

MODULE 5.2

Soil properties

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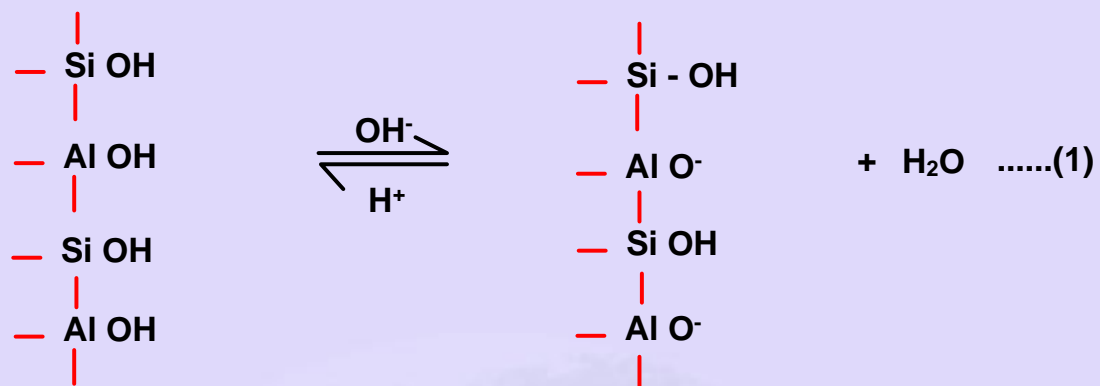
Soil properties

Soils contain clay minerals and organic matter as a result of weathering and the addition of organic debris soils act as buffer zone between atmosphere and ground water, and provides plants a steady supply of nutrients. Soils have this sorptive property because of electrical charges and large surface area of the clay minerals and humus.

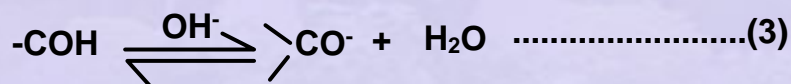
Because of their structure and chemical composition, the clay minerals and humus usually bear a negative charge. The charge is pH independent. From the surfaces of the clay minerals (aluminum silicates and hydrated oxides of iron and aluminium) and from acidic groups in humus, protons dissociate. This dissociation of protons gives a negative charge which is pH dependent. Hydrated oxides of iron and aluminium present in clay become positively charged at low pH by adsorption of protons. The sources of electrical charge on soil clays and humus are shown in the following table 1.

Table .1 Sources of electrical charge on soil clays and humus

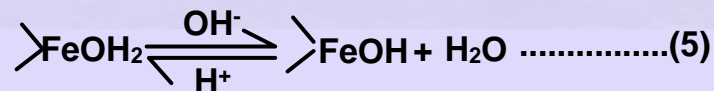
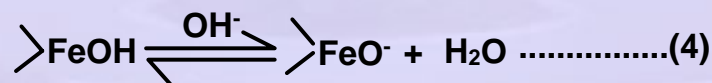
1. Permanent negative charge on 2:1 and 2:2 clay minerals due to isomorphous substitution as discussed above.
2. pH dependent charges:
 - (a) negative charges at broken surfaces and edges of clay minerals.



(b) negative charges on humus due to dissociation of carboxyl and phenolic hydroxyl groups.



(c) negative and positive charges on hydrous oxides of iron and aluminium.



Because the pH-dependent change arises at the surfaces and edges of clay minerals, it is greater the more disordered in the structure.

In clays the negative charge is exactly balanced by the adsorbed cations. Some of the cations in 2:1 clays are held in interlayer spaces and can diffuse

only very slowly into the outer solution. These cations are non exchangeable in these clays (such as illite) since in these, the silicate sheets are held tightly together and don't allow the potassium ions in the inter layer to move out. On the otherhand in smectites , the silicate sheets are not held together strongly. As a result, each interlayer space is wider and cations in this space can readily diffuse into outer solution. The important consequence is that smectites, with more available surface area, hold more exchangeable cations than illite, which has a higher charge density.

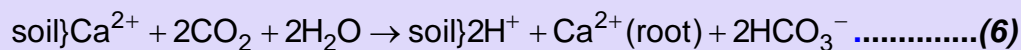
Exchangeable cations and cation exchange capacity:

As discussed previously the negative charge of humus and part of the negative charge of clay minerals varies with pH. The capacity of the soils to hold exchangeable cations therefore also depends on the pH. There are many standard methods for the determination of cation exchange capacity (CEC) of the soil. In one of the method CEC is measured at the soil pH by displacing the exchangeable cations with a solution of potassium chloride, which is unbuffered. All the displaced cations are determined (by flame atomic absorption spectroscopy) and the summation is the cation exchange capacity, now known as the effective cation exchange capacity (ECEC). CEC has been found to be useful in characterising the soils in which most of the negative charge is pH dependent, as with many soils in tropics.

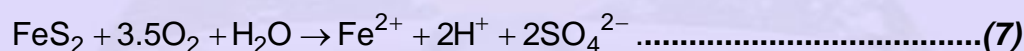
Acid - Base Ion Exchange Reaction In Soils:

Essential trace metals are made available to plants as nutrients by the exchange of cations which is the important function of soils.. Both mineral and organic fractions of soils exchange cations. Humus shows a very high cation exchange capacity (300- 400 meq/100g).

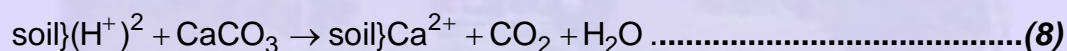
Trace metal nutrients are provided by the cation exchange in soil. The metal ions are taken up by the roots while H⁺ is exchanged for the metal ions.



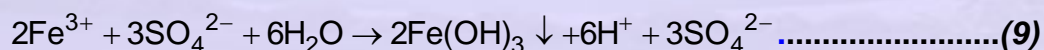
Soil acts as a buffer and resists change in pH. The buffer capacity of the soil depends on its type. The oxidation of pyrite in soil causes formation of acid-sulphate soils called “cat clays” .



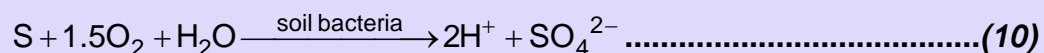
Most common plants grow best in soil with near neutral pH. Acid soils can be improved by the addition of lime.



The soil may turn alkaline in the presence of basic salts such as Na₂CO₃ in drought-prone where there is less rain fall.. Alkaline soils can be improved by the addition of aluminium sulphate or ferric sulphate.



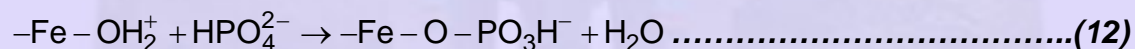
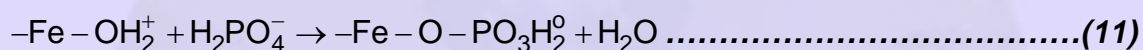
Sulphur also can be used to acidify the alkaline soils, since it is oxidised to sulphuric acid in the presence of bacteria present in the soil.



Anion retention:

At low pH positive charges are developed on the surfaces of hydrated oxides of iron and aluminium as discussed previously and to a less extent on 1:1 clay minerals. Under these conditions Cl^- , NO_3^- and other anions are adsorbed and undergo exchange with each other. Adsorption is however blocked by competition from organic anions.

This can be explained as due to the formation of surface complex between anion and a metal, usually Fe or Al, in a hydrated oxide or clay mineral.



These reactions increase the negative charge on the surface. Silicate, sulphate and probably fulvic acid are adsorbed similarly to phosphate. Sulphate however forms a weaker complex than phosphate. Under field conditions the release of phosphate may depend partly on the generation of organic acids or OH^- by microorganisms.

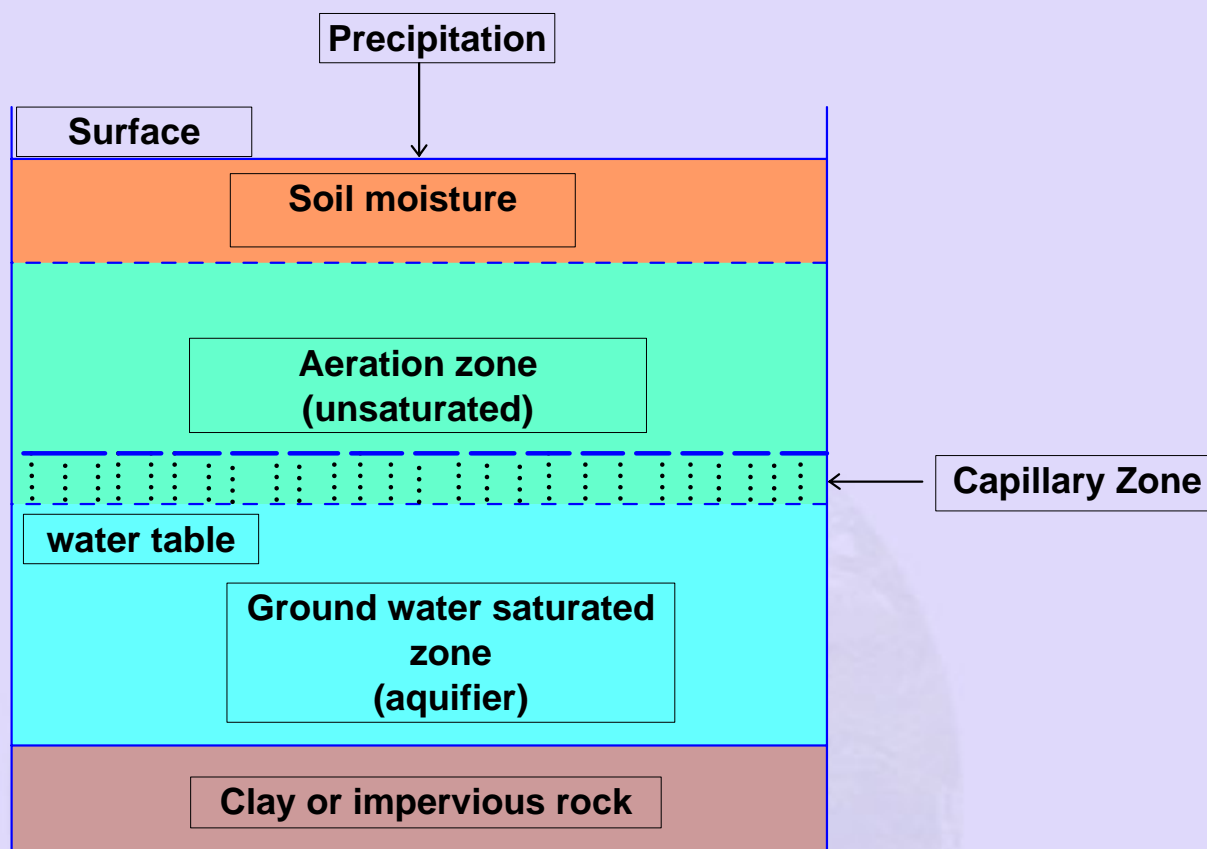


Fig 1. Distribution of water underground

Fig1. gives the distribution of water in the soil. Within the soil there are three zones: aeration, capillary, and ground water. The ground water zone exists below the water table. The capillary zone is the zone through which water will rise through the soil pores by capillary action. The upper zone is the aeration zone where the pores are occupied by air. After rainfall events, the air may be expelled from the pores by hydrostatic pressure to allow the infiltration of water to occupy the pores.

Water table is crucial in predicting the flow of wells and springs and the levels of streams and lakes. It is also an important factor in determining the extent to which pollutant and hazardous chemicals underground are likely to be

transported by water. The water table is not usually level and varies with differences in permeability and water infiltration.

Soil Profile And Its Importance:

As discussed earlier the soil is the result of weathering of parent rocks and is a variable mixture of minerals, organic matter and water capable of supporting plant life on the earth's surface. Fig.2 shows

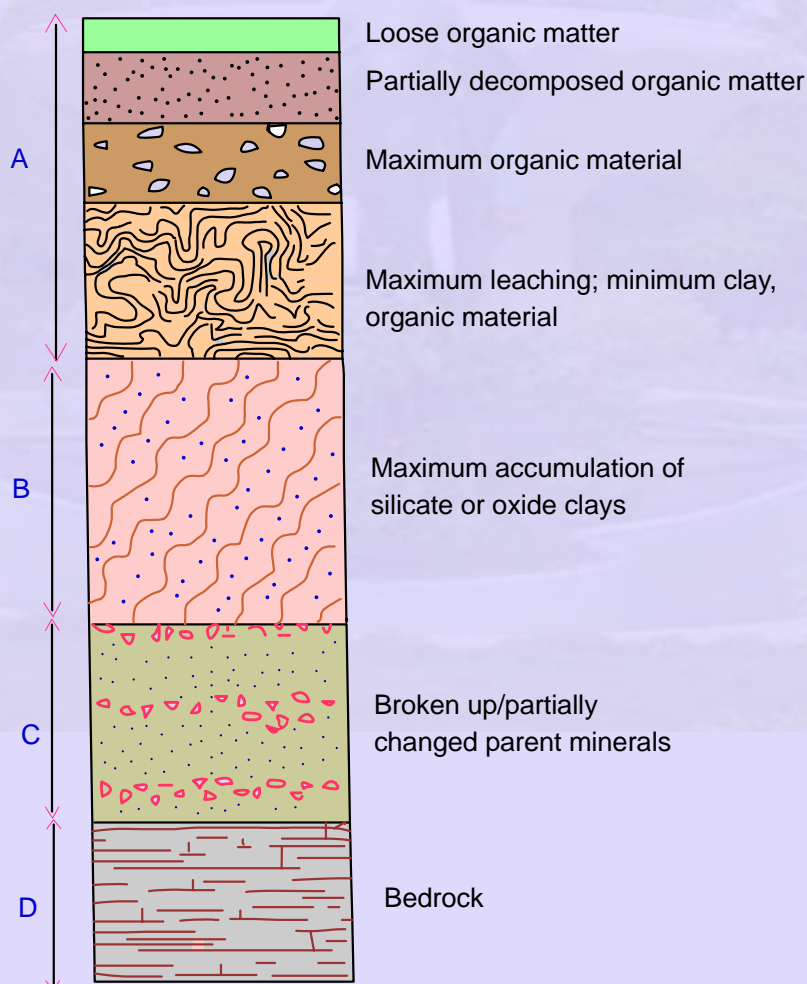


Fig 2. Soil profile showing soil horizons

the idealised vertical profile through a series of soil layers. The top layer is usually a vegetation of grass, crop or trees, but it may base soil. Below this is the litter layer, more easily identifiable in forest areas as composed of dead leaves, bark and other decomposed growth. Below this is the soil proper. The upper or A horizon in mineral soil is generally friable and rich top soil. It is that part of soil in which living matter is most abundant and in which the organic matter is most plentiful. Being closest to the surface, it becomes more leached by rainfall than the lower layers. The middle level or B horizon, often called subsoil, is mainly composed of well-weathered plant material interoven with roots and microorganisms. Lying between A and c horizons, it has some of the properties of both, with fewer living organisms than A but more than C. By comparison with A horizon, the B horizon has a high content of iron and aluminium oxides, humus or clay that have been partly leached from A horizon. The lower C horizon is unconsolidated rock material composed of a wide range of stones of different sizes. Below C horizon is the D horizon which contains parent consolidated rock. The depth of each layer varies from millimeters to meters.

Water, air and particles in soil

Large quantities of water are required for the production of most plant materials. It is the basic transport medium for carrying essential plant nutrients from solid soil particles into plant roots and to the farthest reaches of the plant's leaf structure. The water enters the atmosphere from the plants leaves, through **transpiration**.

Water is made available to plants by gradients arising from capillary and gravitational forces. The availability of nutrient solutes in water depends on concentration gradients. Water present in larger spaces in soil is relatively more

available to plants and readily drains away. But water held in smaller pores or between the unit layers of clay particles is held more strongly. Soil rich in organic matter may hold relatively large amount of water compared to other soils but is relatively less available plants due to physical and chemical sorption of water by organic matter.

Because of the high surface to volume ratio of colloid clay particles, a great deal of water may be bound with them.

When the soil is water logged (water-saturated) it undergoes drastic change in physical, chemical and biological properties. Oxygen in such soil is rapidly used up by the respiration of microorganisms that degrade soil organic matter. Thus excess water in such soils is detrimental to plant growth, since it does not contain the air required for most plant roots. Most useful crops with the exception of rice cannot grow on water logged soils.

Micro And Macro-Nutrients In Soil :

Plants require both macro nutrients and micro nutrients for their growth. The essential micronutrients for plants required are boron, chlorine, sodium, copper, iron, manganese, zinc, vanadium and molybdenum. They are required at trace levels and if present at higher levels, have a toxic effect. Most of these serve as components of essential enzymes. Some of these such as chlorine, manganese, iron, zinc and vanadium are likely to take part in photosynthesis.

The essential macronutrients required for the plants are carbon, hydrogen, oxygen, nitrogen, phosphorous, sulphur, potassium, calcium and magnesium. The atmosphere and water are the sources of carbon, hydrogen and oxygen. Nitrogen may be obtained by some plants, directly from atmosphere, through

nitrogen fixing bacteria. The other essential macronutrients are obtained from the soil. Nitrogen, phosphorus and potassium (NPK) are commonly added to soil as fertilizers. Calcium deficiency in soil is due to calcium uptake by plants, and leaching by carbonic acid in acidic soils, and competitions with high levels of sodium, potassium and magnesium in alkaline soils. Calcium-deficient soils are generally treated with lime (liming) to provide the required calcium supply for plants.

Magnesium is made available to plants through ion-exchanging organic matter or clays. Magnesium deficiency in soil is caused by high levels of calcium, sodium or potassium, sulphur in the form of assimilable SO_4^{2-} is taken up by the plants. Unlike in the case of K^+ , sulphate ions are not bound by ion-exchange binding and it would be available for assimilation by plant roots.

Nitrogen Phosphorous And Potassium In Soil:

Management of N and P cannot be accomplished without the cognizance of the transformations of the nutrients that occur in nature, represented conveniently by Nitrogen and Phosphorous cycles. In agricultural systems, these transformations largely occur in the soil and are a function of complex interactions between the atmosphere, soil particles, soil bacteria, plant and animal life, and soil water. The fig 3 summarises the primary sinks and path ways of nitrogen in soil. The nitrogen content in the soil is mostly organic in nature (90%) resulting from the decay of dead plants (biomass) and animals, plant residues; and faeces, urine of animals, etc. It is hydrolysed to NH_4^+ , which can be oxidised to NO_3^- by the action of bacteria in the soil.

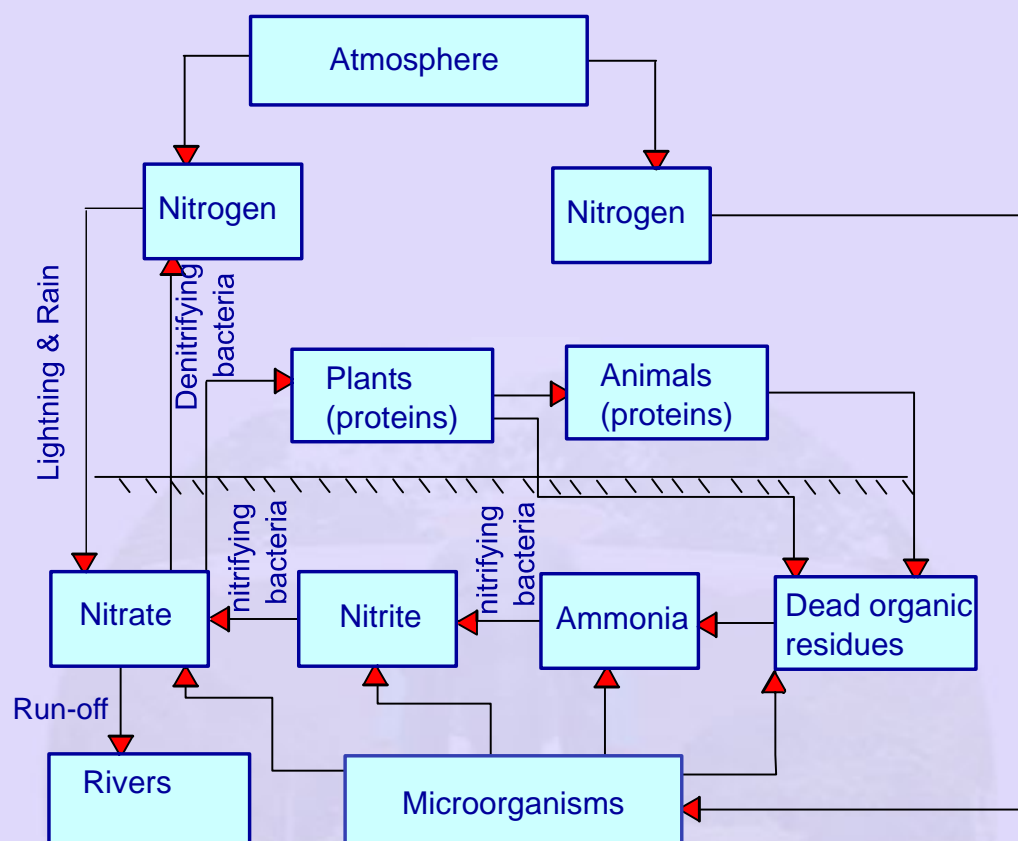


Fig 3 Nitrogen sinks and pathways in soil

Nitrogen bound to soil humus is responsible for maintaining soil fertility. It serves as reservoir for the nitrogen required by plants. An additional advantage of its property is that its rate of release of nitrogen to plants roughly parallels plant growth.

Plants use NO_3^- from soil in general. When nitrogen is applied to soils as NH_4^+ (fertiliser), nitrifying bacteria converts it into NO_3^- for use by plants. Certain leguminous plants, eg: Soya beans, alfalfa, clover etc. possess the unique ability to fix atmospheric nitrogen through nitrogen fixing bacteria on their root modules. Legumes can add considerable quantities of nitrogen to soil.

Phosphorous:

Eventhough the percentage of phosphorous in plant material is very low, it is an essential component of plants. The assimilable phosphate species by the plants are H_2PO_4^- and HPO_4^{2-} which exist at the soil pH. Orthophosphate is most available to plants at pH values near neutrality. In acidic soils, the orthophosphate ions are either precipitated or sorbed by cations, viz, Al^{3+} , Fe^{3+} , etc. In alkaline soils, the following reaction occurs with CaCO_3 , whereby hydroxyapatite is precipitated:



Since phosphorous is fixed as hydroxyapatite very little phosphorous, added as fertiliser, leaches from the soil.

Potassium:

Potassium is one of the three major fertiliser elements required by plants. In general potassium status of soils is satisfactory only when enough potassium is added to compensate for the potassium removed in the crops. This is because any excess potassium added is largely retained in the soil by sorption on clays and organic matter. In areas where crops have been grown for many years without the addition of adequate potassium containing fertilisers, yield gradually decrease as the potassium from between the illite layers is slowly removed. If potassium fertiliser is then added, the increase in yield is not as great as might be expected. This is because the potassium returns to the illite structure rather than remaining immediately available for plant growth. As a consequence the formers are faced with the high costs of potassium fertilisers without receiving

a comparable increase in crop yield. High yields of any crop can be sustained only by replacing the nutrients removed with the crop.

Saline soils and their remediation:

Rainwater always contains small concentrations of many elements and when it percolates freely through a well drained soil, some of these dissolved ionic species are retained at various depths by interaction with soil particles. At the same time weathering and leaching can cause dissolution of elements from the soil. The composition of water in the soil pore is therefore determined by a combination of removal and dissolution reactions. In regions of heavy rain fall therefore, the drainage water usually contains only a very small concentration of ionic species and there is no significant accumulation of salts in any part of the soil profile.

On the otherhand in regions where there is limited precipitation and high rates of evaporation, the downward movement of water may be insufficient to leach out all the salts that accumulate near the soil surface. Salt-affected soils are therefore common in arid and semi-arid regions of the world. When evaporation and evapotranspiration from the soil exceed the downward percolation of rainfall over extended period of time, salinity related problems arise. The possibility of soils accumulating salt is enhanced, when the input irrigation water itself contains relatively high concentrations of salts.

Soil salinity is usually confirmed by measuring the electrical conductivity of the saturated extract of the soil. The sodium hazard from the dissolved salts is expressed as the sodium absorption ratio (SAR) where $SAR = [Na] / \sqrt{[Ca+Mg]}$ with concentrations in millimoles per litre.

The high concentration of accumulated salts in soil leads to several environmentally significant consequences. The large clay minerals present in the fine-grained soils become dispersed into individual particles and remain as separate units. The problem becomes acute for sodic and sodic-saline soils, where in the large (hydrated) monovalent sodium ion contributes most to dispersion of the clay minerals, resulting in losing its structure and thus becomes highly impervious to the movement of water. At elevated salt concentration plants have to expend more energy as physiological response in order to maintain a constant water potential gradient between the root and soil solution. As a result, plant growth is inhibited. Furthermore, high concentrations of particular ions like sodium in the soil solution can create a nutrient ion imbalance; for example, calcium deficiency is frequently observed in high-sodium soils.

Soil reclamation:

Depending on the situation and the specific properties of the salt-affected soil in question, there are a number of technologies that can be applied for their reclamation.

The simplest remediation procedure involves flushing the salts in saline soil with water that is itself low in salts; adequate drainage of the leached water should be ensured. Simple flushing cannot be used when the sodium content in the soil is very high.

For saline-sodic soils, the input flushing water should contain a high concentration of calcium and /or magnesium ion in order to increase the soil permeability. As a result, exchangeable sodium ions are replaced by those of the divalent alkaline earth metals. Subsequent flushing using water with low ion

concentrations can then be done without dispersion of the clays in order to bring the conductivity into the normal range.

Since the sodic soils contain high concentrations of sodium ion and are alkaline due to the presence of the carbonate ion, it is necessary to remove both these species.

One treatment is to add to the soil a large amount of gypsum (calcium sulphate) and maintain continuous moist conditions. The calcium sulphate reacts with sodium carbonate to produce insoluble calcium carbonate and soluble sodium sulphate. Simultaneously, a large fraction of sodium on the exchange sites is replaced by calcium. The soil can then be flushed with low conductivity water to remove the soluble sodium sulphate.

An alternative treatment procedure involves the addition of elemental sulphur to the soil. The added sulphur to the soil is oxidized microbially to produce sulphuric acid. This acid again serves to convert sodium carbonate into sodium sulphate which is then washed out of the soil as mentioned before.

Wastes And Pollutants In Soil:

Large quantities of untreated industrial municipal and agricultural wastes are dumped into the soil. Heavy metals like mercury, lead, cadmium, nickel and arsenic cause serious land pollution problems. For example wastes from mines and factories located in agricultural areas have been found to have contaminated the soil with heavy metals. In some cases, land disposal of degradable hazardous organic wastes is practiced as a means of disposal and degradation. In soil a pesticide may be transported into various sectors of the environment by different physical processes, such as adsorption by the soil, leaching by rain

water or be taken up by plants and animals or carried away by wind. But the processes that actually play important roles in reducing their total amount of residues, are those mediated by microorganisms, animals, plants and sunlight. Other factors are pH and heat. Catalytic agents in the soil and soil enzymes also play important roles in degrading relatively unstable pesticides. The major group of soil microorganisms such as actinomycetes, fungi and bacteria, degrade pesticides through oxidation, ether cleavage, ester and acid hydrolysis, oxidation, epoxidation etc. The notable characteristics of degradation systems in microorganisms are the reductive systems. Combustion of sulfur-containing fuels emit SO_2 and finally leaves sulphate in the soil. Atmospheric nitrogen oxides are converted into nitrates in the atmosphere and the nitrates eventually are deposited on the soil. Particulate lead from automobile exhausts also settles on soil along with rides of highway with heavy automobile traffic. High levels of Pb, Zn etc, are absorbed on soils near lead and zinc mines, etc. All these result in deterioration of soil quality, due to effects on the microfauna, bacteria, fungi, etc. Biological degradation is also associated with lowering or depletion of soil organic matter.