in solution as an exchanged ion. Thus exchange of cations take place.
- The rapidity exchange depends upon zeta potential, which varies with the nature of the adsorbed cation, its size and hydration.
- Cation exchange also depends on the concentration of ions in the replacing solution, nature of colloidal and type of clay mineral.
- Exchangeable cations present in agricultural soils are Ca^{2+} , Mg^{2+} , K^+ , NH_4^+ and H^+ .
- Black soil contains a greater amount of total exchangeable cations than alluvial soil or lateritic soil.

Cation Exchange Capacity(C.E.C.)

- **Cation-exchange capacity (CEC)** is a measure of how many cations can be retained on soil particle surfaces.
- It also represents the total cation adsorbing capacity of soil.

Base Saturation

- It is the total exchangeable bases (Ca, Mg, K and Na) expressed as a percentage of the total cation adsorbing or cation exchange capacity of a soil and is given by

$$\frac{100XS}{T}$$

- Where, \bar{V} = % base saturation, S = Total exchangeable bases
 T = C. E. C.
- The difference between C. E. C. and total exchangeable bases ($T-S$) gives the extent of unsaturation or the amount of exchangeable H_2 present in a soil.
- The replacing power of monovalent increases as $Li < Na < K < Rb < Cs < H$ and for divalent cations $Mg < Ca < Sr < Ba$.
- In case of mixture of monovalent and divalent cations replacing power is $Na < K < NH_4 < Mg < Ca < H$.

Anion Exchange

- The silicate clay minerals, the sesquioxide clay as well as the organic colloidal material possesses the power of adsorbing and exchanging anions from solutions.
- Anions such as SO_4^{2-} , CO_3^{2-} , and HCO_3^- can lower cation adsorption in an exchange reaction by forming complex ions or ion pairs.
- They lower the activities or effective concentrations of the respective free cations.
- The phenomenon of anion exchange assumes importance in relation to phosphate ions and their fixation.
- The exchange is brought about mainly by the replacement of ^-OH ions of clay mineral.

- The adsorption of phosphate ions by clay particles from soil solution reduces its availability to plants. This is known as phosphate fixation.
- It's a reversible reaction.
- -OH ions originate not only from silicate clay minerals but also from sesquioxide clay i.e. hydrous oxides of iron and aluminium present in soil.
- Phosphate reacts with it to form insoluble hydroxy phosphate of iron and aluminium.
- The greater the amount of sesquioxide clay in soil, greater is the fixation. This reaction is reversible under slightly acidic conditions but irreversible under strongly acidic conditions.

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Thank You