Unit V

ION EXCHANGE IN SOILS

Ion exchange is defined as a reversible process by which cations and anions are exchanged between solid and liquid phases and between solid phases, if in close contact with each other. Adsorption is defined as a phenomenon by which an increase in concentration or an accumulation of an ion on a solid occurs due to ion exchange or other reactions. Desorption is a phenomenon by which the replacement or release of an adsorbed ion species occurs.

Ion exchange property is almost entirely to the clay and silt fractions and the organic matter. The soil particles are amphoteric in nature and soil particles have the power to hold both cations and anions. The charge density and potential are higher on edges and corners and in furrows and cavities as compared to flat (plane) surfaces and consequently in exchange phenomena are probably concentrated more in those sites.

The exchangeable ions are held to the surface by coulomb forces and van-der-waal's forces. In most of the soils the exchangeable cations are $Ca^{2+,}$ Mg^{2+}, H^+, K^+, Na^+ and NH_4^+, of which Ca^{2+} is the dominant exchangeable ion. In strong acid soils $Al(OH)^{2+}$ may act as a dominant exchangeable ion. In alkali soil Na^+ becomes dominant and the most common anion SO_4^{2-}, Cl^- and HCO_3^- etc.

Cation Exchange

The process of replacement of cations adsorbed on exchange complex by other cations is called cation exchange. The reaction of cation exchange takes place rapidly and the inter change is chemically equivalent. The exchange of cations in the soil takes place between.

1. Cations in the soil solution and those on the exchange complexes of soil (clay crystal and humus)
2. Cations released by plant roots and those on the exchange complexes of soil.
3. Cation on the surface of either two clay crystals, two organic colloids; or a clay and humus particle.

All the cations are not adsorbed with equal tenacity, and the exchange complex does not possess same strength of negative charge at all points. The cation with less size and higher charge per unit size are held more strongly than other cations.

Power or replacement of cation; $H^+=Al^{3+}>Ca^{2+} >Mg^{2+} > K^+ = NH^{4+} > Na^+$

Cation Exchange capacity of soils (Thomas Way, 1850)

The sum total of the exchangeable cations that a soil can absorb is known as "Cation Exchange Capacity" of that soil. It is the amount of exchangeable cations per unit weight of dry soil. It is measured in mill equivalents of cations per 100 grams of soil (Recently cmol (p+) kg^{-1}). The milli equivalent is used because the number of negative charge sites in a given sample does not change, but the weights of cations, that may be adsorbed to those sites at one time do change because they have different weights.

Base Saturation : The percentage of total CEC satisfied with basic cations is termed base saturation. It is defined as the extent to which the exchange complex of a soil is saturated with exchangeable cations other than hydrogen and aluminum and it is expressed as a percentage of the total cation exchange capacity.

$$\%\, Base\ Saturation = \frac{m.eq.of\ basic\ cations\ per\ 100\ g\ soil}{Total\ CEC\ in\ m.eq.per\ 100\ g\ soil}$$

The degree of base saturation is an important property of soil which usually reflects the extent of leaching and weathering of soils. It is an indication of soil fertility. The ease with which adsorbed cations are released to plants depends on the degree of base saturation.

>80% - Highly fertile soils; 50-80% - Medium fertile; <50% - Low fertile

Liming is the common means by which the percent base saturation of soils is increased. As a general rule, the degree of base saturation of normal cultivated soils is higher for arid than humid region soils. Also, the degree of base saturation of soils formed from lime stones or basic igneous rocks is greater than that of soils formed from sand stones or acid igneous rocks.

Soils with larger amounts of organic colloids or 1:1 type clay colloids can supply the nutrient cations to plants at a much lower degree of base saturation than soils high in 2:1 type clay colloids.

The percent base saturation does provide numerical values of the amount of exchangeable hydrogen and aluminum ion species and this helps in predicting the amount of lime needed to neutralize soil activity.

Kind of adsorbed cations also affects the soil pH. With same base saturation percentage, the soil dominated by Na^+ cation presents higher pH values than the soil dominated by Ca^{2+} and Mg^{2+} cations.

Factors affecting CEC

1. More fine the soil more is the CEC
2. More humus content more is the CEC
3. 2:1 clay minerals have more CEC than 1:1 type minerals
4. In alkaline PH range, CEC would be more
5. Liming & Fertilization increases the CEC

Importance of CEC

1. The most important reaction in nature after photosynthesis.
2. It is an important reaction in correcting soil acidity and basicity
3. It alters soil physical properties
4. Through cation exchange mechanism (large cation exchanger), the percolating waters will be purified or altered (Ground water pollution is checked).
5. Plants absorb exchangeable cations by interchange or contact between the root hairs and colloidal complex.
6. The amounts of cations in the soil solution are intimately related to the exchangeable cations.
7. Offers buffering capacity to soils.

ANION EXCHANGE

Anion exchange occurs on positively charged sites exist on the edges of layer silicate minerals (1:1 type in particular) and surfaces of oxides (with low specific surface area), mainly under acidic conditions. The total amount of exchangeable anions held by a unit mass of soil, is termed as its anion exchange capacity. Anion exchange capacities are generally low and increases as the pH decreases or acidity increases. As the ratio of CEC/AEC of a layer silicate mineral increase, the adsorption of anions decreases. (Monmorillonite 6.7, Illite 2.3 and Koolinite 0.5). Acid soils in tropical and sub tropical regions containing hydrous oxides of Al and Fe exhibit much higher AEC than alkaline and calcareous young soils of arid and semi-arid regions.

Preference of anions for the positive sites : $SiO_4^{4-} > PO_4^{3-} >> SO_4^{2-} > NO_3^- = Cl^-$

$$Al – OH + H_2PO_4^- \longrightarrow Al\text{-}H_2PO_4 + OH^-$$

Like cation exchange, anion exchange largely determines the ability of soils to provide nutrient anions to plants properly.

Calculation of Base Exchange Capacity and Exchangeable Acidity

Problem: The CEC of a soil is 20m.eq./100g soil. The estimated amount of Ca is 0.160g/100g; Mg is 0.048g/100g; Na is 0.046g/100g and K is 0.117g/100g soil. Calculate the percent base saturation and base unsaturation or exchangeable acidity.

Solution: $Exchangeable\ calcium = \frac{0.160}{20} \times 1000\ = 8.0\ m.eq./100g$

$$Exchangeable\ magnesium = \frac{0.048}{12} \times 1000\ = 4.0\ m.eq./100g$$

$$Exchangeable\ sodium = \frac{0.046}{23} \times 1000\ = 2.0\ m.eq./100g$$

$$Exchangeable\ potassium = \frac{0.117}{39} \times 1000\ = 3.0\ m.eq./100g$$

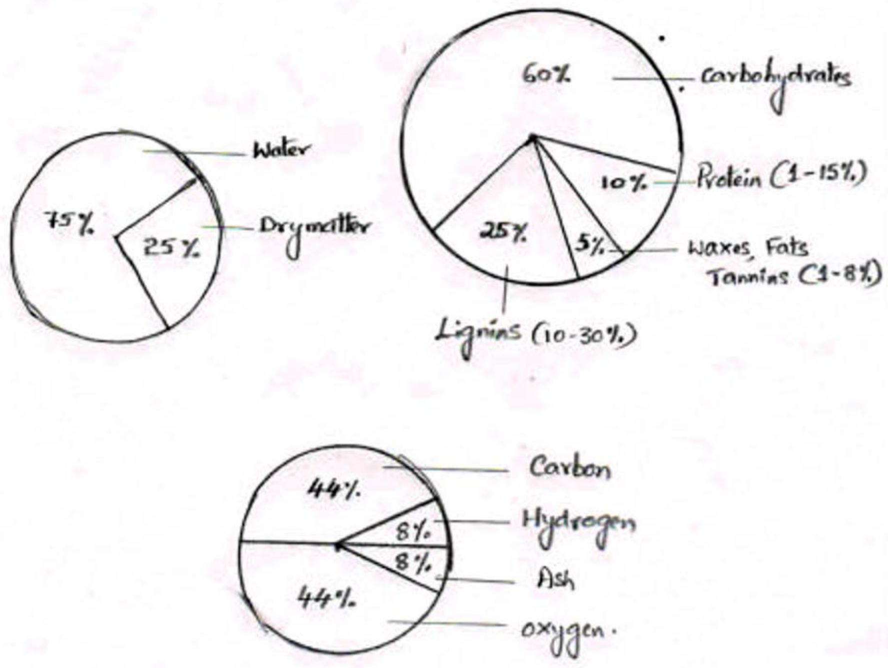
Total Exchangeable bases = 17 m.eq. / 100g

$$Percent\ Base\ Saturation = \frac{17}{20} \times 1000\ = 85$$

Exchangeable acidity or Base unsaturation = 100 – 85 = 15 %

Soil Organic Matter

Sources of soil organic matter: The original source of soil organic matter is plant tissue (leaves, roots and left outs of harvested crops). Animals are the secondary sources of organic matter (their bodies when their life cycles are consummated).



ORGANIC MATTER DECOMPOSITION

When organic tissue is added to soil three general reactions take place.

1. The bulk of the material undergoes enzymatic oxidation with CO_2, H_2O and energy and heat as the major products.
2. The essential elements such as nitrogen, phosphorous and sulphur are released and / or immobilized by a series of specific reactions relatively unique for each element.
3. Compounds very resistant to microbial actions are formed either through modification of compounds in the original plant tissue or by microbial synthesis.

The native flora of soil i.e. bacteria, fungi and actinomycetes are involved in the decomposition of organic matter. Different soil enzymes (protein substances) produced by these microorganisms are directly responsible for the decomposition by reducing the activation energy, necessary to breakdown the bonds of different organic materials.

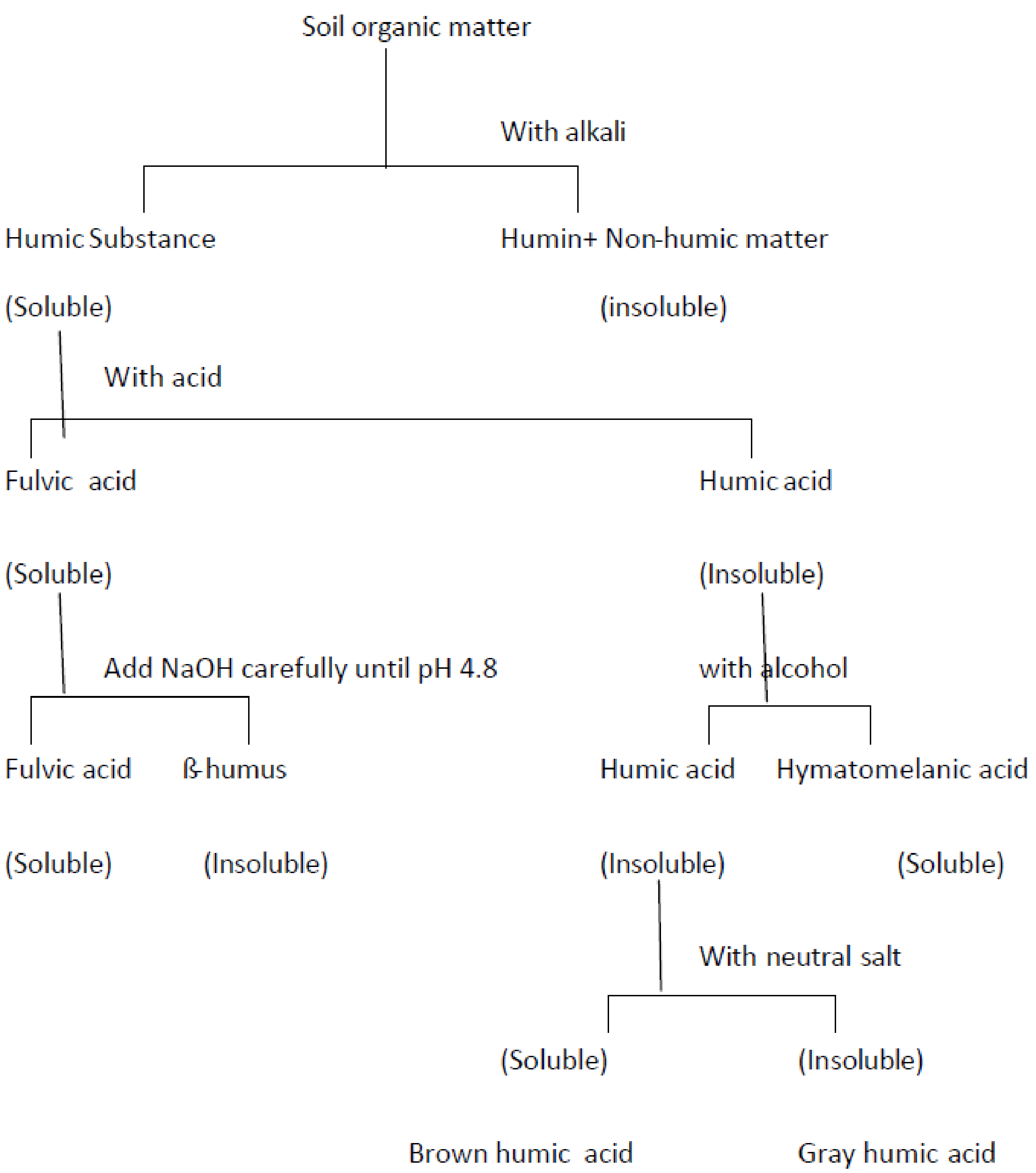
An enzyme is a substance, composed of proteins that are capable of lowering the activation energy of other selective compounds enough to allow the breaking of a particular bond under a particular environment.The action of enzyme to make a split easier does not use up the enzyme. An activator that is not consumed or changed by such a process is called catalyst. Many different enzymes are produces by a single organism and many organisms produce the same enzyme.

SOIL HUMUS

Humus is a complex and rather resistant mixture of brown or dark brown amorphous and colloidal organic substances that results from microbial decomposition and synthesis and has chemical and physical properties of great significance to soils and plants.

Fractionation of Humus or Soil organic matter

Soil humus, the complex array of substances left after extensive chemical and biological break down of fresh plant and animal residues, makes up 60-70% of the total organic carbon in soil. Because of the complexity, humus is often divided through solubility separations.



IMPORTANCE OF SOIL ORGANIC MATTER / HUMUS

Influence of Humus / Organic matter on soil physical, biological and chemical properties

1. Imparts dark color to soils
2. Supplies polysaccharides for binding soil particles for formation of aggregates (genesis of good soil structure)
3. Increases infiltration rate of water and provides better drainage
4. Increases water holding capacity
5. Reduces plasticity, cohesion, stickiness etc in clay soils
6. Reduces bulk density, there by influence porosity favorably
7. Through granulation, reduces wind erosion losses
8. Provides mulching (raw organic matter) and lowers soil temperature during summer. Acts as an insulator and retards heat movement between atmosphere and soil.
9. Reduces alkalinity in soils by releasing organic acids and CO2
10. With high adsorption capacity, it accounts for 30 -90% of the adsorbing power of mineral soils (Carboxylic group – 54% ; phenolic & enolic groups – 36%; imide group – 10%)
11. Acts as a buffering agent and reduces the likelihood damage from acids and alkalis.
12. With its solubilising effect, increses the availability of nutrients
13. Acts as a store house for nutrients. Organic matter is the source of 90-95% of nitrogen in unfertilized soils. Also supplies available ‘P’, ‘S’ and micro nutrients like Fe, Mn, Cu and Zn etc.,
14. Adsorbs temporarily the heavy metal pollutants and cleans the contaminated waters.
15. Serves as a source of energy for macro and micro organisms in soils and helps in performing various beneficial functions in soils (N - fixation, mineralisation etc.)
16. Acts as a chelate and increases the availability of micro nutrients
17. Various organic substances like vitamins, antibiotics and growth promoting substances namely auxins are produced by different micro organisms during decomposition of organic matter. Also some fungi-toxins are produced to control diseases.

Carbon : Nitrogen Ratio

Both mineralization and immobilization are accomplished by microbes under the influence of temperature, moisture and pH etc., These processes are more influenced by C/N, C/P and C/S ratios of decomposing plant residues.

An average proportion of C/N/P/S in soil humus is appropriately 140:10:1.3:1.3. The ratios recorded for C and P are some what more variable than for C and N, or C and S.

C:N Ratio	C:P Ratio	C:S Ratio	N.M	N.I
<20:1	<200:1	<200:1	Yes	No
>30:1	>300:1	>400:1	No	Yes
20-30:1	200-300:1	200-400:1	Neither gain nor loss	

C:N ratios of some organic materials

Material	C:N ratio or C/N
Microbial tissues	6-12
Sewage, Sludge	5-14
Soil Humus	10-12
Annual Manures	13-25
Legume residues and green manures	13-25
Cereal residues and straws	60-80
Forest Wastes	150-500

The quantity of carbon declines with the advancement of decomposition process. Similarly, the inorganic element released during mineralization process is also lost, by several means i.e. plant utilization, leaching, volatilization, conversion to insoluble compounds etc.,. It results in a stabilized C:N ratio to the soil i.e. 10:1 or 12:1.

Significance of C : N ratio in Soil Fertility:

1. C : N ratio determines the microbial activity and their proliferation
2. C:N ratio of organic residues determines the rate of decomposition of organic residues.
3. C : N ratio determines the net availability of nutrients to plants
4. The supply of nitrogen, phosphorus and sulphur are largely determined by C:N ratio of organic residues.

SOIL BIOLOGY

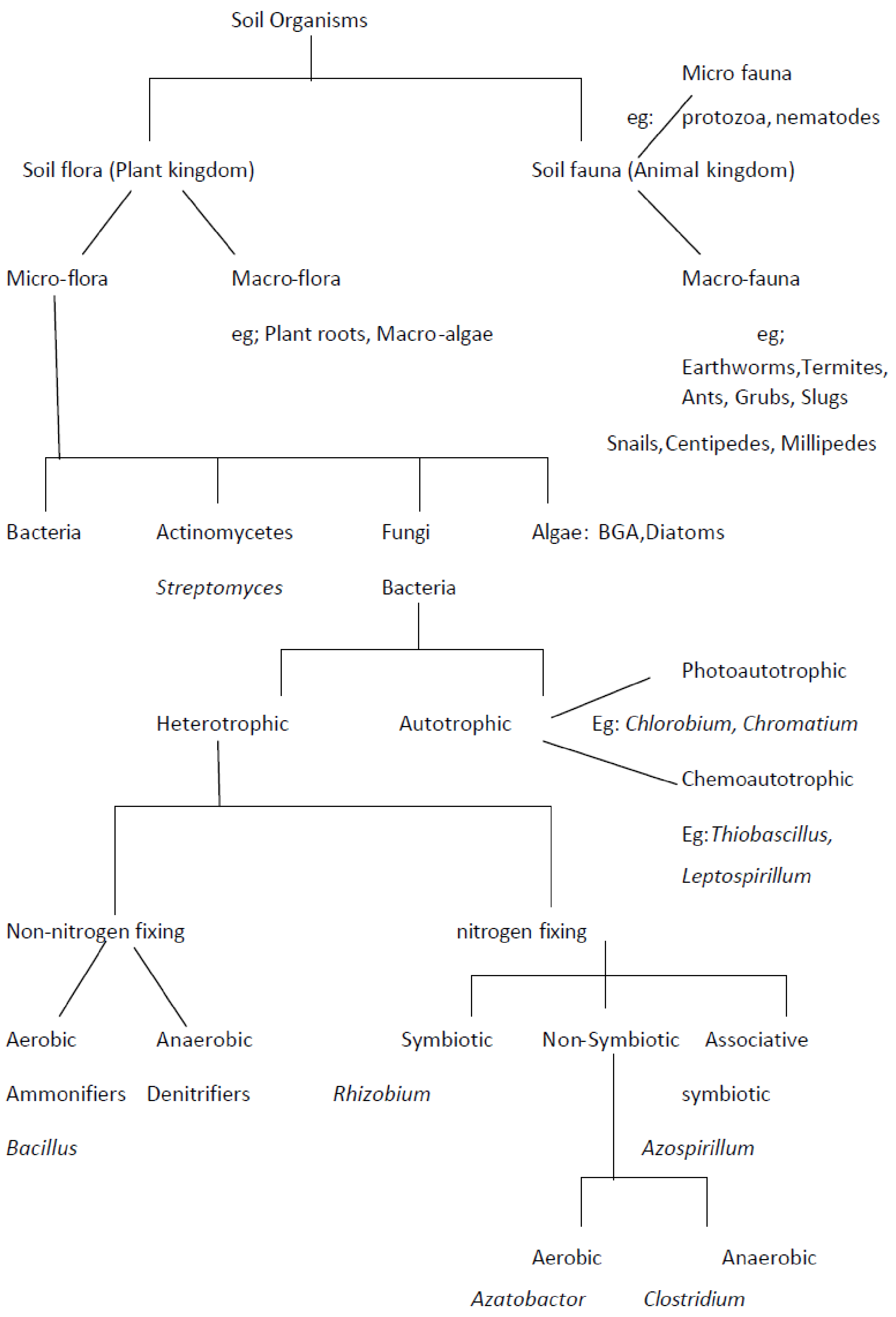
The soil is teeming with millions of living organisms which make it a living and a dynamic system. Under microscope it reveals a complex arrangement of soil particles and pore spaces filled with air and water. It is in these pore spaces that plant roots and millions of organisms develop, ranging from microscopic to macroscopic in size.

The organisms in the soil, not only help in development of soils but carryout a number of transformations facilitating the availability of nutrients to the plants. In the absence of the activities of these organisms, in soil, life on earth would have come to a halt, as all available nutrients would have ended up locked in the organic, disrupting the nutrient cycles.

Greek word Bios= life, logos=study

The study of living organisms in soil is called Soil biology.

Classification of soil organisms:



Fungi

Moulds | Yeasts | Mushrooms

Aspergillus, Pencillium

Fusarium, Mucor

Organisms number, Biomass and Metabolic activity

Biomass: Weight of organisms per unit volume of soil is called biomass. Soil organisms' number is influenced by many factors like climate, vegetation, and the physical and chemical characteristics of soils. The species composition in an arid desert will certainly be different from that in a humid forest area, which in turn would be quite different from that in a cultivated soil. Acid soils are populated by quite different species from those in alkaline soils. Similar differences are expected from tropical forest areas to cool temperate regions.

Forested areas support more diverse fauna than do grasslands, but the activity of flora and fauna is higher in grass lands. Cultivated fields are generally lower than undisturbed native lands in numbers and biomass of soil organisms especially the fauna.

Organisms	Number (Per gram) ODS	Biomass (kg/HFS)
Bacteria	10^8-10^9	450-4500
Actinomycetes	10^7-10^8	450-4500
Fungi Algae	10^5-10^6 10^4-10^5	1120-11200 56-560

Autotrophs : An organism capable of utilizing CO_2 or carbonates as the sole source of carbon and obtaining energy for life processes from the oxidation of inorganic elements or compounds such as iron, sulphur, hydrogen, ammonium and nitrites (chemoautotrophic) or from radiant energy (photoautotrophic)

Heterotrophs: An organism capable of deriving energy for life processes only from the decomposition of organic compounds and incapable of using inorganic compounds as sole sources of energy or for organic synthesis.

Bacteria : Bacteria are single cell organisms. They are known for rapid proliferation. They adjust quickly to changes in environment. Size will seldom exceed 4 -5 μm (length). Shape may be round, rod like or spiral. In the soil, the rod shaped ones seem to predominate.

Bacterial population vary from few billion to three trillion in each kilogram of soil.

Psychrophiles - <100 C

Mesophiles - 200C-400C

Thermophiles - >400C

Acidophiles - Thrive well in acid medium

Alkaliphiles - Thrive well in alkaline medium

Fungi : Like bacteria and actinomycetes, fungi contain no chlorophyll. They are longer than bacteria and heterotrophic in nature (Saprophytic in nature). Fungi are broadly grouped in to yeasts, molds and mushrooms, out of which molds and mushrooms are important in soils. Important molds in soils are Penicillium, Mucor, Fusa rium and Aspergillu Ppefer acid medium (4.5-6.5). Some fungi can tolerate even pH 9.0. Mushroom fungi are found in forests and grasslands. Mushroom fungi are not widely distributed like molds, but are of much significance especially in breaking down of woody tissue.

Actinomycetes: Thread / Filamentous bacteria. Next to bacteria in abundance. A common genus is streptomyces.

Algae : Chlorophyll containing organism. Aerobic. Photoautotrophic Ex:- Blue green algae (Anabaena, Nostoc, Oscillatoria, Tolypothrix etc).

Benefits of soil organisms

1. Organic matter decomposition O.M $\longrightarrow$ humus
2. Inorganic Transformations $NH_4^+ \longrightarrow NO_3^-$ and $S \longrightarrow SO_4^{2-}$
3. Nitrogen fixation
4. Solubilisation of insoluble phosphorous compounds
5. Solubilisation of insoluble Sulphur compounds(S oxidizing and reducing organisms)
6. Formation and development of soil
7. Production of soil enzymes, growth promoting substances and antibiotics
8. Detoxification of soil pollutants

9. Protect plant roots from invasion by soil parasites and pathogens.

MINERALIZATION: Mineralization is the conversion of an element from an organic form to an inorganic as a result of microbial decomposition.

The heterogeneous group of heterotrophic soil micro-organisms takes part in mineralization of organic nitrogen and converts it to inorganic nitrogen. The reactions go uninterrupted, as long as carbon source is available for microbes.

$$\text{Protein} \xrightarrow{\text{Enzymatic reaction}} \text{Polypeptides} \xrightarrow{\text{Enzymatic Hydrolysis}} \text{Amino acids, Amines} + CO_2 + \text{Energy}$$

Ammonification :

Process of conversion of amino acids to ammonia.

$$RNH_2 + HOH \xrightarrow{\text{Enzymatic Hydrolysis}} NH_3 + R\text{-}OH + \text{Energy}$$

$$NH_3 + H_2O \longrightarrow NH_4^+ + OH^- \text{ or } NH_3 + H_2CO_3 \longrightarrow 2NH_4^+ + CO_3^{2-}$$

IMMOBILIZATION: The conversion of the element from the inorganic to the organic form in microbial tissues or in plant tissues, thus rendering the element not readily available to other organisms or to plants, is called immobilization.

Nitrogen Fixation

Biological nitrogen fixation is the bio -chemical process by which elemental nitrogen is combined in to organic forms. It is carried out by a number of organisms including several species of bacteria, a few actinomycetes and blue green algae. The quantity of nitrogen fixed globally each year is enormous (175 million Mg), which is more than the nitrogen applied through chemical fertilizers. Although nitrogen is fixed by a number of different organisms a common mechanism appears to be involved in all the cases.

$$N_2 + 6H + 6e^- \xrightarrow{\text{Nitrogenase (Fe \& Mo)}} 2NH_3$$

$$NH_3 + \text{organic acids} \longrightarrow \text{Amino acids} \longrightarrow \text{Protein}$$

The site of nitrogen reduction is the enzyme nitrogenase, a two-protein complex consisting of a large ion, a molybdenum containing member, and a smaller companion containing iron.

Nitrogen fixing systems

N- Fixing System	Organism Involved	Plant Involved	Site of fixation	Nitrogen kg N/ha/year
Symbiotic				
Legumes	Rhizobium bacteria	Legumes	Nodules	50-100
Non-legumes	Frankia (Actinomycetes)	Alnus	Nodules	50-150
		Casuarinas		
	BGA(Anabaena)	Azolla(Fern)	Leaf	100-150
Associative	Azospirillum	Non -legumes	Rhizosphere	5-30
Non-Symbiotic	BGA (Oscillatoria)	Not involved with plants	Soil & Water	10-50
	Azatobacter, Beijerinckia, (aerobic)			5-30
	Clostridium (anaerobic)			5-20

DENITRIFICATION : In flooded soils the oxygen supply to soil is virtually cut - off because very less diffusion rate. Under such conditions, the facultative anaerobes namely Thiobacillus denitrificans, Thiobacillus thioparus (autotrophic) , Pseudomonas, Micrococcus, Achromobacter and Bacillus, during respiration, utilize the NO_3^- as terminal acceptor and reduce it to NO, N_2O and finally to N_2. In this fashion the nitrate leached from oxidized layer and the nitrate nitrified at the root rhizosphere will be denitrified.

$$4NO_3^- + 5H_2O + 4H^+ + 5C \longrightarrow 2N_2 + CO_2 + 7H_2O$$

The losses due to denitrification may range from 10 to 40 percent of the applied nitrogen. Of the denitrified gas, about 90 % is in the form of N_2. N_2O is lost at pH below 7.0 and causes atmospheric pollution. Denitrification is influenced by high organic matter content, moisture regime, soil type, Eh of soil, high temperature, supply of nitrate and cropping.

Phosphorous Solubilisation: The phosphorous element which is released during mineralization is likely to be converted to an insoluble inorganic compound. Some of the bacteria and other micro organisms are known to solubilise these compounds and make the phosphorous available to plants.

Bacteria --------*Bacillus megatherium*, Pseudomonas

P.Solubilisers

Fungi-----------*Aspergillus awamori*, Penicillium bilajii

P-Absorber ----------VAM fungi (Versicular arbiscular mycorrhizae

Glomus fasciculatum and *Gigaspora margarita.*

Among different phosphorus solubilisers fungi is more efficient, but not exploited commercially, as they do cause some diseases to crop plants also.

VAM is useful to explore more area and utilize phosphorus like immobile elements.

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 measure of nutrient status of soil which decides growth and yield of corp.

Factors affecting soil fertility

1. Natural factors or Pedogenic factors
2. Edaphic factors or Soil management factors

1. **Natural Factors:** are those which influence the formation of the soil. These include

   a. Parent material

   b. Climate and vegetation

   c. Topography and age of soil

a. Parent material:

- Rocks and minerals are the parent materials, act as very important raw materials for the formation of any soils. If the parent material is rich in plant nutrients, the soils formed from it are usually quite fertile. The property of soil depends on the property of parent rock.

Ex: a. Sandy loam soils (Red), formed from granite and granite gneiss are low to medium in fertility

b. Lime stone and Basalt rock which are easily weathered results fine textured, very fertile and dark colored (black) soil.

c. Soils derived from calcareous rock contain more P than the soil derived from granite.

d. Sandstone-leads to coarse textured, sandy soil of low fertility.

e. Shale- forms clayey soil, but not very fertile.

b. Climate and vegetation:

- They are interrelated factors as the amount and type of vegetation in an area depends on climate especially rainfall and temperature. These two factors in turn influence the type of soil fertility. Under heavy rainfall of humid region, the natural vegetation is forest, which develops more fertile soils due to accumulation of forest litter and organic matter.

- On the other hand, temperate soils are not very fertile compared to tropical soils because of the lesser decomposition of organic matter in soil due to very low temperature. The tropical soils are more fertile soils due to constant high temperature which helps in faster rate of disintegration and decomposition of organic matter in the tropics than in temperate regions.

- In semi arid conditions the natural vegetation is grass which leads to more accumulation of organic matter in soil surface layer due to fibrous root system, and good soil aggregation. These soils are hence more fertile than the area under forest vegetation.

c. Topography and Age of soil:

- The soils of hilly tracts are usually poor because of excessive leaching and erosion of the top soil. In sloppy land, the soils of low lying areas are usually richer because of the transportation and accumulation of soil and plant nutrients. Similarly, old soils are less fertile due to excessive weathering, leaching and continuous cultivation.

2. **Edaphic factors or Soil management factors :** Includes the entire soil conditions and their management practices that are concerned with addition or removal of plant nutrients.

   1. **Physical conditions of soil**

a. **Texture of soil:** Fine textured soils (clay rich) are having greater surface area, greater CEC and so better soil fertility than the coarse textured soils (sand rich).
b. **Structure of soil:** Well aggregated soils are more productive compared to non aggregated soils or loose soils.
c. **Soil water:** Clayey soil store more water than sandy soils, hence they are more productive
d. **Soil aeration:** Soil air containing oxygen is essential for root respiration, decomposition of soil organic matter and uptake of nutrients by plants. Higher CO2 content in the soil restrict the uptake of nutrients. Soil aeration decides oxidation and reduction process of soils.
e. **Soil temperature:** It is required for metabolic activity of plants, microbial activity and decomposition process. Temperature variations also affect the nutrient absorption and nutrient conversions in soil and ultimately plant growth.
f. **Soil compaction and tillage operations:** Compactness will decide the aeration status of soil and root penetration. It has direct effect on the ability of plant roots to absorb both nutrients and moisture from the soil. Tillage operations using heavy implements will destroy the good soil structure, make more compact soil which intern affect the soil fertility status.
g. **Soil reaction (pH):** Availability of nutrients in soils is greatly influenced by increase or decrease in soil pH. The neutral pH of 6.5-7.5 is optimum for good productive soils.
h. **Microorganisms:** Soil microorganisms improve the soil fertility as they help in decomposition of organic matter and nutrient mineralization in soil. They also involve in nutrients cycling by mineralization, fixation, absorption and solubilization of nutrients in soils.

2. **Root growth and extension:** Root performs absorption of water and nutrients needed for the plant. Root metabolism creates a nutrient demand. Dense and extensive root system helps better nutrient availability to plants.

3. **Organic matter content of the soil:** Higher the organic matter status higher will be the fertility status. Organic matter increases humus content hence, more CEC of soils. It acts as store house of various nutrients; it improves the physical properties of soil like structure, good aggregation of soil particles, aeration, and water holding capacity, solubility of the minerals and supplies "energy" for the growth and development of microorganisms.

4. **Cropping system:** Cultivation of same crop continuously in the same field without replenishment decreases the soil fertility. Thus, inclusion of various crops and cropping systems like double, mixed , relay, multiple cropping and crop rotation increases the soil fertility.

5. **Soil erosion:** Erosion is the physical removal of top soil by water and wind. As such it decreases the soil fertility and promotes soil degradation due to nutrients are being lost by erosion continuously along with soil.

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.

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 (CO_2, NO_2, N_2O, O_2), 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.

Criteria of Essentiality of Nutrients

This concept was propounded by Arnon and Stout (1939) and they considered 16 elements essential for plant nutrition. For an element be regarded as an essential nutrient, it must satisfy the following criteria:

1. A deficiency of an essential nutrient element makes it impossible for the plant to complete the vegetative or reproductive stage of its life cycle.
2. The deficiency of an element is very specific to the element in question and deficiency can be corrected /prevented only by supplying that particular element.
3. The element must directly be involved in the nutrition and metabolism of the plant and have a direct influence on plant apart from its possible effects in correcting some micro-biological or chemical conditions of the soil or other culture medium.

Table: Essential plant nutrients, chemical symbols and sources

Mostly from air and water ----(non-mineral)----		From soil and/or fertilizers --------------------(mineral)--------------------			
Element	Symbol	Element	Symbol	Element	Symbol
Carbon	C	Nitrogen	N	Iron	Fe
Hydrogen	H	Phosphorus	P	Manganese	Mn
Oxygen	O	Potassium	K	Zinc	Zn
		Calcium	Ca	Copper	Cu
		Magnesium	Mg	Boron	B
		Sulfur	S	Molybdenum	Mo
				Chlorine	Cl

The essential plant nutrients may be grouped into three categories. They are as follows:

1. Primary nutrients - nitrogen, phosphorus and potassium
2. Secondary nutrients - calcium, magnesium and sulfur
3. Micronutrients - iron, manganese, zinc, copper, boron, molybdenum, and chlorine

Functions of Carbon, Hydrogen and Oxygen

Carbon, Hydrogen and Oxygen form about 95% of the dry weight of plants and are obtained from CO_2 and H_2O. They are converted in to simple carbohydrates by photosynthesis and ultimately elaborated into complex amino acids, proteins and protoplasm. These are the major components of carbohydrates, proteins and fats.

Functions:

1. They play a dominant role in the process of photosynthesis and respiration in plants., They are involved in the formation of simple as well as complex organic compounds like carbohydrates, starch proteins etc.
2. Maintaining the structure of the plant cells.
3. They provide 'energy' required for the growth and development of plant by oxidative break down of carbohydrates, proteins and fats during their cellular respiration

Functions and deficiency symptoms of Nitrogen

Nitrogen plays a key role in the nutrition of plants. It is one of the principal growth promoting nutrient elements. Green plants are more markedly influenced by the deficiency of nitrogen than by any other element. It is absorbed by plants in the ionic form of NO_3^-, by most of the plants. Some plants require NH_4^+ form (rice). When applied as foliar nutrition, NH_2 (amide from) is also absorbed. It has got most recognized role in the plant metabolism as it performs the following vital functions.

Functions of Nitrogen in plants

1. The Nitrogen is mainly involved in Photosynthesis of plants as it is essential constituent of chlorophyll, a green pigment essential in photosynthesis.
2. It is very basic constituent of plant life, because, it forms essential constituent of proteins, nucleotides phosphatides, alkaloids, enzymes, hormones, vitamins etc.,
3. It promotes better Vegetative growth and adequate supply of nitrogen promotes rapid early growth and imparts dark green color to plants, improves quality and succulence of leafy vegetables and fodder crops.
4. It stimulates the formation of fruit buds; increases fruit set, and improve quality of fruits.

5. It governs the better utilization of Potassium, Phosphorus & other elements.

Deficiency symptoms of Nitrogen in plants: Nitrogen is highly mobile element in plants and so deficiency is exhibited in older/ bottom leaves. The striking deficiency symptoms are

1. Yellowing of older leaves due to inhibition of chloroplasts and chlorophyll synthesis. As the deficiency of Nitrogen becomes severe “Chlorosis” of leaves is observed.
2. Plants become dwarfed or stunted growth.
3. Tends to advance the time of flower bud formation and reduce yield.
4. Fruits become hard, small, low bearing capacity of trees.
5. Reduces fertilization, premature dropping and fruits may become seed less.
6. Severe deficiency leads to Necrosis of plant leaves (complete death of leaf)
7. Excessive N in plants leads to more vegetative growth. Leaves become more succulent and more susceptible to pest and disease attack. Lodging of plants may occur. Reduces the sugar content of plant, storage and keeping quality of fruits or leaves and prolong the growing period and delay the reproductive phase of plant and crop maturity.

Functions and deficiency symptoms of Phosphorus

Phosphorous is a constituent of essential cell components such as phytins, phosphoproteins, phospholipids, nucleic acids (DNA, RNA), co-enzymes (NAD & NADP), ATP and other high energy compounds. It is also a structural component of cell membrane, chloroplasts, mitochondria and meristematic tissues. Plants absorb the Phosphorus as H2PO4- and HPO42- ionic form. Phosphate compounds act as “energy currency” within plants. It is highly mobile in plants but immobile in soils.

Functions

1. Involved in Energy storage and transfer. Also carry various metabolic processes in plants.
2. Involved in cell division and development of meristematic tissue and thus it improves better vegetative growth of plants.
3. Important for root development and stimulates root growth.
4. Helps in primordial development, flowering, seed formation, ripening of fruits germination of seeds and also early maturity of crops.
5. It is essential for formation of starch, proteins, nucleic acids, photosynthesis, nitrogen-metabolism, carbohydrate metabolism, glycolysis, respiration and fatty acid synthesis.

Deficiency symptoms of Phosphorus in plants

1. Stunted and slow growth of plants due to its effects on cell division and meristematic tissue development.
2. Leaves are small and defoliation starts from the older leaves and premature leaf fall. Purplish discoloration of foliage due to anthocyanin pigment. Plants develop dead necrotic areas on the leaves, petioles or fruits.
3. Slender and woody stem with under developed roots are characteristics symptoms.
4. Delay in flowering and ripening of fruits, inferior quality, shedding of blossom, inflorescence becomes small and premature fruit falling.
5. Inhibit the sugar synthesis or abnormally high sugar levels in plant.

Functions and deficiency symptoms of Potassium

Potassium is indispensable in the plant nutrition and needs to be supplied in relatively large quantities to fruit crops and field crops. Plants absorb K from the soil as K^+ ion and it is mobile in nature in plants. Potassium does not enter in to the composition of any of the constituents of the plant cells such as proteins, chlorophyll, fats and carbohydrates. It primarily occurs as soluble inorganic salts and occasionally as salts of organic acids. It is abundant cation in the cytoplasm, meristematic regions, cell sap. It is considered as Quality element for many crops.

Functions

1. Potassium is responsible for osmoregulation and controls cell turger pressure.
2. It has important role in pH stabilization, enzyme activation, protein synthesis, stomata movement (closing and opening), cell extension and photosynthesis.
3. Impart drought/heat/frost resistance to plants as it regulates transpiration and water conditions in the plant cell. It improves water use efficiency.
4. Impart pest and disease resistance to plants.
5. Required for ATP synthesis and better N use efficiency by favoring the protein formation.
6. Plants become strong and stiff; thus it reduces lodging of plants. 7. Essential in the formation and transfer of starch and sugars especially in potato, sweet potato, turnip, banana, tapioca.

Deficiency symptoms

1. Weakening of stem and Lodging of crops and easy susceptibility to pest and diseases.
2. Scorching of leaves and burning appearance of leaf margins and tip.
3. Poor keeping quality of fruits. The quality of fruits and vegetables decreased.
4. Marginal necrosis and burning of leaf tips.
5. Stunted growth, shortening of internodes.
6. It causes great disturbance in the water economy of plants and more water is lost per unit dry matter.
7. Poor sprouting of vines.
8. Severe attack of the grapes with Botrytis cinerea due to K deficiency.

Acid soil

Soil acidity is an important agricultural problem while evaluating the production potential of most of the crops. Millions of hectares of land lie idle because of strong soil acidity. In India 49 million hectares of land have problems of soil acidity. Soil acidity is more common in regions with high rainfall. This leads to leaching of appreciable amounts of calcium and magnesium from the surface layer leading to build up of H and Al species causing soil more acidity.

Definition: Acid soil is a base unsaturated soil with enough amount of adsorbed exchangeable H^+ & Al_3^+ions with the soil pH of <6.0 is called acid soil. An acid soil is actually a mixed H-Al system, i.e. such a soil has both H^+ and Al_3^+ ions as exchangeable ions.

Chemical problems

1. Acid toxicity
2. Toxicity of different nutrient elements- such as Fe, Al and Mn are more soluble form
3. Nutrient availability is reduced especially N, P, K Ca, Mg, Na,
4. Nutrient imbalances due to fixation of PO4 by Fe, Al and Mn,
5. Boron and Mo availability decreased

Reclamation of Acid soil

1. In general the fertility status of acid soils is very poor and under strongly to moderately acidic soils, the plant growth and development is affected to a great extent. The crops

grown on such problematic soils do not give remunerative returns. One of the most important and practically feasible management practices is the use of LIME AND LIMING MATERIALS to ameliorate the soil acidity.

2. The addition of lime raises the soil pH, thereby eliminating most major problems of acid soils. Cultivation of acid tolerant crops/varieties is also possible option.

Lime requirement (LR): Is defined as the amount of liming material that must be added to raise the pH to some desired value (pH 6.0 to 7.0). There are a number of liming materials available in the market and may be used according to their availability, convenience and economy. Some of the important liming materials are;

1. Lime oxide (CaO)- Burnt lime/quick lime or oxide of lime. Caustic in nature and difficult to handle.
2. Lime hydroxide {Ca (OH)2}- hydrated lime or slaked lime. Caustic in nature and difficult to handle.
3. Lime carbonate (CaCO3)- ground lime stone occurs as Boglime or marl, Calcite, Oysters shells and precipitate carbonates. It is most commonly used and it is largely sold in the market as pulverized or ground lime stone, called agriculture lime.
4. Basic slag: Byproduct of Iron industry.
5. Dolomite (CaMgCO3)

Calcareous soils

Calcareous soils are those that contain enough free calcium carbonate ($CaCO_3$) and give effervescence visibly releasing CO_2 gas when treated with dilute 0.1 N hydrochloric acid. The pH of calcareous soil is > 7.0 and also regarded as an alkaline (basic) soil.

Reclamation of Calcareous soil

1. Fertilizer management in calcareous soils is different from that of non calcareous soils because of the effect of soil pH on soil nutrient availability and chemical reactions that affect the loss or fixation of some nutrients. The presence of CaCO3 directly or indirectly affects the chemistry and availability of nitrogen (N) Phosphorus (P), Magnesium (Mg), Potassium (K), Manganese (Mn), Zinc (Zn) and iron (Fe). The availability of copper (Cu) also is affected.

2. Application of acid forming fertilizers such as ammonium sulphate and urea fertilizers, sulphur compounds, organic manures and green manures is considered as effective measures to reduce the pH of soil to neutral pH value.

Saline soils

They are defined as soils containing appreciable amounts of soluble salts like chlorides, sulphates of Ca, Mg, K, and Na etc. that interfere with plant growth.

Characteristics of saline soil

1. The EC of saturation paste extract of these soils is > $4dSm^{-1}$, pH of the saturation paste is < 8.2 and the ESP is < 15.
2. They are also known as white alkali soils or solon chalks.
3. These soils lack structural B horizon and contain very little organic matter (<1%).
4. Soluble salts mostly consist of chlorides and sulphates of Na^{+}, Ca_2^{+} and Mg_2^{+}.
5. Bicarbonates may or may not be present. However carbonates are generally absent.

Methods of Reclamation of Saline Soils

I. Physical methods

Scraping: The salts accumulated on the surface can be removed by mechanical means. This is the simplest & most economical way to reclaim saline soils if the area is very small e.g. small garden lawn or a patch in a field. This improves plant growth only temporarily as the salts accumulate again & again.

Flushing: Washing of surface salts by flushing water. This is especially practicable for soils having a crust & low permeability. However this is not sound method of practice.

Leaching: leaching with good quality water, irrigation or rain is the only practical way to remove excess salts from the soil. It is effective if drainage facilities are available, as this will lower the water table & remove the salts by draining the salt rich effluent.

Leaching requirement: The amount of water needed to remove the excess soluble salts from the saline soils is called leaching requirement or The fraction of the irrigation water that must be leached through the root zone or soil profile to control soil salinity at any specific level (Salt balance).

$$\boldsymbol{Leaching\ Requirement\ (LR) = \frac{EC_{iw}}{EC_{dw}} \times 100\ or\ \frac{D_{dw}}{D_{iw}} \times 100}$$

Where, EC= Electrical Conductivity in dSm^{-1}

iw= EC of Irrigation water in dSm^{-1}

dw= EC of Drainage water in dSm^{-1}

D_{dw}= Depth of drainage water in inches

D_{iw}= Depth of irrigation water in inches

II. Agronomic and cultural methods

In areas where only saline irrigation water is available or when shallow saline water table prevails and soil permeability is low, the following cultural practices are adopted .

1. Selection of crops and crop rotations:

On the basis of crop tolerance to quality of irrigation water or soil salinity the crops can be classified in four groups viz.

1. Highly tolerant crops: Barley, Sugar beet, datepalm
2. Tolerant: Tapioca,mustard,coconut, spinach, amaranthus, pomegranate, guava, ber
3. Semi-tolerant:Ashguard, bittterguard, brinjal, cabbage, cluster bean, Pea, lady's finger, muskmelon, onion, potato, dolichos, sweet potato, tomato, turnip, water melon
4. Sensitive: Radish, carrot, Coriander, Cumin, Mint, Grape, sweet orange.

2. Method of raising plants:

1. Crop should be raised by transplanting seedlings (especially vegetables, flowers, fruit trees) than germinating the seeds.
2. Wild root stocks grafted with a good quality but salinity sensitive scion. (Mango, citrus, Guava and ornamental plants like rose).

3. Irrigation practices:

1. Method of water application- follow furrow or drip irrigation, sub surface irrigation systems and sprinkler irrigation.
2. Frequency of irrigation- irrigation more often (frequent) can maintain better water availability & decrease the salinity should not too much irrigations.

4. Use of mulching materials to prevent evaporation losses like straws, plastic sheets etc.

Alkali soil

Alkali soils are those that contain measurable amounts of soluble salts mostly as carbonates and bicarbonates of sodium.

Characteristics of Alkali soils

1. These soils have pHs > 8.2 and ESP > 15. The ECe of alkali soils is variable but normally <4 dSm^{-1}.
2. Neutral salts like NaCl and Na_2SO_4 are present in very small quantities.
3. The alkali soils are also known as sodic or solonetz.
4. They are also called as Black alkali soils. It is mainly because of high pH and Na_2CO_3 the finely decomposed organic matter is dissolved along with the water that imparts a dark black or brown colour to the soil.

RECLAMATION OF ALKALI SOILS

A. Use of Amendments

For successful crops in alkali soils ESP of the soil must be lowered which can be achieved by application of amendments. Gypsum ($CaSO_4.2H_2O$) is the most commonly used amendment for reclamation. Elemental S and pyrite are also used.

Gypsum requirement (GR): The amount of gypsum needed for removal of exchangeable sodium from alkali soil and also to decrease the soil pH to a desired level is called gypsum requirement. 1 milli equivalent of Ca_2^+ is required to replace 1 milli equivalent of Na^+ ion from the exchange complex of sodic soil.

Organic Amendments: Organic amendments like straw, rice husk. Ground nut and safflower hulls, FYM, compost, poultry droppings, green manures, tree leaves and saw dust.

Industrial by products as Amendments: Phospho-gypsum, Press mud, Molasses, Acid wash and Effluent from milk plants. They are used to provide soluble Ca directly/indirectly by dissolving soil lime.

B. Cultural practices:

1. Land leveling and shaping
2. Maintain Plant population
3. Age of seedlings
4. Green manuring
5. Continuous cropping

C. Water management:

1. Drainage: Alkali soils have got low infiltration rate and all the rain water accumulates to create surface water logging. This results oxygen stress. So, to avoid this problem provide surface and subsurface drainage system in the field.

2. Good irrigation management: Normally surface method of irrigation such as furrow or basin type flood method is used for alkali soils. However the sprinkler method could be promising because of its ability to supply water uniformly and in small quantities.