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Soil Fertility and Plant Nutrition **(BIOB 548)**

By

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1. Introduction

Soil fertility and plant nutrition play an important role in increasing crop yields. Soil fertility is defined as the quality of a soil to supply nutrients in adequate amounts and proper balance for the growth of crop plants. Generally, soil analysis is used as criteria to make fertilizer recommendations for field crops. If soil analysis is taken as criteria to supply essential nutrients for plant growth, then, soil fertility can be defined as a measure of a quantity of extractable or available nutrients present in a particular soil during a particular period of a season. It combines several soil properties (biological, chemical and physical), all of which affect directly or indirectly nutrient dynamics and availability. Soil fertility is a manageable soil property and its management is of utmost importance for optimizing crop nutrition on both a short-term and a long-term basis to achieve sustainable crop production.

Soil productivity is the ability of a soil to support crop production determined by the entire spectrum of its physical, chemical and biological attributes. The basic aim of sound soil fertility management is to enhance crop productivity, to sustain it, and to keep the soils in good health – physically, chemically and biologically.

1.1. What is Soil?

Any part of earth's surface that supports vegetation also bears a covering of soil. Soil is thus defined as "any part of earth's crust in which plants root". This layer, at most a few feet thick and sometimes only a few inches, might appear insignificant relative to the bulk of the earth. Yet it is in this thin layer of soil that the plant animal kingdoms meet the mineral world and establish a dynamic relationship. Soil is formed over a long period of time. It is made up of many things, such as weathered rock and decayed plant and animal matter. Plants obtain water and essential nutrients from the soil. Animals depend on plants for their lives. Plant and animal residues find their ways back to the soil and are decomposed by the teeming microbial population living there. ***Life is vital to soil, and soil is vital to life.*** Soil is the source from which springs our food, clothing, and shelter. Our existence depends on soil.

"Essentially, all life depends upon the soil ... There can be no life without soil and no soil without life; they have evolved together." - Charles E. Kellogg

In the words of the Greek philosopher, poet Xenophanes, "For all things comes from earth, and all things end by becoming earth."

The origin of the word soil illustrates another facet of its character. It comes from the **Latin** word **solum**, which means **floor**. The French word **sol** and the Spanish word **suelo** are still used to mean either **soil** or **floor**. An edaphologist, considering soils in relation to their use as media for growing plants, may define *soil as a mixture of mineral and organic matter that is capable of supporting plant life*. A pedologist, studying soil as a distinct entity, can define as *the natural product formed from weathered rock by the action of climate and living organisms*. The concept of life is vital in these definitions. In one, the soil supports life; in the other, life helps to form the soil. Both viewpoints are correct. Although, these days, there are many definitions, of a soil, a widely accepted definition today was devised by the Soil Taxonomy in 1999 (Soil Survey Staff, 1999). This definition basically states that *soil is a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs on the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in natural environment*.

Soil is thus not merely a group of mineral particles. It has also a biological system of living organisms as well as some other components. It is thus preferred to call it soil complexes, which have five following five categories of components.

1. **Mineral matter:** It is a matrix of mineral particles derived by varying degrees of breakdown of the parent material rock.
2. **Soil organic matter:** It is an organic component derived from long and short term addition of material from organisms growing above and below ground i.e. plants, animals, and microorganisms.
3. **Soil water:** It refers to all water contained in soil together with its dissolved solids, liquids and gases.
4. **Soil atmosphere:** It occupies the pore space between soil particles, which at any time, is not water filled. Its composition differs from the aboveground atmosphere in the sense that it is normally lower in oxygen and higher in carbon dioxide content.
5. **Biological system:** Each soil has a distinctive flora and fauna of bacteria, viruses, fungi, algae, protozoa, nematodes and arthropods.

Thus, biologically the soil may be said as “the weathered superficial layer of the earth’s crust in which the living organisms grow and also release the products of their activities, death and decay”.

1.2. Why We Study Soil?

Soil is a three-dimensional living-body that you can consider as the skin covering the earth's surface. It plays critical roles in many of the environmental challenges facing the world. Soils are essential for life on earth. People may not realize it, but they are becoming ever more dependent on the ecological functions of soil. Soil is an integral part of the ecosystem. Air, water and soil comprise the various ecosystems of the earth. A biome is a complex system of soil, climate and organisms. Soil is susceptible to pollution. We pollute soil by exposing it to human sewage, industrial waste products, agricultural and milling wastes, and natural contaminants.

Soil is the domain of Archaeology. It can reveal information about ancient climates, geology and peoples. Archaeologists study ancient habitats, dwellings, and other cultural factors by examining soil. Often buried topsoil holds a rich archaeological find.

Soil properties affect engineering projects. To an engineer soil is earthy material that can be excavated with a shovel. Soil is construction material and typically is the natural foundation that supports the man-made foundation of a building. Soil properties limit engineering uses for a parcel of land. Soils may or may not be suitable for such uses as road beds, septic tank drain fields, dwellings with basements, or recreation facilities.

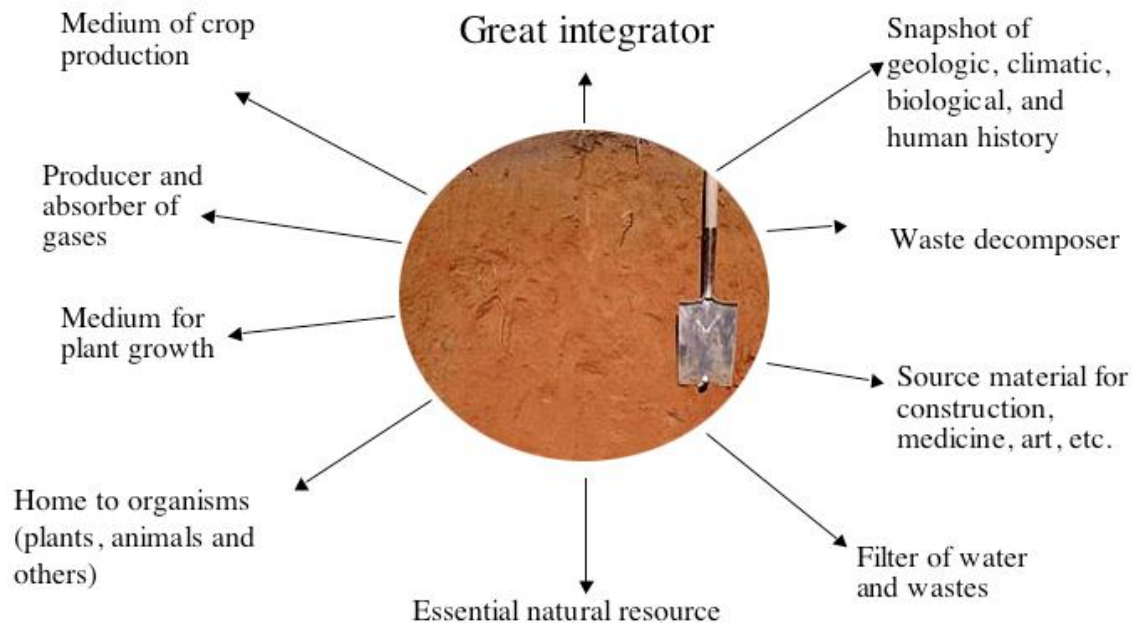
Soil is the primary resource for food Production. A subsistence diet requires about 181 kg of grain per person per year. This amount of grain production requires about 0.11 acres (0.045 hectares). The study of soils is a science of inherent value to mankind.

Edaphology is the study of soils as habitat for plants and other organisms. Pedology is the study of soil as a geologic entity.

Soil is one of our most precious natural resources. It integrates all other parts of the ecosystem. Soil provides a medium for plants so that we can have food, clothing, shelter, health, medicine, archaeology and other materials. We use soil to build on, walk on, and play on. Soil filters water, decomposes waste, stores heat, and exchanges gases. Soil is alive! It is the home of billions of large as well as microscopic organisms. Soil is a source of material for construction, medicine, art, and other uses. Soils provide a snapshot of the geologic, climatic, biological, and human history at the place they are found. There is a limited amount of soil that can be used for growing food, and all the other uses we require. When improperly managed, soil can be eroded, polluted, or destroyed. It can also cause damage to other parts of the ecosystem. Scientists need to know more about what the properties of the soil are all

over the world so that we can study them, protect them, and use them properly. All the living things in the soil, plus essential materials that these organisms use to survive, form the soil **ecosystem**. Scientists study the soil ecosystem because they want to understand how organisms relate to one another and to the environment that surrounds them.

We Study Soil Because It's A(n)



1.3. Approaches to study a soil

1.3.1. Soil Profile description

1.3.1.1. What is soil profile description?

The **soil profile** is defined as a vertical cross section of layers of soil found in a given area. Soil profile description forms the basis for understanding and communicating soil properties among soil scientists and other professionals. The soil profile is an important tool in nutrient management.

1.3.1.2. Soil Horizon

The individual layers are regarded as horizons in a soil profile used to classify soil types. Horizons based on colour, texture, roots, structure, rock fragments and any unique characteristics worth noting. A soil horizon is a layer, approximately parallel to the surface of the soil that is distinguishable from adjacent layers by a distinctive set of properties produced

by the soil-forming processes (i.e., pedogenesis). The term “layer” is used instead of “horizon” if the properties are inherited from the parent material, such as sedimentary strata.

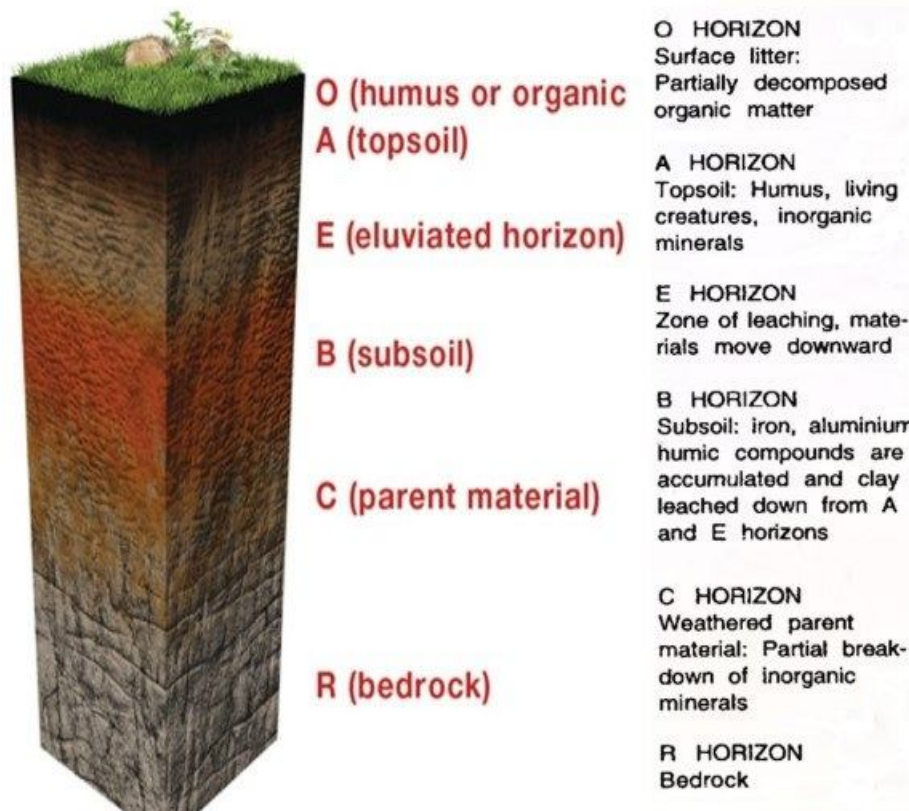


Figure1: A typical soil profile developed over Aeolian loam

The above figure is an example of a deep profile developed over Aeolian loam. The slightly darker topsoil extends over the upper 20-25 cm. The subsoil includes a B-horizon with a well-developed structure (25-60 cm) overlying a less well-structured and rather compact C horizon (60- 110cm+)

Profile descriptions in the field make a distinction between master horizons named with capital letters like O, A, E, B, C, R (Fig.2).

Surface or near-surface horizons relatively high in organic matter (OM) are designated O or A horizons, the difference between the two being determined by the amount of organic matter present.



Chapter-2 **Soil Formation**

The whole process of soil formation is generally divided into two stages:

- (1) **Weathering:** Breakdown of bigger rocks into fine, smaller mineral particles. This is not capable of growing plants.
- (2) **Soil development** or **Pedogenesis:** Modification of the mineral matter through interaction between biological, topographic and climatic effects, which ultimately lead to the development of any of a great variety of potential soil types.

2.1. Weathering process:

Bare rock surfaces are exposed to various types of physical, chemical and biological processes which lead to physical and chemical disruption of their components. Physical process of weathering include action of water, temperature, glaciers, gravity etc., which cause weathering of rock through processes as wetting-drying, heating-cooling, freezing , glaciations, solution and sand blast etc. the chemical processes of weathering include hydration, hydrolysis, oxidation-reduction, carbonation, chelation etc., which are due to chemical composition of rocks, chemicals in the atmosphere, as well as those produced as a result of living organisms, such as lichens, fungi, bacteria, blue-green algae, bryophytes etc.

In biological processes lichens are able to extract nutrients from bare rocks. Lichens, fungi and bacteria on rock surface retain the water for a long period during which the chemical processes can proceed, splitting the rock alumina silicates by hydrolysis and carbonation into the simpler clay alumina- silicates. Algal partners of lichen through photosynthesis, increase the amount of available organic matter at rock surface. Various exudates from these organisms and the respiratory carbon dioxide accelerate the process of weathering, as some of the lichen acids (organic acids) generally dissolve mineral components. Rock weathering is, therefore, for a short time, a physico-chemical process but soon it becomes biogenic, increasing in its rate. The weathering processes are physical as well as chemical.

2.1. Physical processes: Physical processes may be of the following types:

2.1.1. Wetting-Drying: It is disruption of layer lattice minerals which swell on wetting.

2.1.2. Heating-cooling: It is disruption of heterogeneous crystalline rocks in which inclusions have differential coefficients of thermal expansion. It occurs particularly in dry climates, where due to sun heating large boulders flake at surfaces.

2.1.3. Temperature: Warming (day) and cooling (night) is effective in disintegrating rocks. Cracks are created because of variation in the coefficient of expansion of the minerals in the

rocks. The surface of rocks peels away because of the lateral differences in temperature. The phenomenon is called *Exfoliation*. High temperatures accelerate the process of chemical weathering, especially in warm humid regions.

2.1.4. Freezing: This is the disruption of porous, lamellar or vesicular rocks by frost shatter due to expansion of water during freezing.

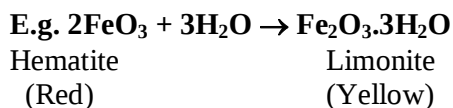
2.1.5. Glaciations: Larger masses of snow and ice-glaciers, while falling may cause physical erosion of rocks through grinding process.

2.1.6. Solution: Some more mobile components of rocks, such as calcium chlorides, sulphates etc., are simply removed by agents like water.

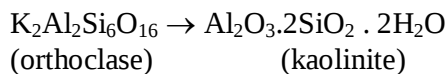
2.1.7. Sand blast: In arid desert conditions the rocks are disrupted by physical action of wind, sand etc.

2.2. Chemical Process: Chemical processes include the following:

Hydration: As a result of taking water, due to reversible change of haematite to limonite, the rock swells. This swelling causes the disruption of sandstones etc.

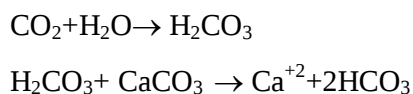


2.3. Hydrolysis: In this process, components like alumina-silicates of rock breakdown, during which elements such as potassium and surplus silicon are washed out which give rise to simpler mineral matter like clay alumina-silicates. For example, hydrolysis of orthoclase to kaolinite.



2.4. Oxidation-Reduction: Some oxidation-reduction chemical reactions, such as reversible change of Fe^{+3} to Fe^{+2} cause disruption of rocks, because Fe^{+2} is more soluble than Fe^{+3} .

2.5. Carbonation: Some chemicals, produced in the atmosphere and those during the metabolism of microorganisms bring about carbonation. As for example reversible change of CaCO_3 to $\text{Ca}(\text{HCO}_3)_2$ leads to solution loss of limestone or disruption of CaCO_3 cemented rocks as the hydrogen carbonate is more soluble than the carbonate.



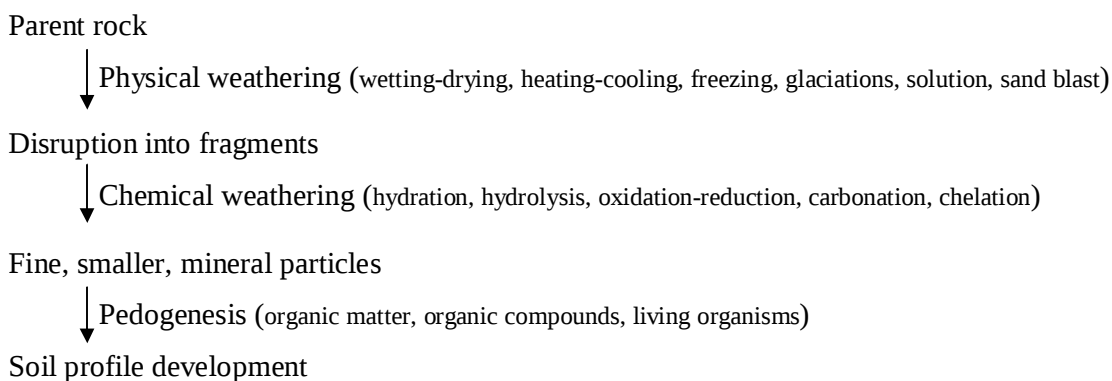
2.6. Chelation: Some chemical exudates, produced through biochemical activity of microorganisms like lichens, bacteria, etc., are able to dissolve out mineral components of

rocks. These metals dissolved with organic products of microbial activity are known as chelates. For example, acids produced by lichens and bacteria have strong chelating properties.

2.2. Pedogenesis:

Pedogenesis (Greek: '**pedo-** or pedon' meaning 'soil, earth' and **genesis** meaning 'origin, birth') is the science and study of the processes that lead to the formation of soil. During weathering, the rocks are broken down into smaller particles. But this is not true soil and plants can not grow in this matter. The weathered material undergoes further a number of changes, which is a complex process, known as pedogenesis or soil development. Whereas in weathering, mostly physical and chemical factors are involved, pedogenesis is largely a biological phenomenon. During this phenomenon, living organisms such as lichens, bacteria, fungi, algae, micro-arthropods, molluscs etc., as a result of secretion of organic acids, enzymes, CO₂ production and addition of organic matter after their death, bring about geochemical, biochemical and biophysical processes. Due to all this the crusts of weathered rock debris are converted to true soils consisting of a complex mineral matrix in association with a variety of organic compounds, and a rich microorganism population.

Thus during pedogenesis, there are added various organic compounds, dead organic matter and living organisms etc. to the mineral matter. As a result of mineralization of dead organic matter, the minerals are then gradually added to different layers of developing soil. This soil, when fully developed can be seen having a number of layers-horizons of a soil, known as soil profile. The overall process of formation (genesis) of soil is shown below-



2.3. Factors of soil formation

Studies of soils have shown that all kind of soils are formed under the interplay of five factors. These, factors that control the formation of, soils are:

- 1) Parent material
- 2) Climate
- 3) Biota
- 4) Topography or Relief
- 5) Time

1. Parent material.

Parent material is defined as the initial state of the soil system. Inorganic parent materials can either be formed in place as **residual material** weathered from rock, or they can be transported from one location and deposited at another(**i.e., transported parent materials**). *It should be stressed that the most important aspect of parent material in soil formation is the **mineralogical and chemical properties**.*

Rock and minerals are the main sources of parent materials over which soils are developed. A **mineral** is defined as a naturally occurring homogeneous solid that has a fairly definite internal structure and composition. This result in fairly definite chemical properties. Whereas, a **rock** is, simply, a complex mineral aggregate. Some rocks weather easily and other decay at a slower rate. Such characteristics make rocks like shale, a better soil-former than the limestone which is a poor soil-former. Faster the rate of weathering as in hot and wet climate faster is the rate of soil formation. Although soils are seldom developed from a deposit of pure minerals, minerals are quite important since they are the component parts of a rock. They will be discussed under the types of rocks. **Rocks (consolidated masses)** are classified into three following groups based on their genesis and structure. These are:

i. Igneous rocks. They are formed from crystallization of magma. According to their mode of occurrence, igneous rocks are separable in to: **Volcanic (extrusive, effusive)** rocks, which result from cooling of lava at the earth's surface and **plutonic (intrusive)** rocks which crystallize at relatively great depth within the earth's crust. The common igneous rocks are granite, rhyolite, gabarro, and basalt.

Igneous rock forming minerals grouped into *felsic* and *mafic* minerals. **Felsic** minerals are generally light coloured in hand specimen and have rather low densities i.e, $<2.8 \text{ g/cm}^3$. Typical felsic minerals are quartz and all kinds of feldspars (plagioclase and alkali feldspar groups). **Mafic** minerals are usually dark-coloured and their density is relatively high i.e, $>2.8 \text{ g/cm}^3$. The chief mafic minerals are ferromagnesian: *pyroxenes, amphiboles, biotite, olivine*, etc. Rocks containing a high proportion

of quartz (60-75%) are classified as acidic rock e.g., granite, whereas those containing less than 50% quartz are classified as basic e.g., basalt.

ii. Sedimentary rocks. These rocks are formed from the igneous rocks and are formed by the consolidation of fragmentary rock materials (sediments) and the products of their decomposition deposited by water. Stratification is the most common feature of these rocks. The common sedimentary rocks are conglomerate, sandstone, shale and limestone.

iii. Metamorphic rocks. These rocks are formed from the igneous or sedimentary rocks by the action of intense heat and high pressure or both resulting in considerable change in the texture and mineral composition. The common metamorphic rocks are **gneiss** from granite, **quartzite** from quartz or sandstone, **marble** from limestone and **slate** from shale.

In any case, the nature of the parent material may have a profound influence on soil formation. Parent materials are composed of mineral or organic matter or both. The most widespread parent materials range from consolidated rocks to various unconsolidated sediments. The consolidated rocks can be **igneous, metamorphic or sedimentary**, whereas the unconsolidated materials include **alluvium, colluvium, dune sand, lacustrine deposits, volcanic ash, etc.**

The role of parent material in soils formation is passive. This is because; there is only weak correlation between the nature of rocks and the soils developed from them. Different kinds of parent materials may give rise more or less identical soil when the climate and vegetation of an area remain the same, or the same kind of rock can give different soils depending up on the other factors specially climate. For instance, basalt may give a red, highly weathered soil (Ferralsols) in the humid tropics or it may give a black tropical soil (Vertisols) in a semi-arid environment. The best correlation is with the texture of the parent material. Materials with high Quartz content give rise to sandy soils while basic and fine-grained sediments tend to give fine textured soils.

2. Climate

Climate is perhaps the most influential active factor because it determines the nature and intensity of weathering that occurs over large area. Rainfall, temperature, humidity/evaporation and wind are the climatic factors that strongly influence soil formation. The principal climatic variables influencing soil formation are temperature and precipitation, both of which affect the rates of chemical, physical, and biological processes. Climate also influences soil formation indirectly through its action on other factors like vegetation and

fauna on which soil formation is dependent. It tends to reduce differences caused by the parent material. That is why two different parent materials may develop the same soil in one type of climate regime. Likewise, the same parent material may produce different types of soil in different types of climates. Crystalline granites produce laterite soil in relatively moist parts of the monsoonal region and non-lateritic towards its drier margins. Hot summer and low rainfall develops black soil irrespective of the parent rock.

Temperature: The main effect of temperature on soils is to influence the rate of soil formation, since for every 10° rise in temperature the speed of a chemical reaction increases by a factor of two. This principally applies to the weathering of minerals. The rate of both biological activity within the soil and the breakdown of organic matter are also increased by a rise in temperature. The amount of moisture evaporated from the soil also increases.

Moisture: Very largely the movement of moisture determines the differentiation of horizons (layers). The moisture entering the soil comes mainly from precipitation as rain and snow and contains appreciable amounts of dissolved CO₂. Thus, actually the water entering the soil is a dilute acid, which is much more active than pure water. It is precipitation of moderate intensity that enters the soil best and that is most influential, as light showers are mainly lost by evaporation and heavy rains are mainly lost as runoff.

The role of moisture in soil formation is profound as it is a transport agent of ions and other solutes. Besides, it facilitates the activity of microbes. The acidic nature of soil-entering moisture facilitates the decay (weathering) of some rock minerals, e.g. Calcite, dolomite and gypsum. Thus moisture also speeds up the rate of soil formation, it does so much strongly under high temperature.

3. BIOTA: Living Organisms

The biota is composed of two elements, namely flora or the plant kingdom and fauna or the animal kingdom. Nearly every organism living on the surface of the earth or in the soil affects the development of soils in one way or another. The actions of living organisms include organic matter accumulation, profile mixing by animals, nutrient cycling by all, structural stability of soils, etc.

The most influential aspect of higher plants is the role of roots, the addition of organic matter, the extraction of water and nutrients from the soil. Plant roots act as binders and prevent soil from erosion. They grow into the cracks of rocks forcing the rocks to break apart. Besides, they die and decompose there adding organic matter to the interior of the soil. Litter fall, from

leaves and trunks, also contribute significant amount of organic matter to the soil surface thereby changing the properties of the soil. Plants extract water and nutrients from the soil body. This leads to the loss of ions from the soil and rapid loss of water from the soil. The losses in turn affect the physical and the bio-chemical properties of the soil.

Few mammals, vertebrates, including rabbits, moles, prairie dogs dig down into the soil mixing the profile considerably. Uncontrolled grazing by animals also leads to susceptibility of the soil to erosion. The addition of organic matter as waste products and dead bodies from animals should not be ignored as well. Recently, human influence on soils is stepping up rapidly because of industrialization and intensive agriculture. Human beings influence soil to the extent that a different soil type is the result.

The predominant micro organisms in the soil are bacteria, fungi, actinomycetes, algae and viruses. The distribution of these micro organisms in soils is determined largely by the presence of food supply. Consequently, their number is greatest in the surface horizons. However, the type and number of micro organisms that occur in soils are determined by temperature and moisture. Micro organisms play considerable role in the decomposition of organic matter and other bio-chemical reactions.

Earthworms, nematodes, mites, millipedes, etc are some of the Mesofauna that are present in soils. Their distribution is determined almost entirely by their food supply. Consequently, they are concentrated in the top 2-5cm; only few, such as earthworms, penetrate below 10-20cm. They are concerned largely with the ingestion and decomposition of organic matter, and mineral matter in some cases. They also transport materials from one place to another and in so doing they produce drainage passages.

4. Topography

Topography relates to the configuration of the land surface and is described in terms of differences in elevation, slope, and landscape position-in other words, the lay of the land. The work of topography may be to hasten or delay the work of climatic forces. It influence runoff, drainage, soil temperature, and soil erosion and consequently soil formation. Topography influences soils in such a way that on flat or gently sloping sites there is the tendency for materials to remain in place and for the soil to be thick but as the slope increases so does the erosion hazard, resulting in tiny stony soils on strongly sloping lands. Topography also influences the drainage and the amount of moisture in the soil. Most soil from slope is carried away by several agents. Such soils are called transported soils.

5. Time

Soil-forming process takes time to show their effects. The clock of soil formation starts ticking when a land slide exposes new rock to the weathering environment at the surface, when a flooding river deposits a new layer of sediment on its floodplain, or when a bulldozer cuts and fills a landscape to level a construction or mine-reclamation site. The length of time required for a soil to develop the distinct layers called genetic horizons depends upon many interrelated factors of climate, nature of the parent material, the organisms, and topography. Soil formation is a very long and slow process requiring thousands and even millions of years. This makes impossible for human beings to study the influence of time as it is much longer than the life span of an individual. Mature soils are developed over a long time reflecting the influence of organic matter and climate. They have well-developed soil profile. It tells us the influence of time factor.

2.4. The Soil Profile:

Soils develop distinct layers at varying depths below the land surface. A vertical section through the soil in the field to expose the layering is called a **profile**. A soil profile has a distinct morphological appearance that varies gradually with distance. The upper layer is usually higher in organic matter and darker in colour than the layers below. This upper layer is called the A horizon, or topsoil.

The middle part of the profile usually contains more clay and has a brighter colour than the top soil. The A and B horizons together are referred to as the **solum**, or **true soil**.

2.4.1. Soil Profile Development:

Most soil profiles show layers approximately parallel to the soil's surface, *soil horizon*. Soil profile is different from geologic column. Generally, soil profile develops through disintegration and synthesis of minerals, addition and transformation of organic matter, nutrient leaching, and all action of water. The material in the A and B horizons was once part of the C horizon but has undergone many changes. The changes, that produce A and B horizons are referred to as soil development.

The upper layer became an A horizon as it accumulated organic matter from roots and plant residues. Other changes resulted from forces that cause physical disintegration and chemical decomposition. The A horizon is the portion of the soil most exposed to the weathering action of the sun, rain, wind and ice and to the action of the living things. The more easily decomposed materials weather away first, thus leaving the more resistant minerals

concentrated in the top soil. The more fertile soils are less weathered and still contain minerals that decompose and release new plant nutrients each year.

Weathering process break down some of the mineral particles in the soil to smaller size, and part of the silt is reduced to clay. Some constituents become soluble and are removed from the soil by the leaching action of water. The A horizon is the most leached portion of the soil.

2.4.2. Soil horizon differentiation:

A soil horizon is defined as “a layer which is approximately parallel to the soil surface and that has properties produced by soil forming processes but that are unlike those of adjoining layers. Horizons may usually be identified visually in the field but also have chemical and physical characteristics which can be diagnosed in the laboratory.

Although, profiles of different types of soil differ markedly in respect of their physico-chemical and biological properties, it is not true that all these horizons are always present in each profile. Six master soil horizons are recognized in a soil profile. The soil profile consists of following five main horizons:

These are designated using the capital letters O, A, E, B, C and R.

1. The ‘O’ Horizon:

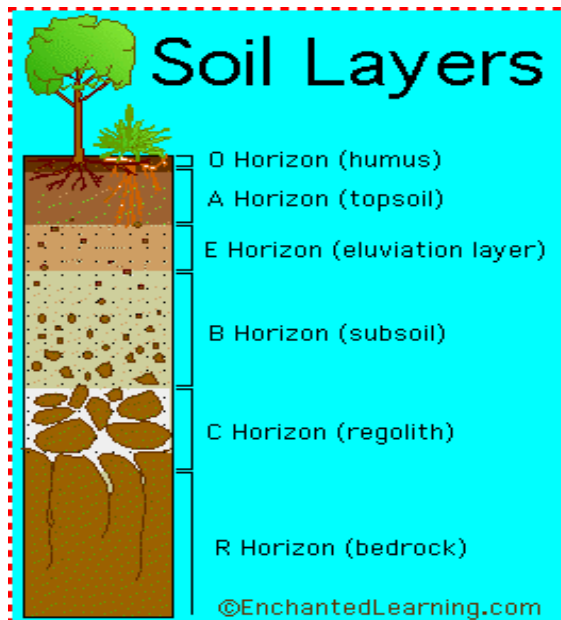
These are the organic horizons forming above the surface of the mineral matrix, mainly composed of organic matter. They occur commonly in forested areas and in grassland regions. This horizon is divided into following two sub layers-

O₁ (A_{oo}) region:

This is the uppermost layer consisting of freshly fallen dead organic matter as dead leaves, branches, flowers and fruits, dead parts of animals etc. these do not show evident breakdown.

O₂ (A_o) region:

It is just below the O₁ region, in which decomposition has begun. Thus organic matter is found under different stages of decomposition and microorganism like bacteria, fungi, actinomycetes are frequently found.



The 'A' horizon:

These are the mineral horizons formed either at or adjacent to the surface. These are rich in organic matter and /or show downward loss eluviation of soluble salts, clay, iron or aluminium, being consequently rich in silica or other resistant minerals. This is thus also known as **zone of eluviation**-downward loss or leaching. This horizon is divided into following two sub layers:

A₁ region:

It is dark and rich in organic matter. The amorphous, finely divided organic matter here becomes mixed with the mineral matter, which is now known as humus, which is dark brown or black coloured. This region having a mixture of finely divided organic matter and the mineral matter is also called **humic** or **melanised region**. In forest soils this region is less deep than those of the grassland.

A₂ region:

This region is of light colour in which the mineral particles of large size as sand are more, with little amount of organic matter. Chiefly in areas of heavy rainfall, the mineral elements and organic chemicals are rapidly lost downward in this region, making it light coloured. This is thus also known as **podsol** or **eluvial zone** or **zone of leaching**.

2. The E Horizon: Zone of leaching, materials move downward.

3. The 'B' Horizon:

The 'B' horizon is dark-coloured and coarse-textured due to the presence of silica-rich clay organic compounds, hydrated oxides of aluminium, iron etc. since the chemicals leached from A₂ region, become collected in this horizon, it is also known as zone of illuviation or illuvial zone. This zone is poorly developed in dry areas. This is divided into B₁, B₂ and B₃ regions.

A₁, A₂ and B collectively are also known as **mineral soil** or **solum**.

4. The 'C' Horizon:

These are the mineral horizons below the 'B' but excluding true bedrock and without any characteristics of 'A' or 'B' horizons. It consists of incompletely weathered, large masses of rocks.

5. The 'R' Horizon:

This is the parent, unweathered bedrock, upon which there is collected water.

Physical properties are those which can be evaluated by visual inspection or by feel. They can be measured against some kind of scale such as size, strength, or intensity. Each soil has its own set physical properties depending on the nature of each component part, the relative amounts of each component present, and the way they fit together.

Soils are composed of solids, liquids, and gases mixed together in variable proportions. The relative amount of air and water present depend greatly on how tightly the solid particles are packed together. The packing of small particles tends to be quite different from the packing of large particles. Both the soil texture (an elevation of the sizes of the particles) and the soil structure (the way the particles are arranged) influence the amount of pore space the soil contains and the way that pore space is distributed.

Soil physical properties are distinguished from chemical properties since they do not require a chemical reaction to be effective. The physical properties of a soil are those responsible for the transport of air, heat, water, and solutes through the soil and largely determine the way in which soils can be used most effectively.

3.1. Soil texture

Soil texture is the relative percentage of sand, silt and clay in a soil. It refers to the relative proportion of particles of various sizes in a given soil (i.e. it refers to the percentage by weight of each of the three mineral fractions: sand, silt and clay in the fine earth fractions i.e. particles <2mm in diameter). Particles larger than 2 mm in diameter are excluded from soil texture determinations. Stones and gravel may influence the use and management of land because of tillage difficulties, but these larger particles make little or no contribution to such basic soil properties as water holding capacity to store and release plant nutrients. Mineral particles are usually separated into convenient groups based on their size, i.e. in terms of the equivalent diameter in mm of the particles, for the ease of study. The term equivalent diameter is used because soils do not have definite spherical shape. These inorganic (mineral) particles, separated according to size, are referred to as **soil separates**. The relative proportions of the soil separates determine the soil texture. Texture of a soil influences many soil properties. Among these are available water holding capacity, infiltration, porosity, aeration, and cation exchange capacity.

A number of different classification systems, to separate mineral particles based on their size, have been devised by different institutions (e.g. British Standards Institution (BSI),

International Society of Soil Science(ISSS), United States Department of Agriculture (USDA), United States Public Road Administration (USPRA)) of which two are widely adopted.

United States Department of Agriculture (USDA) made more classes in the following size ranges (Table2).

Table 1. Particle size classification by USDA

No	Separates	Equivalent Diameter (mm)
1	Very Coarse Sand	1 - 2
2	Coarse Sand	0.5 - 1
3	Medium Sand	0.25 - 0.5
4	Fine Sand	0.10 - 0.25
5	Very Fine Sand	0.05 - 0.10
6	Silt	0.002 - 0.05
7	Clay	<0.002

Sand: Sand particles are those smaller than 2mm but larger than 0.05mm. It feels gritty between the fingers and the particles are generally visible to the naked eye. As sand particles are relatively large, so, too, the voids between them are relatively large and promote free drainage of water and entry of air into soil. Because of their large size, particles of sand have relatively low specific surface area. Therefore sand particles can hold little water. Sand particles are considered non cohesive; that is, they do not tend to stick together in mass. It is dominated by Quartz. In addition, feldspars and micas may exist.

Silt: Silt is considered to have medium nature in between sand and clay. Particles smaller than 0.05mm but larger than 0.002 mm in diameter are classified as silt. Individual silt particles are not visible to the naked eye, nor do they feel gritty when rubbed between the fingers. It feels smooth or silky, like flour. The pores between silt particles are much smaller (and much more numerous) than those in sand, so silt retains more water and lets less drain through. However, even when wet, silt itself does not exhibit much stickiness or plasticity (malleability).

Clay: Particles smaller than 0.002 mm are classified as clay and have a very large specific surface area , giving them a tremendous capacity to adsorb water and other substances. A spoonful of clay may have a surface area the size of a football field. This large adsorptive surface causes clay particles to cohere in a hard mass after drying. When wet, clay is sticky.

Clay size particles are so small that they behave as colloids-if suspended in water they do not readily settle out. The pores between clay particles are very small and convoluted, so movement of both water and air is very slow.

As particle size decreases from sand to clay the following properties of the soil increase:

- Surface area to volume/weight ratio
- adsorbing power for water and nutrients
- swelling and shrinking
- plasticity and cohesion

3.2. Soil Structure

The arrangement of the individual particles into larger units is called soil structure. It results from the tendency of the finer soil particles, specially clay and humus, to stick together. It influences water movement, heat transfer, aeration, bulk density and porosity. Units of soil structure are called **peds**. Peds are natural groups of primary particles (sand, silt, clay and organic materials) that occur and persist within the soil.

Types of soil structure are classified as follows.

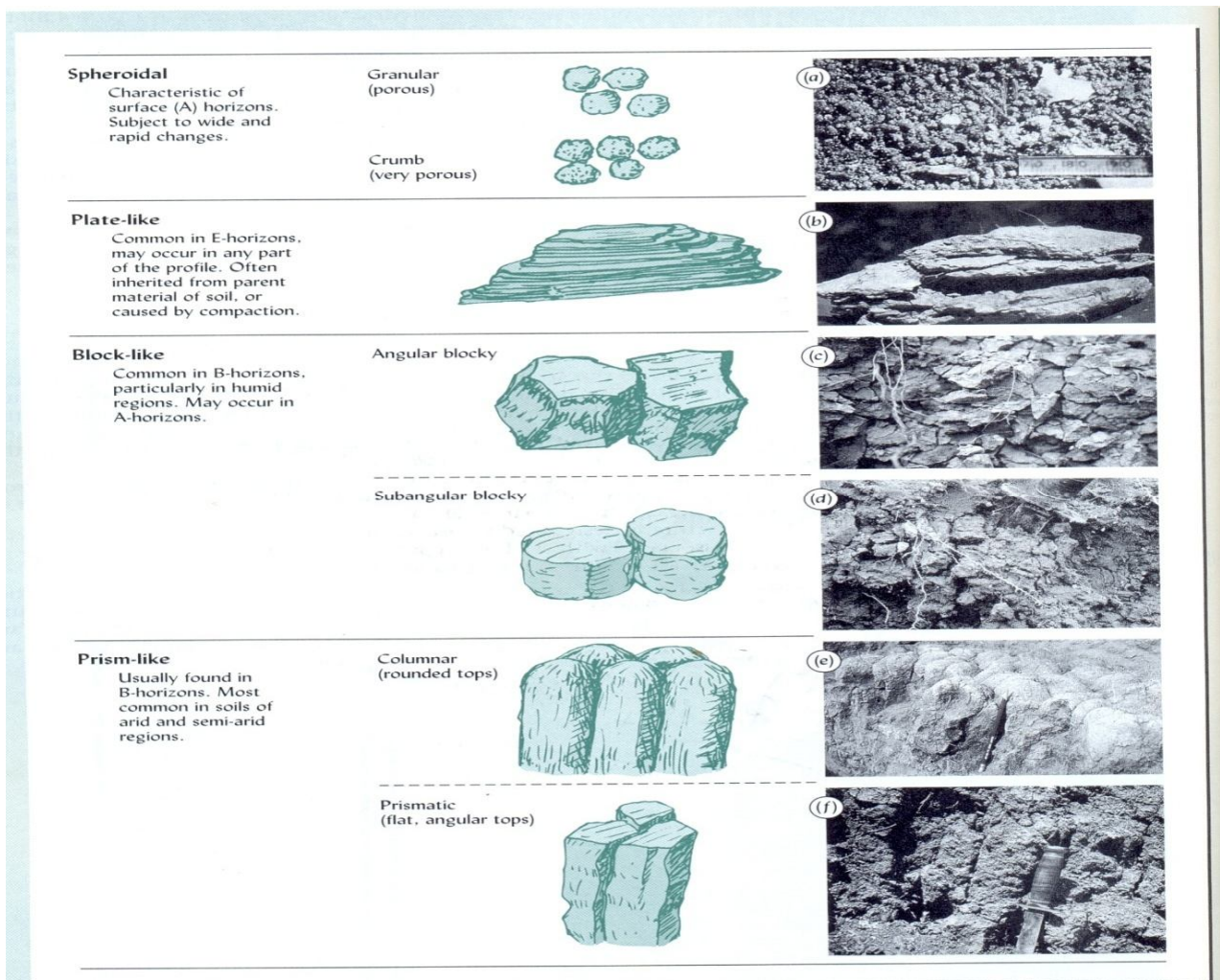
1. Structure less

- a) **Single grain.** Each soil particle is independent of all others in A or c horizons not held together by organic matter or clay. This condition is typical of very sandy materials.
- b) **Massive.** With no definite structure or shape, as in some C horizons or compacted material.

2. Structured: There are four types:

- A. **Platy-** Platy soil structure has peds with horizontal dimensions greater than vertical dimensions. It may occur in any part of the soil. It is mainly laid down by water or ice.
- B. **Prism-like:** Prismatic peds are taller than they are wide. Vertically oriented aggregates or pillars varying in length. Most commonly, **it occurs in the B-horizons of arid and semi arid Soils.** They can be grouped in to two:
 - **Columnar:** when the **tops are rounded.** This occurs when the profile is changing and certain horizons are degrading.
 - **Prismatic:** when the tops are level plane and clean cut.

- C. **Block-like:** Blocky peds are approximately equal in their vertical and horizontal dimensions. Aggregates have been reduced to block, **six faced, with the 3 dimensions more or less equal**. These can also be classified in to two:
- **Angular blocky** - edges are sharp and the faces distinct. Angular blocks are common in B horizons.
 - **Sub-angular blocky** – Peds with mostly rounded corners. This type is confined to the subsoil.
- D. **Spheroidal** - includes all rounded aggregates. Such types of structure lie loosely and are shaken apart easily. They are **common in A-horizons** that are high in organic matter content. Practical soil management like manuring can influence them. It is divided into two types. These are:
- **Granular** - Ordinary aggregates(are relatively less porous crumbs
 - **Crumb** - When the aggregates are especially crumb(very porous)



Importance of Structure in soils:

The structure of the soil is important for (1) aeration, (2) water permeability and its relation to runoff, (3) the degree of resistance the soil has to erosion, and (4) formation of a good seedbed to initiate plant growth.

A granular structure is ideal for air and water relations. The space between granules is important for aeration and for water percolation. All of the water entering the soil must pass through the upper part so the permeability of the A horizon is most significant. Rainfall that cannot enter the soil becomes runoff and may cause erosion.

3.3. Soil Air

Soil air is a continuation of the atmospheric air. Unlike the other components, it is constant state of motion from the soil pores into the atmosphere and from the atmosphere into the pore space. This constant movement or circulation of air in the soil mass resulting in the renewal of its component gases is known as **soil aeration**. Sufficiently aerated soil must have at least two characteristics:

- Sufficient space devoid of solids and water
- Ample opportunity for the ready movement of essential gases into and out of these spaces.

Two biological reactions account for oxygen and carbon dioxide proportions and amount in the soil:

- Respiration of higher plant roots
- The aerobic of organic residues by micro organisms

Mass flow and diffusion facilitate the exchange of gases between the soil and the atmosphere. Soil air constantly moves from the soil pores into the atmosphere and from the atmosphere into the pore space. Soil air and atmospheric air differ in the compositions. Soil air contains higher level of CO₂, water vapour, methane (CH₄), and H₂S as compared to atmospheric air. This composition is determined by the amount of airspace available, biochemical reactions, gaseous interchange, depth within the profile and season.

Composition of soil and atmospheric air:

Percentage by volume			
	Nitrogen	Oxygen	Carbon dioxide
Soil Air	79.2	20.6	0.3
Atmospheric Air	79.9	20.97	0.03

Effects of soil aeration on biological activities

- i. **On micro organisms:** A decrease in the rate of organic matter oxidation results from poor aeration because of the lack of oxygen, not excess CO₂. Only anaerobic and facultative organisms function properly under poor aeration.
- ii. **On higher plants:** Poor aeration results in the following phenomena in higher plants:
 - The growth of the plants, especially root, is curtained.
 - The absorption of nutrients is decreased.
 - The absorption of water is decreased.
 - The formation of certain inorganic compounds toxic to plant growth is facilitated.

The most common remedies for poor aeration are removal of excess water, aggregation (granulation) and breaking compacted layers.

3.4. Factors Affecting the Composition of Soil Air:

1. Type of crop: Plant roots require oxygen, which they take from the soil air and deplete the concentration of oxygen in the soil air. The amount of CO₂ is usually much greater near the roots of plants than further away. It may be due to respiration by roots.

2. Microbial activity: The microorganisms in soil require oxygen for respiration and they take it from the soil air and thus deplete its concentration in the soil air. Decomposition of organic matter produces CO₂ because of increased microbial activity. Hence, soils rich in organic matter contain higher percentage of CO₂.

3. Seasonal variation: The quantity of oxygen is usually higher in dry season than during the monsoon. Because soils are normally drier during the summer months, opportunity for gaseous exchange is greater during this period. This results in relatively high O₂ and low CO₂ levels. Temperature also influences the CO₂ content in the soil air. High temperature during summer season encourages microorganism activity which results in higher production of CO₂.

4. Soil Porosity

The fact that mineral soils have a particle density and bulk density of about 2.65 and 1.3 g/cm³, respectively, means that soils have about 50 percent total pore space or porosity. In simple terms, rocks without pore space are broken down by weathering to form mineral soils that have about 50 percent porosity. The pore spaces vary in size, and the size of pore spaces themselves can be as important as the total amount of pore space.

Chapter 4. Chemistry of Soil

4. Introduction

The chemical properties of a soil affect mineral solubility and nutrient availability to crop plants. Chemical properties give soils their ability to hold nutrients and create a desirable chemical environment for plant growth. Chemical properties of soil are determined by the nature of soil colloids (organic and inorganic). Mainly the focuses of attention are their mineral and chemical composition, charges, and exchange of ions, reaction, salinity, and other properties.

4.1. The Soil Colloid

A colloid is a solid substance whose particles are very small. In *Greek*, colloid meant *glue*. The soil colloids are the most active portion of the soil and largely determine the physical and chemical properties of the soils. Soil colloid includes particles with diameter less than 0.001mm in diameter, and the clay fractions includes particles less than 0.002 mm in diameter. Soil colloids are the sites within the soil where ions of essential mineral elements such as calcium, potassium and sulphur are held and protected from excessive loss by percolating rain or irrigation water.

4.1.1. General properties of soil colloids

1. Size: The most important common property of colloids is their extremely small size. They are too small to be seen with an ordinary light microscope.

2. Surface area: Because of their small size, all soil colloids expose a large external surface per unit mass. The external surface area of a unit mass of colloidal clay is at least 1000 times that of 1g of coarse sand.

3. Surface charges: Soil colloidal surfaces both external and internal, carry negative and/or positive charges. For most soil colloids, electro negative charges predominate, although some mineral colloids in very acid soils have a net electropositive charge.

4. Adsorption of cations and water: The charges on soil colloids attract ions of opposite charge to the colloidal surfaces. Such attraction is of particular significance for negatively charged colloids. The colloidal particles referred to as micelles (micro cells), attract hundreds of thousands of positively charged ions or cations such as H^+ , Al^{3+} , Ca^{2+} , Mg^{2+} . Anions such as NO_3^- , Cl^- , SO_4^{2-} may also be adsorbed on some soil colloids; however, the adsorption of anions is not as extensive as that of cations.

In addition to adsorbing cations and anions, soil colloids attract and hold a large number of water molecules. The charges on the internal and external colloids surfaces attract the positively charged end of the polar water molecules.

4.2. Types of Soil Colloids

There are four major types of soil colloids in soils:

1. Layer silicates,
2. Iron and aluminium oxide clays,
3. Allophane and associated clays and
4. Humus.

4.2.1. Sources of the Negative Charges on soil colloids

Colloids are predominantly negatively charged. This charge arises because of two reasons:

1) Broken edges of layer silicates and dissociation of H^+ from surface functional groups: Clays have OH groups on edges, which exhibit amphoteric behaviour. May be positively charged at low pH, and negatively charged at high pH. This charge is variable depending on the pH of the soil solution and therefore called **pH dependent charge**.

2) Isomorphous substitution: Substitution of ions (Mg^{+2} , Fe^{+2} , etc) for Al^{+3} in octahedral sheets, or Al^{+3} for Si^{+4} in tetrahedral sheets creates a net negative charge on clay particles. This charge is fixed, and not dependent on the environment. Since these charges are not dependent on the pH, they are termed **Permanent or constant charges**.

Isomorphous substitution is vital because it is the primary source of charges. Isomorphous substitution could be the source of both negative and positive charges. A net negative charge is found in mineral where there has been an isomorphous substitution of a lower charge ion substitutes for a higher charge ion. For example: Al^{+3} substitutes for Mg^{+2} in dioctahedral sheets and Al^{+3} substitutes for a Si^{+4} in a tetrahedral sheet. Isomorphous substitution can also be a source of positive charges if the substituting cation has a higher charge than the ion for which it substitutes.

4.2.2. Organic Colloids (Humus): Humus is an organic colloid. Humus is a mixture of residues left after partial decay of organic substances (plants and animal residues) in and on top of soils. Humus is composed mainly of C, H and O. It has very high CEC (net negative charge).

Humus particles are often among the smallest of soil colloids and exhibit very high capacity to adsorb water, but almost no plasticity or stickiness. Humus has high amounts of both negative and positive charge per unit mass, but the net charge is always negative and varies with soil pH. The negative charge on humus is extremely high in neutral to alkaline soils.

Sources of negative charges in humus: There are two sources of negative charges in humus: neutralized carboxylic (-COOH) and phenolic hydroxyl (OH) groups. The charge is pH dependent. The hydrogen ion in both groups is firmly held at low pH while it easily dissociates at high pH leaving the oxygen with unsatisfied one negative charge. Thus the number of negative charges is high at high pH and low under acidic condition.

4.3. Cation exchange

Any electrically charged colloidal surface area will attract mobile substances of opposite charged in the soil water. The dominant residual charge on most soil colloids is negative. These negatively charged sites attract positively charged ions in the soil water. Positively charged ions are called cations. Adsorbed cations resist removal by leaching water but can be replaced (exchanged) by other cations in solution by mass action (competition for the negative site because of the large number of ions present). **Cation exchange is the exchange of one cation in the soil solution with another on the surface of a colloid.** Cation exchange takes place on the surfaces of clay and humus colloids as well as on the surface of plant root cell walls. The major factors will determine the relative proportion of the different cations adsorbed by layers is their charge. First these ions are not all held with equal tightness by the soil colloids. The order of strength of adsorption when they are present in equivalent quantities is $\text{Al}^{3+} > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ = \text{NH}_4^+ > \text{Na}^+$.

Second the concentration of the cations will help determine the degree to which adsorption occurs. Thus in the solution of very acid soils, the concentration of Al^{3+} is high and some H^+ ions is present; consequently, these ions dominate the adsorbed cations. At neutral pH and above, however, the concentration of Al^{3+} and H^+ ions in the soil solution is very low. Consequently, the adsorption of these ions is minimal. In these soils, Ca^{2+} and Mg^{2+} dominate. In poorly drained soils, of the arid regions, salts high in sodium accumulate and adsorption of Na^+ becomes much more prominent.

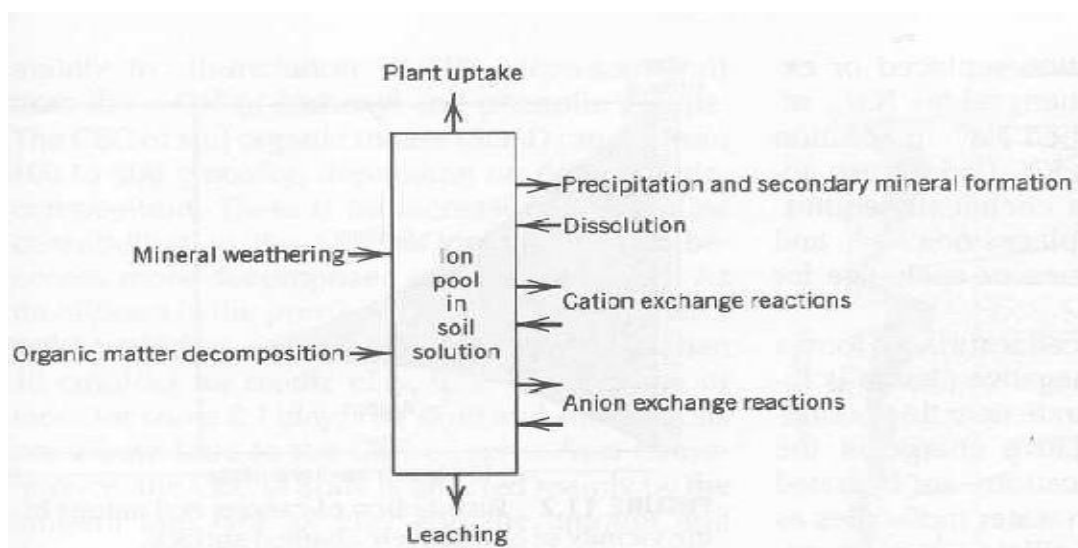


FIGURE: Major chemical processes and reactions in soils. Weathering of minerals and decomposition of organic matter supply ions to the ion pool of the soil solution. Ions are lost from the pool by plant uptake and leaching. Some ions precipitate and some ions form secondary minerals, especially clay minerals, and are subject to dissolution. Ions also sorb onto and desorb from cation and anion exchange sites.

4.3.1. The Importance of Cation Exchange:

Cation exchange is an important reaction in soil fertility, in causing and correcting soil acidity and basicity, in changes altering soil physical properties, and as a mechanism in purifying or altering percolating waters. The plant nutrient calcium, magnesium, and potassium are supplied to plants in large measure from exchangeable forms. In fact, the usual “soil test” to predict a soils ability to furnish potassium to the plant is a measure of its exchangeable potassium content. Cation exchanged is very important in soils because of the following relationship:

1. The exchangeable K is a major source of plant K.
2. The exchangeable Mg is often a major source of plant Mg.
3. Cation exchange sites hold Ca^{+2} , Mg^{+2} , K^{+} , Na^{+} and NH_4^{+} ions and slow their losses by leaching.
4. Cation exchange site hold fertilizer K^{+} and NH_4^{+} and greatly reduced their mobility in soils.
5. Cation exchange sites adsorb many metals (Cd^{+2} , Zn^{+2} , Ni^{+2} , Pb^{+2}) that might be present in wastewaters. Adsorption removes them from the percolating water, thereby cleansing the water that drains into ground waters or surface waters.

4.3.1.1. Cation Exchange Capacity (CEC)

Clay have negatively charged sites in their lattices and attract and hold positively charged ions (cations) at the clay surface. The quality of these cations that can be held, or exchanged, by a given amount of soil is the **cation exchange capacity** of the soils. **Cation exchange capacity is the capacity of soils to hold (adsorb) and exchange cations** (i.e. exchange of one cation in the soil solution with another on the surface of a colloid). It is measured in *centimoles_c of cations per kilogram of soil* (cmol_c kg⁻¹). The term *centimoles_c* is used because the number of negative sites in a given soil sample does not change, but the weights of the cations that may be adsorbed to those sites at one time do change. It is the quantitative measure of all the cations adsorbed on the surface of the soil colloids. It is expressed (the amount is usually expressed) in terms of cmol(+)/kg of soil. The CEC is strongly affected by the nature and amount of mineral and organic colloid present in the soil. Soils with large amounts of clay and organic matter have higher CEC than sandy soils low in organic matter. Soils with smectite type of clays have a higher CEC than soils with kaolinitic type of clays. Soils rich in organic matter have high CEC as organic colloids have many-very charged sites.

Table. Types of soil colloids and their CEC

Colloid	CEC (cmol _c /kg of soil)
Humus	200
Vermiculite	150
Montmorillonite	100
Chlorite/illite	30
Kaolinite	8
Hydrous oxides	41

4.3.1.2. Basic Cation Saturation Percentage (BCSP)

The cations commonly adsorbed on exchange sites of soil colloids can be divided into **acid-forming cations** (aluminium and hydrogen) and **base-forming cations** (calcium, magnesium, potassium, sodium and some others). The proportion of basic cations in percentage to the total cations on the cation exchange complex is the **basic cation saturation percentage (BCSP)**. For example, if a soil has a cation exchange capacity of 16 cmol_c/kg and 4.2 cmol_c of the cations are aluminium and hydrogen, the remaining cation exchange sites always contains the basic cations. The basic cations = 16.0 - 4.2 = 11.8 cmol_c/kg. The basic

cation saturation percentage is $(11.8/16) (100) = 73.75\%$. Exchangeable aluminium (Al^{+3}) and hydrogen (H^+) are called acid cations and their proportion on the CEC is called **percent acid saturation**.

The relationships among these terms can be summarized as follows:

$$\text{Percent Base Saturation} = \frac{\text{cmol}_c/\text{kg of exchangeable}(\text{Ca}^{2+} + \text{Mg}^{2+} + \text{K}^+ + \text{Na})}{\text{cmol}_c/\text{kg of CEC}} \times 100$$

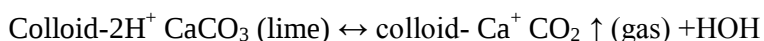
$$\text{Percent Acid Saturation} = \frac{\text{cmol}_c/\text{kg of exchangeable } \text{Al}^{+3} + \text{H}^+}{\text{cmol}_c/\text{kg of CEC}} \times 100$$

$$\text{Percent Base Saturation} + \text{Percent Acid Saturation} = 100$$

Question: Consider a soil with a CEC of 20 cmol_c/kg holding these amounts of exchangeable cations (in cmol_c/kg): 10 of Ca^{+2} , 3 of Mg^{+2} , 1 of Na^+ , 1 of H^+ and 4 of Al^{+3} . Calculate the percent calcium saturation, percent aluminium saturation percentage, Percent Base Saturation and Percent Acid Saturation.

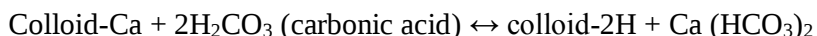
4.3.1.3. Buffering Capacity of Soils:

Most soils can resist appreciable pH changes when large amounts of a material either strongly acidic or basic are added, such as an acid-forming or base-forming fertilizer. **This ability to resist a change in pH is the buffering capacity of the soil.** The buffering capacity increase as the cation exchange capacity increases. To exit buffering, the soil must “remove” hydrogen ions (H^+) of added acids or neutralize the hydrolysis (OH^-) of added bases. This occurs by cation exchange and neutralization:



In these two examples, neither the aqueous ammonia fertilizer nor lime greatly changes the soil pH because the base is “neutralized” to either exchangeable NH_4^+ or Ca^{+2} plus the neutral water. A small pH change does not occur, and the pH will gradually change as more and more base is added.

A similar buffering reaction occurs with an added acid:



Carbon dioxide dissolves in water to form weak carbonic acid (H_2CO_3), which ionizes to produce free H^+ . The free H^+ goes on the exchange sites and the calcium replaced forms calcium bicarbonate that is slightly basic. Eventually, the bicarbonate will precipitate as lime.

Chapter 5. Organic Matter of Mineral Soil

5.1. Introduction:

Soil organic materials consist of plant and animal residues in various stages of decay. Primary sources of organic material inputs are dead roots, root exudates, litter and leaf drop, and the bodies of soil animals such as insects and worms. Earthworms, insects, bacteria, fungi, and other soil organisms use organic materials as their primary energy and nutrient source. Nutrients released from the residues through decomposition are then available for use by growing plants.

Waste is human concept. In nature nothing is wasted, for everything is part of a continuous cycle. Even the death of a creature provides nutrients that will eventually be reincorporated in the chain of life.

- Denis Hayes

Soil organic matter is by definition the organic fraction derived from living organisms. It includes the partly decomposed and decomposed plant and animal residues as well as the living organisms of the soil (micro organisms and plant roots). The decomposed organic fraction is usually called “humus”. Humus is the most reactive and important component of soil organic matter, and is the form of soil organic material that is typically reported as “organic matter” on soil testing reports. It is composed of (1) Non-humic substances, and (2) Humic substances.

The non humic substances include carbohydrates, amino acids, lipids, lignins, etc., all of which are the metabolic products of organisms. On the other hand, humic substances, such as humic acids and fluvic acids, which are brown to black in colour, are high molecular weight compounds that are synthesized by soil micro organisms. Approximately 50% to 85% of the total organic matter content is humus. About 65% to 75% of this humus is composed of humic matter, while the remaining 35% to 25% consists of non humic matter.

Organic matter contents in mineral soils of warm humid regions are relatively small. Mineral soils generally contain less than 20% organic matter and greater than 80% mineral matter on a weight basis. On volume basis, a fertile loamy top soil has an average organic matter content of only 5%. In less fertile soils and in sub soils, the organic matter content is less than 5% by volume.

5.2. Sources and Composition of SOM

5.2.1. Sources of SOM:

The primary or original source of soil organic matter (SOM) is the production of the primary producers-the higher plants. This organic material is subsequently consumed and decomposed by soil organisms. The result is the decomposition and the accumulation of organic matter in soils that has great diversity and a highly variable composition.

Because plant residues are the principal material undergoing decomposition in soils and, hence plants, are the primary source of soil organic matter.

5.2.1.1. Plants as Sources of Soil Organic Matter

Plant (mainly higher) plant tissue is the major and primary (original) source of soil organic matter:

- Under natural vegetation: The tops and roots of trees, bushes, shrubs, grasses and other native plants supply large quantities of organic residues annually.
- Under cultivated lands: Although a good portion of the tops are left in the soil.

5.2.1.2. Animals as Sources of Soil Organic Matter

Animals are considered as secondary sources of soil organic matter. As they feed on plant tissue, they:

- ✓ Contribute their waste products
- ✓ Leave their own bodies as they complete their life cycle.

5.3. Composition of SOM

The plant residues, including tops and roots, contain a wide variety of compounds: sugar, cellulose, hemicelluloses, protein, lignin, fat, wax, and others. As plant residues dominate SOM, composition-wise SOM is similar to the composition of plant residues. Green plant residues of higher plants are composed of:

- Water: 60 – 90 % (75% being an average)
- Dry matter (DM): 25% at an average

5.3.1. Elemental Composition of the DM: The dry matter (DM) portion of soil organic matter is predominantly composed of C, O, and H:

- a) Carbon: 11% of 25% (or 44% of total DM)
- b) Oxygen: 10% of 25% (or 40% of total DM)
- c) Hydrogen: 2% of 25%(or 8% of total DM)
- d) N,P,S plus inorganic elements (ash): 2% of 25% (or 8% of total DM)

Carbon, H and O dominate the bulk of organic tissue in the soil, making up over 90% of the dry matter. However, the other elements although found in small amounts play a vital role in plant nutrition. Nitrogen, P, S, K, Ca, and Mg are particularly significant, as are the micronutrients contained in plant materials. The C: N: S: P ratio of soil organic matter is 100:10:1:1.

5.3.2. Types (composition) of compounds in DM:

- a) Cellulose: 45% of total DM
- b) lignin: 20% of total DM
- c) Hemicelluloses: 18% of total DM
- d) Protein: 8% of total DM
- e) Sugars and starch: 5% of total DM
- f) Fats and waxes: 2% of total DM
- g) Polyphenols: 2% of total DM

5.4. Distribution of organic matter in the soil:

Most of the roots occur in the upper part; the soil organic matter is naturally most concentrated in this zone. Most decomposition occurs in the upper layers because more organic matter is added there; furthermore aeration is more adequate there than it is below. The organic matter content of any horizon of any soil depends partly on how much organic matter is turned over to the soil every year and partly on what percentage of the organic matter decomposes during the year.

5.4.1. Effect of vegetation: Changes in vegetation alter the pattern of organic matter accumulation within the soil. Much of the organic matter of forest soil is derived from leaf fall. The roots are less important sources of organic matter than grass roots because much of the root system lives for many years. The annual turnover of organic matter from dying tree root is therefore smaller than from grass roots. The smaller accumulations of organic matter at lower levels in forest soils come mostly from root residues plus some illuvial humus.

5.4.2. Effect of climate: warmer climates have much the same effect on organic matter contents as drier climates because they accelerate decomposition. The weather during the winters of cooler climates tends to preserve the organic matter of soils by preventing microbial activity. The organic matter is produced during the warm summer and preserved during the cold winter.

5.4.3. Topography: The soil, water and organic matter moved by runoff and erosion accumulate at the foot of the slope.

5.4.4. Parent material: the organic matter content of soil is influenced by parent material thickness, texture, and mineral content. Thin soils resulting from parent materials formed from hard rock produce less plant growth and contain less organic matter than deeper soils.

5.5. Decomposition of Organic Matter

5.5.1. Rate of Decomposition: Decomposition is a speciality of soil organisms. Almost any organic material will decompose sooner or later in the soil whether it be plant or animal waste or a pesticide such as DDT or 2, 4-D. Organic compounds vary greatly in their rate of decomposition in terms of their ease of decomposition as follows:

Sugars, Starches, and simple proteins	Rapid decomposition
Crude Proteins	
Hemi-cellulose	
Cellulose	
Fats, waxes, and so forth	
Lignin and phenolic compounds	
	Very slow decomposition

In an experiment, wheat straw was added to soil and the changes in the major components in the straw were followed over time. It was found that proteins, the soluble fraction, and the cellulose and hemicelluloses disappeared or decomposed very rapidly, whereas lignin decomposed very slowly. As a result of the rapid decomposition of proteins and the soluble fraction, cellulose and hemicelluloses, and other readily degradable compounds, there was a corresponding and rapid increase in microbial products.

Microbial products include living and dead microbial cells and their waste or excretion products.

Some of the organic compounds that are synthesized in the soil during decomposition react with each other and with mineral soil components. Consequently, the decomposition of plant residues results in: (1) the production of a considerable mass of microbial products, and (2) the production of a wide variety of materials of varying resistance to decomposition. As a result of the addition and decomposition of plant and animal residues in soils, *labile* and *stable* fractions of organic matter are produced. Labile organic matter is organic matter that is liable to change or is unstable. The labile and stable organic matter fractions correspond, in general, to the organic residues and humus fractions, respectively.

5.6. Labile Soil Organic Matter

The labile fraction of SOM consists of any readily degradable materials from the plant and animal residues, and readily degradable microbial products. The labile organic matter composes about 10 to 20 percent of the total SOM. Labile organic matter is an important reservoir of nutrients because the nutrients, especially nitrogen, are rapidly recycled in the soil ecosystem. The addition to the soil of a relatively small amount of easily degraded organic matter, such as manure, organic waste materials, and plant residues, may contribute more to the available nutrient supply than the slow release of nutrients from the much larger amount of stable organic matter. The labile organic matter is rapidly degraded when conditions are favorable. As a result, any labile organic matter incorporated within soils tends to disappear quickly if conditions are favorable for decomposition. Therefore, the decomposers are frequently quite inactive, owing to the rapid disappearance of readily decomposable substrates or labile organic matter.

5.7. Stable Soil Organic Matter

The stable organic matter has a long residence time in the soil and plays important roles in structure formation and stability, water adsorption, and adsorption of nutrient cations.

Stable soil organic matter, or humus, originates from several processes. Lignin, a 6-carbon ring structure, is a plant compound and is very resistant. Thus, lignin accumulates in soils because of its resistant or stable nature. Organic compounds of varying resistance interact with lignin and form new compounds that are resistant. These accounts for the significant quantity of protein or protein like material in humus.

Scientists believe that the organic matter is protected from decomposition; this protection helps to increase the stability of both readily decomposable and resistant organic matter. Much of the humus is associated intimately with clay and silt particles, and the humus plays an important role in formation of soil structure.

Polysaccharides include microbial gum and two other abundant compounds found in microbial cell walls: hemicelluloses and cellulose. These polysaccharides are organic polymers (giant organic molecules formed by the combination of smaller molecules) having high molecular weight and are present as ropes and nets. These polymers are widely and intimately associated with the soil fabric. On drying, soil particle surfaces are brought into very close contact with the netlike arrangement of the organic compounds.

The hydroxyls of the polymers and the exposed oxygen atoms of the mineral soil particles bind strongly to each other. The result is an intimate association of mineral and organic

matter that protects the organic matter from decomposition and forms stable soil peds. One half or more of the SOM is likely to be protected.

5.8. Decomposition of Compounds in Aerobic Soils

When organic tissue is added to an aerobic soil, three general reactions take place:

Carbon compounds are enzymatically oxidized to produce carbon dioxide, water, energy, and decomposer biomass.

It is a **burning/Oxidation process**. In this oxidation process largely C and H are involved and it takes place under aerobic condition. Though, there are many intermediate steps involved, the complete process may be expressed as:



(C and H containing Oxidation Compound)

The essential nutrient elements, such as N, P and S are released and/or immobilized by a series of specific reactions relatively unique for each element. **Example: Break down of Proteins.** The breakdown of the proteins is a little bit complex. Organic compounds break down to amides and amino acids in addition to the CO₂ and H₂O. The compounds are hydrolysed readily to CO₂, ammonium compounds and other products. The ammonium compounds may be changed to nitrates, the form in which higher plants take up nitrogen.

Compounds very resistant to microbial action are formed, either through modification of compounds in the original tissues or by microbial synthesis. **Example: Organic decay**

The generalized organic decay may be complex but can be generalized. When fresh organic matter is added to a mixed soil, the number of micro organisms increases in many folds, bringing a marked change. Then, soon microbial activity reaches its peak, at which energy is being liberated rapidly. CO₂ and bacteria, fungi and actinomycetes are fully active. At this stage, the SOM contains a great variety of substances; intermediate products of all kinds, ranging from the more stable compounds such as lignin, to microbial cell, both living and dead. As the readily available energy is used up a food supply diminishes and microbial activity gradually lessens. This is associated with a release of simple products such as nitrates and sulphates. The organic matter now remaining is a dark, incoherent, heterogeneous colloidal mass usually referred to as **humus**. The decomposition of both plant residues and SOM is nothing more than a process of *enzymatic digestion*. It is as though the plant materials entered the stomach of domestic animal. The product of this enzymatic

activity can be put under three headings:

1. Energy appropriated by the micro organisms or liberated as heat
2. Simple end products e.g. nitrate, sulphates, etc.
3. Humus

5.9. Decomposition of Compounds in Anaerobic Soils

Microbial decomposition proceeds most rapidly in the presence of plentiful supplies of O₂, which acts as the electron acceptor during aerobic oxidation of organic compounds. Oxygen supplies may become depleted when soil pores filled with water prevent the diffusion of O₂ into the soil from the atmosphere. Without sufficient oxygen present, aerobic organisms cannot function, so anaerobic or facultative organisms become dominant. Under low-oxygen or anaerobic conditions, decomposition takes place much more slowly than when oxygen is plentiful. Hence, wet, anaerobic soils tend to accumulate large amounts of organic matter in a particularly decomposed condition. The products of anaerobic decomposition include a wide variety of partially oxidized organic compounds, such as organic acids, alcohols, and methane gas. Anaerobic decomposition releases relatively little energy for the organisms involved; therefore, the end products still contain much energy. (For this reason, alcohol and methane can serve as fuel.)

5.10. Role (Significance) of organic matter

Soil organic matter influences considerably soil physical, chemical and biological properties and growth and productivity of higher plants. The most obvious influences of organic matter on soil properties and plant growth include:

i. Effect on soil physical properties:

- Soil colour becomes brown to black
- Granulation encouraged
- Aggregate (structure) stability assisted
- Plasticity and cohesion reduced
- Water holding capacity increased

ii. Cation Exchange Capacity:

- Provide high CEC, increase the pH-dependent CEC of soils
- 2-30 times as great as mineral colloids
- Accounts for 30-90% of the absorbing power of mineral soils

iii. Supply and availability of nutrients:

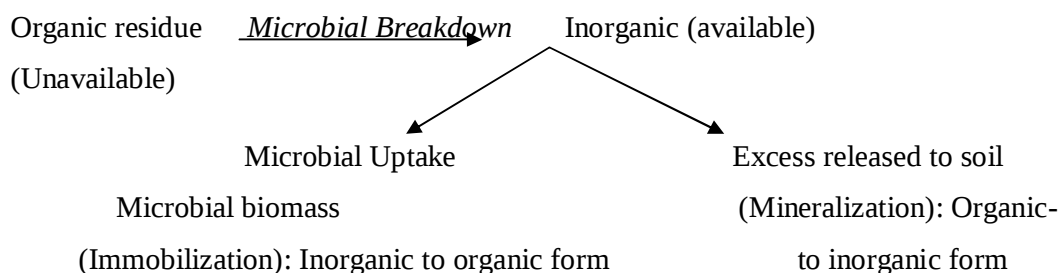
- Easily replaceable cations are present
- N, P, S and micronutrients held in organic forms are slowly released
- Release of elements from minerals by acid humus, and
- Provide N, S and over half of soil P through decay.

5.11. Influence of C/N Ratio in Decomposition

Another important aspect of soil organic matter is the carbon to nitrogen (C/N) ratio. This ratio of soils ranges between 8:1 and 15:1, the most common range being 10:1 to 12:1. In higher plants, it ranges between 20:1 and 30:1 (for legumes and farm manure). In microbial bodies, it is very low, more constant and the range is narrower, i.e. 4:1 to 9:1, average is 8:1. Soil microbes, like other organisms, require a balance of nutrients from which to build their cells and extract energy. The majority of soil organisms metabolize carbonaceous materials both in order to obtain carbon for building essential organic compounds and to obtain energy for life process. Organisms must also obtain sufficient nitrogen to synthesize nitrogen-containing cellular components, such as amino acids, enzymes, and DNA.

On the average, soil microbes must incorporate into their cells about 8 parts of carbon for every one part of nitrogen (i.e., assuming the microbes have an average C/N ratio of 8:1). Because only about one-third of the carbon metabolized by microbes incorporated into their cells (the remainder is respired and lost as CO₂), the microbes need to find about 1g of N for every 24g of C in their “food”). This requirement results in two extremely important practical consequences. First, if the C/N ratio of organic material added to soil exceeds about 25:1, the soil microbes will have to scavenge the soil solution to obtain enough nitrogen. Thus, the incorporation of high C/N residues will deplete the soil’s supply of soluble nitrogen, causing higher plants to suffer from nitrogen deficiency. Second, the decay of organic materials can be delayed if sufficient nitrogen to support microbial growth is neither present in the material undergoing decomposition nor available in the soil solution.

Immobilization and Mineralization



Some plant residue materials such as wheat straw, corn stover, and sawdust have very small nitrogen content relative to their carbon content. As a consequence, the ratio of carbon to nitrogen (C: N ratio) is relatively large compared with soil humus and the leguminous plants, which tend to be rich in nitrogen. Consequently, when straw is added to the soil, there is insufficient nitrogen to meet the needs of the decomposing organisms. Under these conditions, decomposition of the straw is limited by an insufficient supply of nitrogen; unless, nitrogen is available from some other source. This other source could be nitrogen mineralized within the soil from SOM. The decomposing microorganisms have first priority for any mineralized nitrogen (nitrogen released in decomposition).

When there is insufficient nitrogen in the straw to supply the needs of the decomposers, they will use any nitrogen that is available. This results in a deprivation of nitrogen for growing plants, and means that plants may be starved for nitrogen for a period of several weeks.

Humus, animal manure, and legume residues are relatively rich in nitrogen, have a relatively small C:N ratio, and contain more nitrogen than the decomposers need. These materials with small C:N ratios are excellent materials to add to soils to increase the available nitrogen for growing plants. An addition of about 20 pounds of nitrogen to the soil as fertilizer per ton of straw is required to prevent a temporary nitrogen deficiency, as a result of the microbial decomposition of the straw.

When a large amount of straw or other similar material is added to soils without supplemental nitrogen fertilizer, a month or so is required for the temporary nitrogen-deficient period to pass under conditions favorable for decomposition.

5.12. Factors that affect soil organic matter content:

The organic matter content of a particular soil will depend on:

1. **Type of vegetation:** Soils that have been in grass for long periods usually have a relatively high percentage of organic matter in their surface. Soils that develop under trees usually have a low organic matter percentage in the surface mineral soil, but do contain a surface litter layer (O horizon). Organic matter levels are typically higher in topsoil supporting hay, pasture, or forest than in a topsoil used for cultivated crops.
2. **Tillage:** Soils that are tilled frequently are usually low in organic matter. Plowing and otherwise tilling the soil increases the amount of air in the soil, which increases the rate of organic matter decomposition. This detrimental effect of tillage on organic

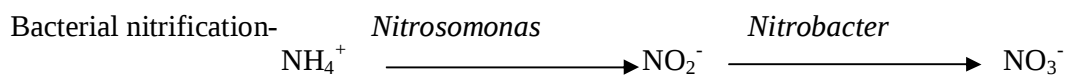
matter is particularly pronounced in very sandy well-aerated soils because of the tendency of frequent tillage to promote organic matter oxidation to CO_2 .

3. **Drainage:** Soil organic matter and N is usually higher in poorly-drained soils because of limited oxidation, which slows down the overall biological decomposition process.
4. **Soil texture:** Soil organic matter is usually higher in fine-textured soils because soil humus forms stable complexes with clay particles.
5. **Cropping:** Cultivation reduces the organic matter content of the soil through the encouragement of the decomposition process and the removal of the organic material.
6. SOM content can be managed by the addition of the organic matter from various sources, i.e. green manure, farm manure, composts, Current Crops (roots and foliages) and other plant and animal remains.
7. **Climate:** mainly temperature and rainfall. Organic matter content increases with moisture but decrease with temperature.

5.13. Microbial Population of the Soil:

Roots and other plant part growing below ground constitute most of the mass of living microorganisms in most soils but animal life should not be overlooked. Microbial populations are following:

1. **Bacteria-** i) aerobic ii) anaerobic- sugars and ions reduced as NO_3 or SO_4



Rhizobium fix the atmospheric nitrogen in the root of leguminous crops and increase the productivity of crop.

2. **Mycorrhiza:** (myco= fungus; rhiza= root means root fungus) the root- fungus association.

- i. Ectomycorrhiza – hyphae remains on upper surface of the plant
- ii. Endomycorrhiza- hyphae penetrate the epidermal cell and reach to the cortex.

Mycorrhiza increase the nutrient uptake capacity of plant particularly less mobile nutrient ie. P, Zn, Cu, and Mo.

Mycorrhiza- provides the resistant capacity of plant, protect from other pathogens, tolerate to drought, high temperature and even to extreme soil acidity.

3. **Actinomycetes:** antibiotics are obtained from actinomycetes eg. Streptomycin and aureomycin. Actinomycetes like *Trichoderma* and other fungus increase the solubility and

uptake of nutrients from the soil. *Aspergillus*, *Rhizopus*, *Fusarium*, *Verticillium*, *Mucor*, *Penicillium*, *Trichoderma*, *Cladosporium*, *Alternaria*, *Cephalosporium*, *Gliocladium*, *Monilia*, *Chaetomium*, and *Pentium* are the most commonly encountered fungal genera in soil.

4. Algae: Cyanobacteria fix the atmospheric nitrogen eg. *Nostoc*, *Anabaena*.

Lichen: this symbiotic with algae and help in rock weathering, and atmospheric nitrogen fixation.

5. Protozoans- feed on bacteria

6. Nematode: live mainly on decaying organic materials.

a) Free living

b) Parasitic- on bacteria, fungi, algae. Predaceous nematode (*Mononchus*) engulf other parasitic nematodes.

7. Earthworm: feed on animal and plant residues, aerate and stir the soil, which allow better water infiltration and easier root penetration.

8. Arthropods: mites, termites, millipedes, centipedes- feed on decaying vegetation and help to aerate the soil with their burrows.

Chapter 6. Soil Erosion and Its Control

Definition:

6.1. Soil Erosion: - defined as the detachment, transportation, and deposition of soil particles from one place to another under the influence of wind, water or gravity forces. Soil erosion is a quick process; reduce the soil productivity through physical loss of top soil, reduction in rooting depth, removal of plant nutrient & loss of water. The soil erosion can be expressed quantitatively by the depth, volume or weight of soil removed per unit area & time.

6.2. Kinds of soil erosion

Depending on the disturbance of natural processes, there are two types of erosions namely Geologic Erosion, and Accelerated Erosion

i. Geological Erosion

- Occurs when the soil is in its natural environment under the protective cover of native vegetation.
- No disturbance or interference of human beings
- This type of erosion is assisted by the complex process of rock weathering.
- The process may take place as the result of the action of wind, water or gravity the erosion can take the form of splash, sheet, runoff, concentrated surface flow, stream flow, wave action & subsurface water flow.

ii. Accelerated Erosion.

Accelerated Erosion is associated with changes in natural cover of the earth or soil condition and is caused mainly by wind and water. Man's interference with the natural vegetation & upset of nature's balance by removing the protective vegetation cover in order to introduce his land use activities resulted in accelerated erosion. This situation is the combined effect of interference in the natural protective cover & the improper land use techniques. This in turn gives an opportunity to water & wind to damages to the land.

Accelerated erosion is soil loss or degradation in excess of geologic erosion, which can also termed as **man-made erosion**. Accelerated erosion takes place by the action of water; it causes the soil erosion through sheet flow, stream flow, wave action, & ground water flow, wind & gravity.

6.3. Agents of erosion

- **Water starts** with the splash effect. I.e. impact of raindrops, particularly on the bare soil surface that destroys soil aggregates, transport soil particles through the air & prepares them for further transportation.
- **Wind:**-high speed winds take up soil particles, particularly from a dry surface & also mechanically loosen other particles.
- **Gravity:** - causes the mass movement such as soil creep, rock creep, rock slide & subsidence of the soil surface.
- **Glaciers:** - Common on polar areas. It is the movement of mass of ice with soil particles slowly to lower (position) land.

6.4. Effects of Soil Erosion

Erosion damages the site on which it occurs (on-site effect) and also has undesirable effects on off-site effect in the large environment. This refers to effects of erosion outside of the farm boundary or outside of where the erosion is occurred.

i. On-Site Effect

- *Loss of soil*
- *Deteriorating of soil structure*
- *Loss of nutrients*
- *Soil textural change*
- *Soil productivity loss*
- *The capacity of the land/ soil to produce crop is lost / reduced*
- *Reduction in moisture availability*
- *Damage from uncontrolled run - off & flooding*
- *Di - section of field /Gully formation/*

ii. Off-Site Effects

- *Silting up reservoir & channel*
- *Disease & public health hazard*
- Environmental alteration at sediment destinations such as lake used for fisheries, dam for hydroelectric power generations & domestic water supply.
- Damages to roads, recreational sites, crop lands etc.
- Loss of water quality due to water pollution

6.5. Forms of Erosion

i. Raindrop Erosion

It is also known as splash erosion. The process of rain drop erosion can be described as: when raindrops strikes on open moist soil surface, forms a crater. This is accomplished by forming a blast which bounces the water and soil up and returns back around the crater. The soil may splash into the air up to a height of 50 to 75 cm depending upon the size of rain drops. At the same time, the soil particles also move horizontally as much as 1.50 m on level land surface. On sloping land, more than half of the splashed particles move down with the runoff. Since the raindrops fall in rapid succession and strike the soil at all locations, thus the soil is subject to rigorous and repeated loosening and lifting action during heavy rains. In this way, the soil becomes more susceptible to water erosion.

ii. Sheet Erosion

Sheet erosion may be defined as more or less uniform removal of soil in the form of a thin layer or in “sheet” form by the flowing water from a given width of sloping land .It is an inconspicuous type of soil erosion because the total amount of soil erosion because the total amount of soil removed during any storm is usually small.

In sheet erosion there are two basic erosion processes are involved. First process, in which soil particles are detached from the soil surface by falling rain drops and in second process, the detached soil particles are transported away by runoff from their original place. The detachment process is referred to the raindrop erosion or splash erosion and transportation of detached particles by flowing water is noticed as wash erosion.

iii. Rill Erosion

Sometimes this type of water erosion is also known as micro channel erosion. Normally, the sheet flow over the soil surface occurs when land surface is smooth and has uniform slope. But this condition rarely exists in cultivated fields. The surface is almost irregular in cultivated lands. The surface irregularities may be in the form of low and high tracts in the field. Irregularities between soil clods and aggregates of different sizes and irregularities caused by tillage implements etc. As rain starts, the water tends to accumulate in these surface depressions and begins to flow following least resistance path. During movement of water a large amount soil particles are eroded from the sides and bottom of the flow path, which are mixed in the flowing water. This surface

flow containing soil particle in suspension form moves ahead and forms micro channels or rills.

iv. Gully Erosion

It is the advance and last stage of water erosion. In other words gully erosion is the advance stage of rill erosion. If the rills have been formed in the field and are avoided by the farmers, then they tend to increase in their size and shape with commencement of further rainfall. The channel or rill of large size is termed as gully.

6.6. Factors Affecting Water Erosion

Water erosion is resulted due to dispersive and transporting power of the water; as in case of splash erosion first the soil particles are detached from the soil surface by the raindrop force and then transported with surface runoff. There is a direct relationship between the soil loss and runoff volume.

The major factors which affect the amount of soil erosion in large extent are given as under:

1. **Climatic factor:** The climatic factors which affect the soil erosion are the rainfall characteristics, atmospheric temperature and wind velocity. Rainfall characteristic is one of the most effective factors among them. The rainfall characteristic includes amount, intensity, frequency and duration of rainfall. All these have a great effect on runoff and soil loss.
2. **Soil:** The soil characteristics which influence the soil erosion are the infiltration rate and soil cover providing resistance to the runoff. When infiltration rate is greater than the rainfall intensity, then whatever rain occurs over the land surface, is absorbed by the soil and thus surface runoff becomes zero. The infiltration rate mainly depends upon the permeability of soil profile, surface condition and presence of moisture content in the soil.
3. **Vegetation:** Vegetations create a surface obstruction for direct falling of raindrops on the land surface as well as in the flowing path of surface runoff. A good vegetative cover completely negates the effect of rainfall on soil erosion.
4. **Topographic factors:** The land slope, length of slope and shape of slope are the main topographic factors which influence the soil erosion. A flat land has not the problem of soil erosion, while the sloping lands are predominantly affected by the erosion. As the

land slope increases from mild to steep, the erosion increases in large proportion. Land slope has a great effect on flow velocity, kinetic energy as well as on transportation of soil particles.

6.7. Soil and Water Conservation

Soil conservation is the management of the soil to prevent soil erosion. Soil conservation not only increases crop yields, but also prevents further deterioration of land. Generally soil conservation measures aim at the preservation of the (agricultural) topsoil and at the balance between soil loss and soil formation in natural areas without loss of soil fertility.

❖ SWC measures could be categorized into four main components

- a land use component (choice of a land use that does not lead to long-term soil damage),
- a biological component (that maintain and improve the protective cover to intercept the energy of the falling raindrops and to reduce the splash effect),
- an agronomic component (supports the biological component by enhancing plant growth, e.g. optimized seeding time and rate, fertilization, use of appropriate tools and soil management)
- a mechanical/structural/physical/engineering component (are used to control the movement of water over the soil surface and limit its erosive capacity).

6.7.1. Biological Conservation Measures

The biological conservation measures can be defined as follows:

Various land use systems and farming techniques employed in growing maximum biomass from various plant species grown on the land with the object to conserve soil and water and improve land productivity at the same time.

In soil and water conservation programs the biological measures are counted as second line of defense, the first being mechanical or engineering measures which are employed to arrest the soil erosion immediately. The role of biological measures is more economical, long lasting and effective. Always it is advisable to use, but when its use is either inadequate or not efficient to achieve erosion control, then use of mechanical measures to control erosion is recommended.

Advantages of biological measures

- These provide plant cover on the land preventing and controlling loss of soil and water and enhance water conservation in situ.
- These produce biomass on the land which is the source of food, fuel, fodder etc.
- These improve physical, chemical and biological properties of soil
- These improve organic matter and fertility of soil which improves biomass production
- These are simple, inexpensive and part of regular land management practices
- These can become effective in a short time on a large area
- These reduce pollution and provide clean environment
- These reduce the adverse impact of climate change resulting from global warming.
- These can prevent erosion if effectively implemented before erosion becomes serious. Later on they support the physical measures in controlling soil erosion.

I. Contour Cultivation

Contour cultivation refers to all the tillage practices or mechanical treatments like planting, tillage and intercultural, performed nearly on the contour of the area, applied across the land slope. In low rainfall regions the primary purpose of contour cultivation is to conserve the rain water into the soil as much as possible. While in humid regions its basic purpose is to reduce the soil erosion/ or soil loss by retarding the overland flow. In this farming system, the furrows between the ridges made on the contours, hold the runoff water and store them into the soil. In this way, they reduce the runoff and soil erosion, both.

II. Tillage Practices

Tillage is defined as mechanical manipulation of soil to provide a favorable environment for good germination of seeds and crop growth; to control the weeds; to maintain infiltration capacity and soil aeration. A well planned tillage practice provides a favorable environment, suitable for better seed germination and effective plant growth. In addition, it also protects and maintains a strong soil structure to fight against erosion.

Tillage for Soil Conservation

Tillage is an important and primary tool for conservation of the land. As per definition, its

primary purpose is to provide a favorable soil environment for the plant growth, which is indirectly related to the soil conservation. The effect of tillage on soil erosion is the function of its several efforts on soil, such as aggregation, surface sealing, infiltration and resistance to erosion.

Destruction of soil structure either by excessive tillage or tillage operations at improper soil moisture condition tends to increase the soil erodibility, causing significant soil loss.

To achieve a best result for soil conservation, the following points should be considered for tillage operations:

1. Till no more than necessary.
2. Till only, when soil moisture is in the favorable limit and
3. Vary the depth of plowing.

Types of Soil Conservation Tillage Practices

There are a number of modified tillage practices have been developed; each of them are related to the specific objectives for providing a better soil and water-plant relations, reducing the runoff as well as soil erosion by enhancing infiltration capacity of the soil.

The important types of soil conservation tillage practices are:

a) Mulch Tillage: Mulching is defined as the application of any plant residues or other materials to cover the top soil surface for:

- Conserving the soil moisture
- Reducing the runoff and thereby to control soil erosion
- Checking weed growth
- Protecting from winter climate
- Improving the soil temperature
- Modifying the micro-environment of soil to meet the needs of seeds for their good germination and better growth of seedlings

Mulch Tillage is performed either by making the soil surface cloddy or mulched with help of crop residues. Mulch tillage is happened to be an effective measure to minimize soil erosion and to conserve the moisture, when it is combined with strip cropping system. This type of tillage is also practiced to utilize the crop residues as mulch and also performing farming operations, simultaneously. It can be defined as a method, which permits the crops to grow, where all or most of the residues from pervious crops are left on the soil surface.

b) Minimum Tillage: Minimum tillage implies the preparation of seedbed with minimum disturbance of soil. It is a general term, covers several methods. One approach is to reduce the number of operations by planting directly after ploughing without any intervening cultivation, which is usually carried out for providing a fine seed bed. It also consists of killing of weed's vegetation presents in the field using chemicals followed by secondary tillage practices.

c) Conventional Tillage: The tillage operations, such as ploughing, secondary cultivation with one or more disc harrowing and planking, as conventional tillage have been found suitable for wide range of soils to control the erosion. The ploughing of soil at inappropriate moisture content produces a rough cloddy surface with local variations in the height ranging from 120 to 160 mm.

III. Crop Management Measures

In crop management practices, the soil loss is minimized or conserved by adjusting the cropping system and cropping pattern.

i. Crop Rotation: - is the practice of growing different crops one at a time in a definite sequence of the same piece of land.

Several advantages are associated with crop rotation.

1. Improves soil structure with consequent reduction in erosion.
2. Different plant species are able to extract nutrient at different soil depth.
3. Allows a balanced nutrient removal from the soil.

ii. Shifting Cultivation: - It is a traditional method of reducing soil erosion in the tropics by rotating the location of fields. The practice of shifting cultivation will maintain soil fertility and reduce erosion to tolerable levels provided the associated conditions of low yields and low ratio of population to land area remain socially and economically acceptable. The critical factor in the system is the length of the fallow period.

iii. Cover Crops: Cover crops are any covers grown as a conservation measure either during the off-season or as ground protection under trees.

iv. Strip Cropping: Strip cropping is the agronomical practice in which row crops and protection effective crops are grown in alternating strips aligned on the contour or perpendicular to the wind.

This method is more effective in erosion control when it is combined with crop rotations in the area where terraces are not practically feasible due to the fact that the length of slope is divided into different parts.

vi. Multiple Cropping: The aim of multiple cropping is to increase the production from the land while providing protection of the soil from erosion. The method involves either sequential cropping, growing two or more crops a year in sequence, or intercropping, growing two or more crops on the same piece of land at the same time. Many schemes involve the mixture of the two. Relay cropping is a type of cropping system where two crops are planted with a little overlap. Intercropping is a combination of two or more crops at the same time in the same plot.

6.7.2. Physical/Mechanical Conservation Measures

The physical SWC measures are permanent features formed from earth, stone or masonry that are designed to protect the soil from uncontrolled runoff and erosion and to retain water where it is needed. They regulate runoff velocity and deposition of eroded material at specific points. Measures involving earth movement like soil bunds, bench terraces, retention (infiltration) ditches, diversion ditches.

6.7.2.1. Terraces

It is an engineering soil conservation practice, used to control the soil erosion in highly sloped areas. Terracing involves the construction of embankment or ridge and steps like structure, across the land slope to check the flow of surface runoff and to reduce the soil loss. In this system, the effective length of land slope is reduced to a large extent. From experimental evidence it has been found that the soil loss is directly proportional to the slope length of power 0.5. According to this statement, if the length of slope is increased twice the soil erosion increases in proportion of 1.4 times. In addition, terraces also play an additional role in trapping the splashed soil particles and depositing them over the benches.

Terracing practice is not feasible in flat and cropped land. However, if there is any chance to occur the erosion, simply agronomical measures should be adopted to control that. The agronomical measures consist of contour cropping, crop rotation, strip cropping etc, but

the land which is more erodible, has steep slope and prevail high rainfall intensity, the use of agronomical measures is not justified, and only terracing is an alternative measure.

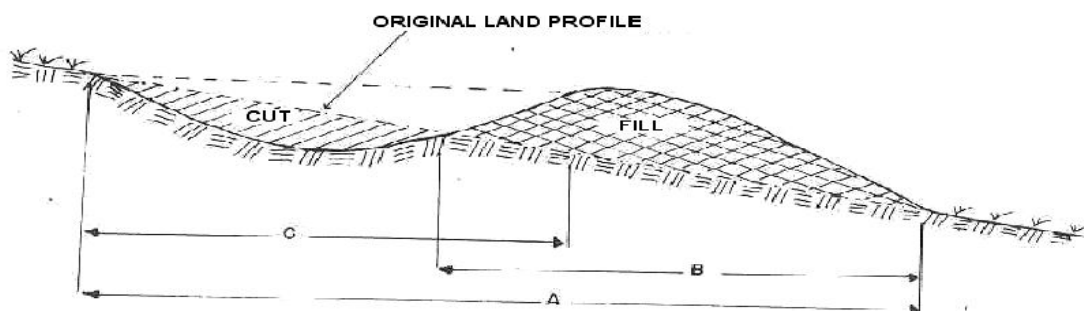
Principal objectives of terraces

- ✓ To reduce the velocity of runoff;
- ✓ To reduce the volume of runoff;
- ✓ To reduce the losses of soil, seed and fertilizer;
- ✓ To increase soil moisture content through improved infiltration;
- ✓ To reduce peak discharge rates of rivers;
- ✓ To smooth the topography and improve the conditions for mechanization

In brief the terracing involves following main features:

- These are constructed across the slope to intercept the surface runoff and convey it to a suitable outlet, at non erosive velocity.
- They reduce the length of slope by splitting the slope length in different parts.
- The terracing practice is adopted for soil and water conservation in that area, where land slope is greater than 10%, soil is more erodible and prevail high rainfall intensity.
- Terraces, not only control the soil loss caused by sheet flow, but also play an important role in trapping the splashed soil particles.
- This practice is not possible, particularly on those hill sloped areas, where soil depth is not sufficient.
- Since it involves greater earthwork, therefore it proves a costly work.

Schematic representation of the terrace profile showing zones A: of earth movement; B: the bank, and C: the channel. Source: Lombardi Neto *et al.* (1991)



6.7.2.1.1. Terrace Classification

As far as classification of terraces is concerned, these are classified into three main classes as: *diversion, retention and bench type terraces*. The primary aim of diversion terrace is to intercept the overland flow and channel it across the slope to a suitable outlet. Diversion terraces are constructed on a small gradient, usually 1:250 to the contour. The diversion terraces are again classified as Magnum, Nichols and Broad based type. The retention terraces are used, where conservation of surface water by storing it on hill side is required. The design of such terraces is done for the return periods of 10 years. The permeable soils with the slope less than 4.5% are suitable for retention type terraces.

Terrace Types	Description
1.Diversion terrace	Used for intercepting the overland flow from hilly slopes and channel it across the slope to a suitable outlet i.e. grassed water ways etc built at slight down slope grade from contour.
(a)Magnum type	It is constructed by taking the soil from both sides of the embankment.
(b)Nichols type	Formed by taking the soil from side of upslope of the embankment, only.
(c)Broad-based type	These terraces are constructed with embankment and channel occupying a width of about 15 m.
(d)Narrow-based type	These terraces are only 3 to 4 m wide; the banks have steeper slope which can not be cultivated. For cultivation to make possible, the bank should not exceed 14° slope for use of small machines, otherwise it should be 8.5° , for large size machine.
2.Retention terraces	These are level terraces, used particularly when water is required to conserve by making storage on hill sides.
3.Bench terraces	Such types of terraces are constructed in form of alternate series of shelves and risers, used to cultivate the steep slopes.

Table 7. Classification of Terraces

I. Bench Terraces

Bench terraces are the platform like construction which is constructed along the contour of the slopping land. These type of terraces are generally constructed on the land of 6 to 33% slope. Bench terraces play a significant role to make the hilly land suitable for cultivation. In this system the hilly land is modified in the form of several steps, which intercept the flowing water through the soil surface. These steps are also used for cultivation purposes. Generally tea, coffee, sugarcane etc are successfully grown on these terraces, depending upon the climatic factors such as rainfall etc.

Bench terraces are classified on the basis of the slope of bench as follows:

1. Level bench terraces
2. Bench terrace sloping outward, and
3. Bench terrace sloping inward

1. Level Bench Terraces

This type of bench terraces consists of level top surface. Level bench terraces are generally used in areas which receive medium rainfall and have highly permeable soils. Since the soils are highly permeable, therefore it is expected that most of flowing surface runoff passing through these terraces are absorbed by the soil and remaining portion is drained into the drain. The level bench terraces are also known as irrigated bench terraces provided that they must be under irrigation. Sometimes level bench terraces are also called as table top or paddy terraces, because such terraces have level top surface that can be easily impounded with water and plantation of paddy crop can be performed. The level bench terraces used for paddy cultivation, the bench slope is kept as mild as 1%, so that uniform water impounding over them can be easily made.

2. Bench Terraces Sloping Outward

Such bench terraces are adopted in low rainfall areas with permeable soil. For these terraces a shoulder bund is essential even though this bund is also provided in other two types. The main function of shoulder bund is to provide the stability to the outer edge of the terrace. In addition, this bund also helps in retaining the surface runoff on the benches that is either absorbed by the soil or drained. Bench terraces sloping outward are also known as orchard type bench terraces. For outwardly sloping bench terraces constructed on soils having poor permeability, the provision of graded channel at lower end is most essential for disposing surplus surface water to the grassed waterway. Whereas, in very less permeable soil case, a strong bund along with spillway arrangement should be essentially equipped, for making the terrace safe against heavy storm and allowing the water very safely, downward to the next terrace.

3. Bench Terraces Sloping Inward

Bench terraces sloping inward are performed to construct in the areas of heavy rainfall and less permeable soils, from where large portion of rain water is drained as surface runoff. Such type of bench terraces has a provision to drain the runoff from their side by constructing a drainage channel. The drain ultimately leads to a suitable outlet (grassed water ways). This type of bench terrace is also known as hill type bench terrace. The

inwardly sloping bench terraces are usually preferred for growing those crops, which are extremely susceptible to water-logging, such as potato.

II. Bunding:

It is an engineering soil conservation measure, used for retaining the water, creating obstruction and thus to control erosion. Bunds are simply embankment like structures, constructed across the land slope. When they are constructed on the contour of the area called as contour bund and when a grade is provided to them, they are known as graded bund.

By bunding practice, the entire area is divided into several small parts; thereby the effective slope length of the area is reduced. The reduction of slope length causes not only to reduce the soil erosion but also to retain the runoff water in the surrounded area of the bund. Contour bunds are generally used in relatively low rainfall areas for the purpose to control the soil erosion and to store the rain water, while graded bunds are constructed in relatively medium to high rainfall areas for the same purpose as the contour bunds.

Types of Bund

1. Contour Bund: the bunds constructed exactly on the contour or with permissible deviation from the contour, and are defined as contour bunds.
2. Side Bund: these bunds are formed at extreme ends of the contour bunds, running along the slope of the land.
3. Lateral Bunds: the lateral bunds are constructed between two side bunds, along the slope for preventing the concentration of water at one side and also to break the length of contour bund into convenient bits.
4. Supplemental Bunds: the bunds constructed between two contour bunds so as to limit the horizontal spacing to maximum required, are nomenclature as supplemental bunds.
5. Marginal Bunds: these bunds are formed at the margin points of the watershed, road, river etc to define their boundary.
6. Shoulder Bunds: such types of bunds are formed at the outer edge of the terraces, to hold the runoff over the top the terrace and also to provide the stability to the terrace system.



Figure6.1: Level soil bund

6.8. Relationships of Water to Soil

Water is the most common substance on the earth; it is necessary for all life. The supply of fresh water on a sustained basis is equal to the annual precipitation, which averages 66 centimeters for the world's land surface. The soil, located at the atmosphere-lithosphere interface, plays an important role in determining the amount of precipitation that runs off the land and the amount that enters the soil for storage and future use.

6.8.1. Kinds of soil water

- (a) *Hygroscopic Water* : Water held tightly to the surface of soil particles by adsorption forces
- (b) *Capillary Water*: Water held by forces of surface tension and continuous films around soil particles and in the capillary spaces.
- (c) *Gravitational Water*: Water that moves freely in response to gravity and drains out of the soil.

In these 3 forms of water, only capillary and gravitational water are available to the plants. Hygroscopic water is not available to plants.

6.8.2. Soil Moisture Constants and Water Available to the Plant

Soil moisture is always being subjected to pressure gradients and vapor pressure differences that cause it to move. Thus, soil moisture cannot be said to be constant at any pressure. However, it has experimentally been found that certain moisture contents described below are of particular significance in agriculture and these are often called “Soil Moisture Constants”.

Saturation Capacity:

When all the pores of the soil are filled with water, the soil is said to be under saturation capacity. The tension of water at saturation capacity is almost zero and it is equal to free water surface.

Field Capacity:

The field capacity of soil is the moisture content after drainage of gravitational water has become very slow and the moisture content has become relatively stable. This situation usually exists 1 to 3 days after the soil has been thoroughly wetted by rain or irrigation. This value represents the maximum amount of water that a soil can hold against gravity following saturation by rain or irrigation. Field capacity is usually expressed as percentage by weight (for example, a soil holding 25% water at field capacity contains 25% of its dry weight as retained water).

Permanent Wilting Percentage:

The amount of water a soil contains after plants are wilted beyond recovery is called the *permanent wilting percentage*. Considerable water may still be present at this point, particularly in clays, but is held so tightly that plants are unable to extract it. The amount of water held by the soil between field capacity and the permanent wilting point is the *plant-available water*.

Available Water

Soil moisture between field capacity and permanent wilting point is referred to as readily available moisture. It is the moisture available for plant use. In general, fine textured soils have a wide range of water between field capacity and permanent wilting point than coarse textured soils.

6.8.3. Retention of Soil Water and its Energy Concepts

As water flows over a dam, the potential energy (ability of the water to do work) will decrease. If water that has gone over a dam is returned to the reservoir, work will be required to lift the water back up into the reservoir, and the energy content of the water will be restored. Therefore, in a cascading waterfall, the water at the top has the greatest energy and water at the bottom has the lowest energy.

As water cascades down a falls, the continuous decrease in energy results in an energy continuum from the top to the bottom of the falls. As an analogy, when wet soil dries, there is a continuous decrease in the energy content of the remaining water. When dry soil gets wetter, there is a continuous increase in the energy of soil water. The continuous nature of the changes in the amount of soil water, and corresponding changes in energy, produce the *soil water energy continuum*.

6.9. Land use and Land management

It is usually considered to have three main aspects reflecting physical, chemical, and biological soil properties and is important for assessment of land degradation and for identification of sustainable land use practices. The main consequences of inappropriate land use changes are land degradation and soil quality deterioration through loss of vegetative cover, top soil moisture, infiltration capacity, water storage, soil organic matter, fertility, resilience, natural regeneration capacity, and a lower water table, factors that are critical for soil health. Land use and management are influencing not only soil properties but also soil erosion processes.

6.9.1. Land use: Land use applies to the current use of the land, whether agricultural or nonagricultural, in which the soil is located. Land use has a major influence on the direction and rate of soil formation; its recording enhances the interpretative value of the soil data considerably.

For arable land use, the dominant crops grown should be mentioned and as much information as possible given on soil management, use of fertilizers, duration of fallow period, rotation systems and yields.

6.9.2. Land management: Land management concerns all operations, practices and treatments used to protect the land and enhance the goods and services provided by the ecosystem the land is part of. Land management activities, starting with the ability of farmers to prepare the field to the type of fertilizers applied and the systems of management adopted, can greatly affect the soil quality. Although this process of conversion of natural vegetation (Deforestation and expansion of cropland) had started in early hunter-gatherer societies.

Land-use classification

A – Crop agriculture (cropping)			
AA	– Annual field cropping		
	AA1	– Shifting cultivation	
	AA2	– Fallow system cultivation	
	AA3	– Ley system cultivation	
	AA4	– Rainfed arable cultivation	
	AA5	– Wet rice cultivation	
	AA6	– Irrigated cultivation	
	AP	– Perennial field cropping	
		AP1	– Non-irrigated cultivation
		AP2	– Irrigated cultivation
	AT	– Tree and shrub cropping	
		AT1	– Non-irrigated tree crop cultivation
		AT2	– Irrigated tree crop cultivation
		AT3	– Non-irrigated shrub crop cultivation
AT4		– Irrigated shrub crop cultivation	
Additional codes may be used to further specify the land-use type. For example:			
AA4	– Rainfed arable cultivation		
AA4T	– Traditional		
AA4I	– Improved traditional		
AA4M	– Mechanized traditional		
AA4C	– Commercial		
AA4U	– Unspecified		
M – Mixed farming			
MF	– Agroforestry		
MP	– Agropastoralism		
H – Animal husbandry			
HE	– Extensive grazing		
	HE1	– Nomadism	
	HE2	– Semi-nomadism	
	HE3	– Ranching	
	HI	– Intensive grazing	
		HI1	– Animal production
HI2		– Dairying	
F – Forestry			
FN	– Natural forest and woodland		
	FN1	– Selective felling	
	FN2	– Clear felling	
	FP	– Plantation forestry	
P – Nature protection			
PN	– Nature and game preservation		
	PN1	– Reserves	
	PN2	– Parks	
	PN3	– Wildlife management	
	PD	– Degradation control	
		PD1	– Without interference
PD2		– With interference	
S – Settlement, Industry			
SR	– Residential use		
SI	– Industrial use		
ST	– Transport		
SC	– Recreational use		
SX	– Excavations		
SD	– Disposal sites		
Y – Military area			
O – Other land uses			
U – Not used and not managed			

Specific soil management practices that affect soil health include:

- Controlling traffic on the soil surface helps to reduce soil compaction, which can reduce aeration and water infiltration.
- Planting cover crops that keep the soil anchored and covered in off-seasons so that the soil is not eroded by wind and rain.
- Crop rotations for row crops alternate high-residue crops with lower-residue crops to increase the amount of plant material left on the surface of the soil during the year to protect the soil from erosion.
- Nutrient management can help to improve the fertility of the soil and the amount of organic matter content, which improves soil structure and function.
- Tilling the soil, or tillage, is the breaking of soil, such as with a plough or harrow, to prepare the soil for new seeds. Tillage systems vary in intensity and disturbance. Conventional tillage is the most intense tillage system and disturbs the deepest level of soils. At least 30% of plant residue remains on the soil surface in conservation tillage. Reduced-tillage or no-till operations limit the amount of soil disturbance while cultivating a new crop, and help to maintain plant residues on the surface of the soil for erosion protection and water retention.
- Adding organic matter to the soil surface can increase carbon in the soil and the abundance and diversity of microbial organisms in the soil.
- Using fertilizers increases nutrients such as nitrogen, phosphorus, sulfur, and potassium in the soil. The use of fertilizers influences soil pH and often acidifies soils, with the exception of potassium fertilizer. Fertilizers can be organic or synthetic.

6.10. Soil Water Management

The three approaches to water management on agricultural fields include

1. the conservation of natural precipitation in arid and sub-humid regions
2. the removal of water (drainage) from wetlands, and
3. irrigation to supplement natural precipitation.

Protection of the land surface by vegetation and plant residues shields the soil surface from raindrop impact and encourages water infiltration. Summer fallowing enhances storage of water which will support crop production at a later time. Fertilizer use may increase the efficiency of water use by plants by increasing the rate of plant growth.

Chapter-7 Soil classification and Survey:

Soil taxonomy is a classification of soils. It is grouping of soils into categories (systematic manner) based on each soil's morphology (appearance and form). Soil Classification Systems have been developed to provide scientists and resource managers with generalized information about the nature of a soil found in a particular location.

7.1. Purpose of soil classification:

A classification system must organise knowledge in a meaningful way that properties of objects may be remembered and their relationships understood most easily for a *specific objective*. With regard to soil classification that specific objective may be:

- Practical (applied) purposes, e.g. for a certain kind of land use. Such kind of soil classification is referred to as interpretative classification.
- Basic objectives e.g. distinguish soils characteristically. This kind, on the other side, is referred to as taxonomic classification.

7.2. History of soil classification: It is long ago that people started to classify soil. The earliest attempt, in the recorded history, is a 4000 years old Chinese system. The Chinese, better said, classified their land into nine groups mainly based on the productivity of the land. The purpose of their classification was for tax imposition. Another recorded history of soil classification is that of the Romans about 2000 years ago. It is important to try to remember and appreciate the different traditional soil classification systems in Ethiopia. Modern soil classification began from the early 19th century. The bases for the classification vary. However, geology (residual, granite, sedimentary, marl etc.) and pedological concepts like normal soils, abnormal soils, etc were the main ones. The pedological concept was developed by **Dokuchaev (1880)**, the late Russian scientist remembered as **“the father of soil science.”** Basically, soil is a three-dimensional body with its properties varying respectively. The variation is the result of climate, vegetation and fauna, topography, parent material and time, plus human interference. Soil varies temporally and spatially. Variation leads to differentiation or types or classes. Early classification relied on the soil forming factors e.g. desert soil (climate) mountain soil (topography). Later individual soil properties were used as bases e.g. sandy soil (texture), red soil (colour).

The earliest systems varied from country to country e.g. USA, Canada, USSR, France, Central and Western Europe had their own classification systems.

Among the different soil classification systems two enjoy very wide international recognition: USDA Soil Taxonomy and World Reference Base for Soil Resources (WRB) systems of soil classifications (David, 2001). Both systems have been revised a number of times based on latest findings.

7.3. System of Soil classification:

The USDA soil taxonomy system completely new in design and nomenclature was created and continues to evolve in the United States (Soil Survey Staff 1960, 1964, 1975, 1999). The system was developed to serve the national cooperative soil survey of the United States (Soil Survey Staff, 1975). But, in its history, the taxonomy system envisioned the continuing need for a system that would include all soils in the world and would accommodate new knowledge. In Soil Taxonomy the key counts **12 Soil Orders**.

1. **Orders** (12) Examples: Andisol, Spodosols etc
2. **Sub Order**
3. **Great Group**
4. **Sub Group**
5. **Family**
6. **Series**

7.3.1. Distribution of soil orders:

1. Alfisol - Soils with aluminium and iron. They have horizons of clay accumulation, and form where there is enough moisture and warmth for at least three months of plant growth. They constitute 10.1% of soils worldwide. **Distribution** – Worldwide, Large areas of Alfisols are found in North America, South and Central America, Eurasia, Africa, and Australia is being identified as Alfisols.

2. Andisols - Volcanic ash soils. They are young and very fertile. They cover 1% of the world's ice-free surface. **Distribution** -Japan, west coast of North and South America and the east coast of Asia, and with several islands, such as New Zealand, Iceland, Hawaii.

3. Aridisol - Dry soils forming under desert conditions which have fewer than 90 consecutive days of moisture during the growing season. They include nearly 12% of soils on Earth. Soil formation is slow, and accumulated organic matter is scarce. Aridisols also tend to be light coloured because of limited humus additions from vegetation. The hot climate under which these soils develop tends to restrict vegetation growth. Because of limited rain and high

temperatures soil water tends to migrate in these soils in and upward direction. This condition causes the deposition of salts carried by the water at or near the ground surface because of evaporation. This soil process is of course called salinization. **Distribution-** Western United States, Australia, Northern Africa, Arabia, Northern China, Chile, and Argentina.

4. Entisol - Recently formed soils that lack well-developed horizons. Commonly found on unconsolidated river and beach sediments of sand and clay or volcanic ash, some have an A horizon on top of bedrock. They are 18% of soils worldwide. Entisol can occur almost anywhere.

5. Gelisols - Permafrost soils with permafrost within two metres of the surface or gelic materials and permafrost within one metre. They constitute 9.1% of soils worldwide.

6. Histosol - Histosols are organic soils that form in areas of poor drainage. **Distribution** - Canada, California, Alaska, Siberia, Louisiana and Minnesota. Most histosols are formed in lakes, marshes and swamp.

7. Inceptisol (latin-beginning) - Young soils. They constitute 15% of soils worldwide. These soils are found in arctic tundra environments, glacial deposits. **Distribution-**Widespread except in arid regions.

8. Mollisols - Soft, deep, dark fertile soil formed in grasslands and some hardwood forests with very thick A horizons. The dark color of the A horizon is the result of humus enrichment from the decomposition of litterfall. **Distribution-** central plains of the United States and Canada, Washington, some parts of California, grasslands of Russia, and China.

9. Oxisols- Develop in tropical and subtropical latitudes that experience an environment with high precipitation and temperature. They are 7.5% of soils worldwide. The profiles of oxisols contain mixtures of quartz, kaolin clay, iron and aluminum oxides, and organic matter. The abundance of iron and aluminum oxides found in these soils results from strong chemical weathering and heavy leaching. Extensive areas occur in the subtropics and tropics, with most of the acreage in South America and Africa occurring below the equator. Oxisols are also found in Hawaii, southern Asia and many other tropical islands.

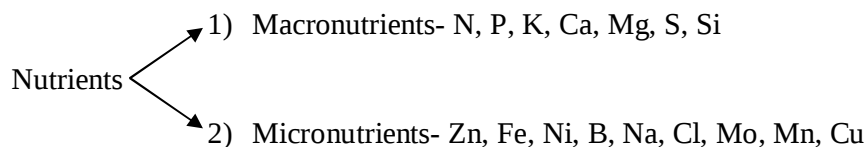
10. Spodosol - Acid soils with organic colloid layer complexed with iron and aluminium leached from A to the B horizons. They are typical soils of coniferous and deciduous forests in cooler climates. Spodosols are colourful, but they are not very fertile. They constitute 4% of soils worldwide. **Distribution-**forests of the USSR, US, Canada, British and Columbia.

11. Ultisol - Acid soils in humid climates, tropical to subtropical temperatures, which are heavily leached of Ca, Mg, and K nutrients. This region receives high amounts of precipitation because of summer thunderstorms and the winter dominance of the mid-latitude cyclone. Warm temperatures and the abundant availability of moisture enhance the weathering process and increase the rate of leaching in these soils. **Distribution**- common to the Southeastern United States, Asia, Africa, Australia, and California.

12. Vertisol - They are clay-rich and tend to swell when wet and shrink upon drying, often forming deep cracks (50 cm) that surface layers can fall into. They support neither farming nor construction due to their high expansion rate. **Distribution**-Large areas occur in India, Australia, the U.S., and northern Africa.

Chapter-8 Plant Nutrition

8.1. Nutrients in the soil system: To complete the life cycle normally, a living organism requires the supply of a large number of nutrients from outside are called **nutrients**. Almost all the nutrients are present in the soil except than C, H and O. Soil is the main source of mineral salts. There are two types of nutrients-



1. Macronutrients: The macronutrients are needed in concentrations of more than 100 mg kg⁻¹ of dry matter. Nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, carbon, hydrogen and oxygen are essential macronutrients.

2. Micronutrients: The micronutrients or trace elements are needed in tissues concentrations equal to or less than 100 mg kg⁻¹ of dry matter. The Cl, Fe, B, Mn, Zn, Mo, Na, Ni, and Cu come in this group.

8.2. Essential nutrients: Those elements which are necessary to complete the vegetative and reproductive life cycle of a plant are called essential nutrients. It means it is impossible to complete the life cycle of a plant without these nutrients e.g. N, P, K, Ca, Mg, S, C, H and O.

8.3. Beneficial Nutrients: Beneficial nutrients are nutrients that are not for the plant to complete its life cycle, but may provide other benefits such as disease resistant etc eg. Si, Co and Na. beneficial nutrients can improve the growth of some crops in some respects.

1. Nickel (Ni): a part of enzyme urease for breaking urea in the soil, imparts useful role in disease resistance and seed development.
2. Sodium (Na): for beets, partly able to replace K (uptake as Na⁺).
3. Cobalt (Co): for N fixation in legumes and for other plants (uptake as Co²⁺).
4. Silicon (Si): for stalk stability of cereals particularly rice (uptake as silicate anion).
5. Aluminium (Al): for tea plants (uptake as Al³⁺ or similar forms).

Essentiality criteria: The term essential mineral element (or mineral nutrient) was proposed by Arnon and Stout (1939) who concluded that, for an element to be considered essential, it must fulfil following criteria.

1. A given plant must be unable to complete its life in the absence of that mineral element.

2. The function of the element must not be replaced by another mineral element.
3. The element must be directly involved in plant metabolism. Those elements which are required for the normal growth of the plants.

Plants show physiological abnormalities, chlorosis, premature, falling of leaves, stunting etc. in the absence of essential nutrients.

8.4. Uptake and translocation of nutrients by root from the soil solution:

The available nutrient forms in the soil are free to move in the soil solution by mass flow or diffusion or up and down the soil profile with water movement. The acquisition of nutrients depends on the size and fineness of the root system, the number of root hairs, the cation exchange capacity (CEC) of the apparent free space (AFS) or the apoplast, etc.

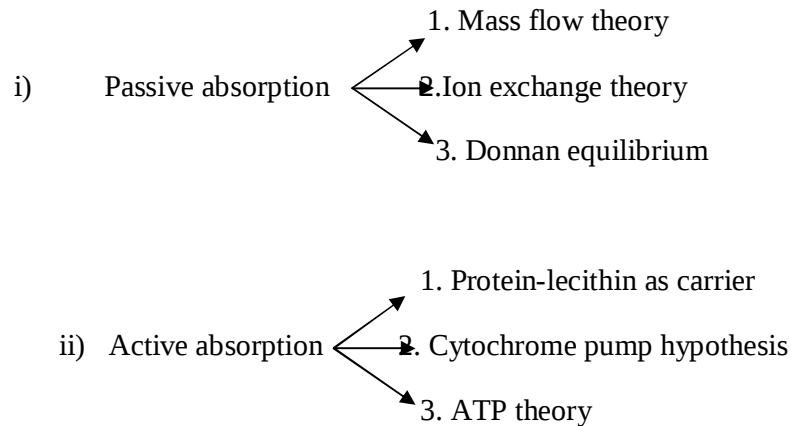
The first step in uptake is the entry of the nutrient ion and its passing the outer layer. Nutrients can enter the cell wall without hindrance. Because of their extremely small size (hydrated K ions have a diameter of about 0.001 μm), they are able to penetrate the cell wall tissue of the root hairs.

The second step in nutrient uptake involves movement of the nutrient ion into the cytoplasm by crossing the membrane.

The nutrients must be actively taken up into the interior of the cell. The energy required for this uptake is delivered by root respiration, a process that needs oxygen from the soil air and special uptake mechanisms. Thus, nutrient uptake by roots can be active or passive:

1. Nutrients can flow passively through the cell wall (AFS) of the root hairs along with the water.
2. The free flow ends at the membrane surrounding the active cell substance (cytoplasm).
3. Nutrients are actively transported through the membrane by special ion carriers (ionophores).
4. Active uptake needs energy from root respiration, which requires sugar and oxygen (O_2).
5. Cations are taken up in exchange for H^+ and anions for bicarbonate ions (HCO_3^-) on the root surface.
6. Plants can preferentially select nutrients and attempt to exclude unwanted substances.

Nutrients or inorganic substances are absorbed by root hairs and translocated by tracheary elements (xylem cells). Various theories proposed to explain the mechanism of mineral salt absorption can be placed under two broad categories-



i) Passive absorption: In passive absorption, the ions move into a cell along their electrochemical potential gradient without any expenditure of energy by cells. At equilibrium, no further net movement of solute can occur without any application of a driving force. When a plant cell or tissue is transferred from a medium of low salt concentration to a medium of relatively high salt concentration, there is an initial rapid uptake of ions, followed by a slow steady uptake that is under metabolic control. The temperature or metabolic inhibitors did not affect the initial rapid uptake. It indicates that metabolic energy is not involved in the process. The direction of initial uptake gets reversed if the tissue is transferred back to a low concentration. It means a part of the cell or tissue immersed into salt solution is opened to free diffusion of ions.

1. Mass Flow theory: According to this theory ions are taken up by roots along with mass flow of water under the influence of transpiration.

2. Ion Exchange theory: According to this theory ions from the external solution in which tissue is immersed may exchange with the ions absorbed on the surface of the cell wall of the tissue. **Cations** may exchange with hydrogen ions and **anions** with hydroxyl ions adsorbed on the surface of tissue.

3. Donnan Equilibrium: This theory assumes that certain fixed ions are present in cell sap. In order to maintain an internal balance, such ions would require ions of other charges.

ii) Active absorption: In active absorption, the movement may occur against the electrochemical potential gradient. It is not spontaneous and it requires that work be done on the system by the application of cellular energy. The transfer of one ion or particle across the membrane has been found to require 1340 cal/mol.

1. ATP theories: Ion uptake into the cell is energised by ATP. The energy from hydrolysis of ATP molecules can be made available to energise ion pump through the action of enzymes.

8.5 Factors affecting the uptake of nutrients (or factors affecting the salt absorption): There are several factors which affect the uptake of nutrients. Some of those are as follows-

- 1. Temperature:** When temperature increase passive and active salt absorption also increased.
- 2. Light:** When stomata open allow more transpiration and increased mass flow and photosynthesis provides energy and oxygen for salt uptake. Light affects the rate of salt absorption by affecting the opening and closing of stomata and the process of photosynthesis.
- 3. pH:** Low pH damage the plant tissue and affect the rate of absorption. Some nutrients dissolved at low pH.
- 4. Oxygen tension:** Deficiency of oxygen decreases salt absorption as the active phase of salt absorption is inhibited by the absence of oxygen.
- 5. Interaction:** Absorption of one ion may be influenced by the presence of another ion. If enough binding sites on the carriers are present, the interaction will not be apparent.
- 6. Growth:** Increase in surface area, number of cells, synthesis of new binding sites or carriers and volumes of water uptake stimulate salt absorption. Vegetative growth and increased metabolic activity with more water uptake enhances salt absorption.

8.6. Nutrients – Their Functions, Mobility in Plants and Deficiency/Toxicity Symptoms

Some knowledge of the properties and functions of plant nutrients is helpful for their efficient management and, thus, for good plant growth and high yields.

Available nutrients in the soil solution can be taken up by the roots, transported to the leaves and used according to their functions in plant metabolism. In general, N and K make up about 80 percent of the total mineral nutrients in plants; P, S, Ca and Mg together constitute 19 percent, while all the micronutrients together constitute less than 1 percent.

Most plant nutrients are taken up as positively or negatively charged ions (cations and anions, respectively) from the soil solution. However, some nutrients may be taken up as entire molecules, e.g. boric acid and amino acids, or organic complexes such as metal chelates and to a very small extent urea. Whether the original sources of nutrient ions in the soil solution are from organic substances or inorganic fertilizers, ultimately, the plants absorb them only in mineral forms.

Plants exhibit many shades of greenness but a medium to dark green colour is usually considered a sign of good health and active growth. Chlorosis or yellowing of leaf colour can be a sign of a marginal deficiency and is often associated with retarded growth. The chlorotic symptoms are reversible, i.e. leaves can become green again after the missing nutrient (responsible for chlorophyll formation) is added. A severe deficiency results in death of the tissue (necrosis). Necrosis is a brownish discoloration caused by decaying tissue, which is destroyed irreversibly. Necrotic leaves cannot be recovered by addition of the missing nutrient, but the plant may survive by forming new leaves. However, chlorotic and necrotic leaves might also result from the toxic effects of nutrients, pollution and also from disease and insect attacks. Therefore, confirmation of the cause is important before corrective measures are taken.

Nitrogen

N is the most abundant mineral nutrient in plants. It constitutes 2–4 percent of plant dry matter. Apart from the process of N fixation that occurs in legumes, plants absorb N either as the nitrate ion (NO_3^-) or the ammonium ion (NH_4^+). N is a part of the chlorophyll (the green pigment in leaves) and is an essential constituent of all proteins. It is responsible for the dark green colour of stem and leaves, vigorous growth, branching/tillering, leaf production, size enlargement, and yield formation. Absorbed N is transported through the xylem (in stem) to the leaf canopy as nitrate ions, or it may be reduced in the root region and transported in an organic form, such as amino acids or amides. N is mobile in the phloem (the plant tissue through which the sap containing dissolved food materials passes downwards to the stem, roots, etc.); as such, it can be re-translocated from older to younger leaves under N deficiency and translocated from leaves to the developing seed or fruit. The principal organic forms of N in phloem sap are amides, amino acids and ureides. Nitrate and ammonium ions are not present in this sap.

N deficiency in plants results in a marked reduction in growth rate. N-deficient plants have a short and spindly appearance. Tillering is poor, and leaf area is small. As N is a constituent of chlorophyll, its deficiency appears as a yellowing or chlorosis of the leaves. This yellowness usually appears first on the lower leaves while upper leaves remain green as they receive some N from older leaves. In a case of severe deficiency, leaves turn brown and die. As a result, crop yield and protein content are reduced. The effects of N toxicity are less evident than those of its deficiency. They include prolonged growing (vegetative) period and delayed crop maturity. High NH_4^+ in solution can be toxic to plant growth, particularly where the

solution is alkaline. The toxicity results from ammonia (NH_3), which is able to diffuse through plant membranes and interfere with plant metabolism. The potential hydrogen (pH – negative log of H^+ concentration) determines the balance between NH_3 and NH_4^+ .

Phosphorus

P is much less abundant in plants (as compared with N and K) having a concentration of about one-fifth to one-tenth that of N in plant dry matter. P is absorbed as the orthophosphate ion (either as H_2PO_4^- or HPO_4^{2-}) depending on soil pH. As the soil pH increases, the relative proportion of H_2PO_4^- decreases and that of HPO_4^{2-} increases. P is essential for growth, cell division, root lengthening, seed and fruit development, and early ripening. It is a part of several compounds including oils and amino acids. The P compounds adenosine diphosphate (ADP) and adenosine triphosphate (ATP) act as energy carriers within the plants.

P is readily mobile within the plant (unlike in the soil) both in the xylem and phloem tissues. When the plant faces P shortage (stress), P from the old leaves is readily translocated to young tissue. With such a mobile element, the pattern of redistribution seems to be determined by the properties of the source (old leaves, developing seed). Plant growth is markedly restricted under P deficiency, which retards growth, tillering and root development and delays ripening. The deficiency symptoms usually start on older leaves. A bluish-green to reddish colour develops, which can lead to bronze tints and red colour. A shortage of inorganic phosphate in the chloroplast reduces photosynthesis. Because ribonucleic acid (RNA) synthesis is reduced, protein synthesis is also reduced. A decreased shoot/root ratio is a feature of P deficiency, as is the overall lower growth of tops.

Extremely high levels of P can result in toxicity symptoms. These generally manifest as a watery edge on the leaf tissue, which subsequently becomes necrotic. In very severe cases, P toxicity can result in the death of the plant.

Potassium

K is the second most abundant mineral nutrient in plants after N. It is 4–6 times more abundant than the macronutrients P, Ca, Mg and S. K is absorbed as the monovalent cation K^+ and it is mobile in the phloem tissue of the plants. K is involved in the working of more than 60 enzymes, in photosynthesis and the movement of its products (photosynthates) to storage organs (seeds, tubers, roots and fruits), water economy and providing resistance against a number of pests, diseases and stresses (frost and drought). It plays a role in regulating stomatal opening and, therefore, in the internal water relations of plants.

The general symptom of K deficiency is chlorosis along the leaf boundary followed by scorching and browning of tips of older leaves. The affected area moves inwards as the severity of deficiency increases. K-deficiency symptoms show on the older tissues because of the mobility of K. Affected plants are generally stunted and have shortened internodes. Such plants have: slow and stunted growth; weak stalks and susceptibility to lodging; greater incidence of pests and diseases; low yield; shrivelled grains; and, in general, poor crop quality. Slow plant growth can be accompanied by a higher rate of respiration, which means a wasteful consumption of water per unit of dry matter produced. K-deficient plants may lose control over the rate of transpiration and suffer from internal drought.

Calcium

Calcium (Ca) ranks with Mg, P and S in the group of least abundant macronutrients in plants. It is absorbed by plant roots as the divalent cation Ca^{2+} . Ca is a part of the architecture of cell walls and membranes. It is involved in cell division, growth, root lengthening and activation or inhibition of enzymes. Ca is immobile in the phloem.

Ca deficiency is seen first on growing tips and the youngest leaves. This is the case with all nutrients that are not very mobile in the plants. The Ca-deficiency problems are often related to the inability of Ca to be transported in the phloem. The problems occur in organs that do not transpire readily, i.e. large, fleshy developing fruits. Ca-deficient leaves become small, distorted, cup-shaped, crinkled and dark green. They cease growing, become disorganized, twisted and, under severe deficiency, die. Although all growing points are sensitive to Ca deficiency, those of the roots are affected more severely. Groundnut shells may be hollow or poorly filled as a result of incomplete kernel development.

Magnesium

Mg ranks with Ca, P and S in the group of least abundant macronutrients in plants. Plants take up Mg in the form of Mg^{2+} . Mg occupies the centre-spot in the chlorophyll molecule and, thus, is vital for photosynthesis. It is associated with the activation of enzymes, energy transfer, maintenance of electrical balance, production of proteins, metabolism of carbohydrates, etc. Mg is mobile within the plants. As Mg is readily translocated from older to younger plant parts, its deficiency symptoms first appear in the older parts of the plant. A typical symptom of Mg deficiency is the interveinal chlorosis of older leaves in which the veins remain green but the area between them turns yellow. As the deficiency becomes more severe, the leaf tissue becomes uniformly pale, then brown and necrotic. Leaves are small and break easily (brittle). Twigs become weak and leaves drop early.

However, the variety of symptoms in different plant species is so great that their generalized description is more difficult in case of Mg than for other nutrients.

Sulphur

S is required by crops in amounts comparable with P. The normal total S concentration in vegetative tissue is 0.12–0.35 percent and the total N/total S ratio is about 15. Plant roots absorb S primarily as the sulphate ion (SO_4^{2-}). However, it is possible for plants to absorb sulphur dioxide (SO_2) gas from the atmosphere at low concentrations.

S is a part of amino acids cysteine, cystine and methionine. Hence, it is essential for protein production. S is involved in the formation of chlorophyll and in the activation of enzymes. It is a part of the vitamins biotin and thiamine (B_1), and it is needed for the formation of mustard oils, and the sulphhydryl linkages that are the source of pungency in onion, oils, etc.

S moves upwards in the plant as inorganic sulphate anion (SO_4^{2-}). Under low S conditions, mobility is low as the S in structural compounds cannot be translocated. As the S status of the plant rises, so does its mobility. This pattern of mobility means that in plants with adequate S, sulphate is preferentially translocated to young, actively growing leaves. As the supply of S becomes more limiting, young leaves lack S and, hence, show deficiency symptoms.

In many ways, S deficiency resembles that of N. It starts with the appearance of pale yellow or light-green leaves. Unlike N deficiency, S-deficiency symptoms in most cases appear first on the younger leaves, and are present even after N application. Plants deficient in S are small and spindly with short and slender stalks. Their growth is retarded, and maturity in cereals is delayed. Nodulation in legumes is poor and N fixation is reduced. Fruits often do not mature fully and remain light green in colour. Oilseed crops deficient in S produce a low yield and the seeds have less oil in them. S toxicity can occur under highly reduced conditions, possibly as a result of sulphide (H_2S) injury. Most plants are susceptible to high levels of atmospheric SO_2 . Normal SO_2 concentrations range from 0.1 to 0.2 mg SO_2/m^3 , and toxicity symptoms are observed when these exceed 0.6 mg SO_2/m^3 . S-toxicity symptoms appear as necrotic spots on leaves, which then spread over the whole leaf.

Boron

Boron (B) is probably taken up by plants as the undissociated boric acid (H_3BO_3). It appears that much of the B uptake mainly follows water flow through roots. B in a plant is like the mortar in a brick wall, the bricks being the cells of growing parts such as tips (meristems). Key roles of B relate to: (i) membrane integrity and cell-wall development, which affect permeability, cell division and extension; and (ii) pollen tube growth, which affects seed/fruit

set and, hence, yield. B is relatively immobile in plants and, frequently, the B content increases from the lower to the upper parts of plants.

B deficiency usually appears on the growing points of roots, shoots and youngest leaves. Young leaves are deformed and arranged in the form of a rosette. There may be cracking and cork formation in the stalks, stem and fruits; thickening of stem and leaves; shortened internodes, withering or dying of growing points and reduced bud, flower and seed production. Other symptoms are: premature seed drop or fruit drop; crown and heart rot in sugar beet; hen- and chicken-type bunches in grapes; barren cobs in maize; hollow heart in groundnut; unsatisfactory pollination; and poor translocation of assimilates. Death of the growing tip leads to sprouting of auxiliary meristem and a bushy broom-type growth. Roots become thick, slimy and have brownish necrotic spots. B toxicity can arise under excessive B application, in arid or semi-arid areas, and where irrigation water is rich in B content (more than 1–2 ppm B). B-toxicity symptoms are yellowing of the leaf tip followed by gradual necrosis of the tip and leaf margins, which spreads towards the midrib (central vein). Leaves become scorched and may drop early.

Chlorine

Chlorine (Cl) is absorbed as the chloride anion (Cl^-). It is thought to be involved in the production of oxygen during photosynthesis, in raising cell osmotic pressure and in maintaining tissue hydration. Some workers consider it essential only for palm and kiwi fruit. Deficiency of Cl leads to chlorosis in younger leaves and overall wilting as a consequence of the possible effect on transpiration. Cl^- toxicity symptoms are: burning of the leaf tips or margins; bronzing; premature yellowing; leaf fall; and poor burning quality of tobacco.

Copper

Copper (Cu) is taken up as Cu^{2+} . Its uptake appears to be a metabolically mediated process. However, Cu uptake is largely independent of competitive effects and relates primarily to the levels of available Cu in the soil. Cu is involved in chlorophyll formation and is a part of several enzymes such as cytochrome oxidase. As much as 70 percent of the Cu in plants may be present in the chlorophyll, largely bound to chloroplasts. It participates in lignin formation, protein and carbohydrate metabolism, and is possibly required for symbiotic N fixation. Cu is a part of plastocyanin, which forms a link in the electron transport chain involved in photosynthesis. Cu is not readily mobile in the plant and its movement is strongly dependent on the Cu status of the plant.

Cu-deficiency symptoms are first visible in the form of narrow, twisted leaves and pale white shoot tips. At maturity, panicles/ears are poorly filled and even empty where the deficiency is severe. In fruit trees, dieback of the terminal growth can occur. In maize, yellowing between leaf veins takes place, while in citrus the leaves appear mottled and there is dieback of new twigs. Cu-toxicity symptoms are more variable with species and less established than its deficiency symptoms. Excess Cu induces Fe deficiency and, therefore, chlorosis is a common symptom.

Iron

Fe is absorbed by plant roots as Fe^{2+} , and to a lesser extent as Fe chelates. For efficient utilization of chelated Fe, separation between Fe and the organic ligand has to take place at the root surface, after the reduction of Fe^{3+} to Fe^{2+} . Absorbed Fe is immobile in the phloem. Fe is generally the most abundant of the micronutrients with a dry-matter concentration of about 100 $\mu\text{g/g}$ (ppm). It plays a role in the synthesis of chlorophyll, carbohydrate production, cell respiration, chemical reduction of nitrate and sulphate, and in N assimilation. Fe deficiency begins to appear on younger leaves first. Otherwise, its deficiency symptoms are somewhat similar to those of Mn, as both Fe and Mn lead to failure in chlorophyll production. Yellowing of the interveinal areas of leaves (commonly referred to as iron chlorosis) occurs. In severe deficiency, leaves become almost pale white because of the loss of chlorophyll. In cereals, alternate yellow and green stripes along the length of the leaf blade may be observed. Complete leaf fall can occur and shoots can die.

Fe toxicity of rice is known as bronzing. In this disorder, the leaves are first covered by tiny brown spots that develop into a uniform brown colour. It can be a problem in highly reduced rice soils as flooding may increase the levels of soluble Fe from 0.1 to 50–100 $\mu\text{g/g}$ Fe within a few weeks. It can also be a problem in highly weathered, lowland acid soils.

Manganese

Manganese (Mn) is taken up by plants as the divalent ion Mn^{2+} . It is known to activate several enzymes and functions as an auto-catalyst. It is essential for splitting the water molecule during photosynthesis. It has certain properties similar to Mg. It is also important in N metabolism and in CO_2 assimilation. Like Fe, it is generally immobile in the phloem.

Mn-deficiency symptoms resemble those of Fe and Mg deficiency where interveinal chlorosis occurs in the leaves. However, Mn-deficiency symptoms are first visible on the younger leaves whereas in Mg deficiency, the older leaves are affected first. Mn deficiency in oats is characterized by “grey-speck” where the leaf blade develops grey lesions but the tip

remains green, the base dies and the panicle may be empty. In dicots (e.g. legumes), younger leaves develop chlorotic patches between the veins (somewhat resembling Mg deficiency).

Mn-toxicity symptoms lead to the development of brown spots, mainly on older leaves and uneven green colour. Some disorders caused by Mn toxicity are: crinkle leaf spot in cotton; stem streak; necrosis of potato; and internal bark necrosis of apple trees.

Molybdenum

Mo is absorbed as the molybdate anion MoO_4^{2-} and its uptake is controlled metabolically. Mo is involved in several enzyme systems, particularly nitrate reductase, which is needed for the reduction of nitrate, and nitrogenase, which is involved in BNF. Thus, it is involved directly in protein synthesis and N fixation by legumes. Mo appears to be moderately mobile in the plant. This is suggested by the relatively high levels of Mo in seeds, and because deficiency symptoms appear in the middle and older leaves.

Mo deficiency in legumes can resemble N deficiency because of its role in N fixation. Mo deficiency can cause marginal scorching and rolling or cupping of leaves and yellowing and stunting in plants. Yellow spot disease in citrus and whip tail in cauliflower are commonly associated with Mo deficiency. Fodders containing more than 5 $\mu\text{g/g}$ Mo in the dry matter are suspected to contain toxic levels of Mo for grazing animals (associated with the disease molybdenosis).

Zinc

Zn is taken up as the divalent cation Zn^{2+} . Early work suggested that Zn uptake was passive, but more recent work indicates that it is active (energy-dependent).

Zn is required directly or indirectly by several enzymes systems, auxins and in protein synthesis, seed production and rate of maturity. Zn is believed to promote RNA synthesis, which in turn is needed for protein production. The mobility of Zn is low. The rate of Zn mobility to younger tissue is particularly depressed in Zn-deficient plants.

Common symptoms of Zn deficiency are: stunted plant growth; poor tillering; development of light green, yellowish, bleached spots; chlorotic bands on either side of the midrib in monocots (particularly maize); brown rusty spots on leaves in some crops, which in acute Zn deficiency as in rice may cover the lower leaves; and in fruit trees the shoots may fail to extend and the small leaves may bunch together at the tip in a rosette-type cluster. Little-leaf condition is also a common symptom. Internodes are short. Flowering, fruiting and maturity can be delayed. Shoots may die off and leaves can fall prematurely. Deficiency symptoms are not the same in all plants.

Zn toxicity can result in reduction in root growth and leaf expansion followed by chlorosis. It is generally associated with tissue concentrations greater than 200 µg/g Zn.

BENEFICIAL ELEMENTS

Nickel

Ni is a part of the enzyme urease, which breaks down urea in the soil. It also plays a role in imparting disease resistance and is considered essential for seed development. Information on various aspects of Ni as a micronutrient is gradually becoming available.

Silicon

Si is taken up as the undissociated Si(OH)_4 monosilicic acid. The prevalent form of Si in plants is silica gel in the form of hydrated amorphous silica (SiO_2 in H_2O), or polymerized silicic acid, which is immobile in the plant. The beneficial effects of Si on plants include increases in yield that can result from increasing leaf erectness, decreasing susceptibility to lodging, decreasing incidence to fungal infections, and prevention of Mn and/or Fe toxicity. Thus, Si is able to counteract the effects of high N, which tend to increase lodging.

In lowland or wetland rice that is low in Si, vegetative growth and grain production is reduced severely and deficiency symptoms such as necrosis of the mature leaves and wilting can occur. Similarly, sugar cane suffers growth reduction under conditions of low Si availability.

Cobalt

Co is taken up as the divalent cation Co^{2+} . It is essential for N-fixing microorganisms, irrespective of whether they are free-living or symbiotic. Co is the metal component of vitamin B₁₂. Thus, Co deficiency inhibits the formation of leghaemoglobin and, hence, N₂ fixation. The Co content of the shoots can be used as an indicator of Co deficiency in legumes, where the critical levels are between 20 and 40 ppb of shoot dry weight.

Nutrient demand and supply

Plants require nutrients in balanced amounts depending on their stage of development and yield levels. For optimal nutrition of crops, a sufficient concentration of the individual nutrients should be present in the plant leaves at any time. An optimal nutrient supply requires:

1. sufficient available nutrients in the rootzone of the soil;
2. rapid transport of nutrients in the soil solution towards the root surface;
3. satisfactory root growth to access available nutrients;

4. unimpeded nutrient uptake, especially with sufficient oxygen present;
5. Satisfactory mobility and activity of nutrients within the plant.

The nutrient concentrations required in plants, or rather in the active tissues, are usually indicated on a dry-matter basis, as this is more reliable than on a fresh-matter basis with its varying water content. Leaves usually have higher nutrient concentrations than do roots. These are usually stated as a percentage for macronutrients and in micrograms per gram (parts per million) for micronutrients.

The law of the minimum and its implications

In plant nutrition, there is a law known as Liebig's law of the minimum. It is named after its author, Justus von Liebig, who said that the growth of a plant is limited by the nutrient that is in shortest supply (in relation to plant need). Once its supply is improved, the next limiting nutrient controls plant growth. A plant can also produce to its full potential when all nutrients (production factors in an enlarged sense) are at an optimal level, i.e. without any deficiencies or excesses. In order to produce high yields, plant nutrition requires a continuous effort to eliminate minimum factors and provide balanced nutrition in the optimal range. Even if the law of the minimum is only a guiding rule, it serves as a useful basis for nutrient management. In a broader sense, the law of the minimum can be extended to include all production inputs, not only nutrients.

Important aspects of the influence of nutrient supply on plant growth are:

1. Plants need certain concentrations of nutrient in their tissue for active growth.
2. Nutrient requirement comes somewhat in advance of plant growth.
3. Insufficient nutrient uptake results in slight to severe deficiencies.
4. Slight deficiencies are not visible and denote "hidden hunger".
5. Deficiency symptoms indicate a severe shortage of the nutrient in question.
6. High yields are only obtained where all nutrients are in the optimal supply range.
7. The nutrient with the lowest (minimum) supply determines the yield level.
8. Many mistakes in fertilization can be attributed to disregarding the law of the minimum.
9. It is easier to correct nutrient deficiencies than to eliminate nutrient toxicities.

Nutrient uptake in time and contents

The pattern of nutrient uptake follows a sigmoid (S-shaped) curve in most cases, being first low in the early stages of crop growth, increasing rapidly when drymatter production is

maximal and then declining towards crop maturity. During vegetative growth, the daily nutrient uptake increases as growth progresses and reaches a maximum during the main growing period.

N, P and K are mainly taken up during active vegetative growth for high photosynthetic activity. The rate of N uptake generally exceeds the rate of drymatter production in the early stages. Phosphate has an additional small peak requirement for early root growth. Modern high-yielding grain varieties continue to absorb P close to maturity. During the final stages of growth as the plant approaches its reproductive phase before maturity, nutrient uptake decreases. Perennial plants retrieve most of the nutrients from the leaves before leaf fall and relocate these for future use. In certain plants, such as jute, a considerable proportion of the absorbed nutrients is returned to the soil through leaf shedding before the crop matures. The highest concentrations of nutrients are found in leaves at early growth stages, and the lowest in leaves near harvest. This decrease in nutrient concentration over time is because of the transfer to other organs and also what is called the dilution effect.

Nutrient mobility and its effect on deficiency symptoms

While nutrients are transported easily from roots to shoots, their redistribution from the original place of deposition is more difficult for the so-called immobile nutrients. In the event of nutrient deficiency, a partial re-activation is required in order to supply newly formed leaves from the reserves of older ones. The relative mobility of a nutrient within the plant is helpful in understanding the reasons for the differential appearance of nutrient deficiency symptoms as discussed above.

For example:

1. The appearance of deficiency symptoms on older leaves indicates the shortage of a mobile nutrient because the plant can transport some nutrient quantities from old to new leaves.
2. The appearance of deficiency symptoms on younger leaves indicates the shortage of an immobile nutrient because of lack of supply from older to younger leaves.

The range of nutrient supply from deficiency to toxicity

The nutrient status of a plant can range from acute deficiency to acute toxicity. A broad division of nutrient status into three groups namely deficient, optimal and excess may be useful for general purposes.

1. Acute deficiency: It is associated with definite visible symptoms and poor growth. The addition of the deficient nutrient usually results in increased growth and yields.

2. Marginal or latent deficiency (hidden hunger): It is a small range with or without visible deficiency symptoms. However, growth and yield are reduced.

Addition of the yield-limiting nutrient results in higher yields but this may not be visible. Optimal nutrient supply prevents hidden hunger.

3. Optimal supply: This is the range to aim for. Here all nutrients are at the most desired level. In this range, healthy green plants, good growth and high yields with good quality can be expected.

4. Luxury supply: Although there is no definite borderline between optimal and luxury supply, it is useful to identify this range of unnecessarily high nutrient supply. Even if there may not be any negative effects on plant growth or yield, nutrient input is wasted and product quality as well as disease resistance may be reduced especially in the case of excess N. Therefore, luxury consumption of a nutrient should be avoided.

5. Marginal or light (hidden) toxicity: Here the nutrient concentration is moving towards toxicity. Above the critical toxic concentration, crop growth and yield start to decrease because of the harmful effects of a nutrient surplus.

6. Acute toxicity: This is the other extreme of excessive supply or poor nutrient management. Plants are damaged by toxic levels resulting in toxicity symptoms, poor or no growth, poor yield, low quality and damage to soil and plant health. The disease resistance of plants may also be lowered and the plant may even die. This range should definitely be avoided for any nutrient.

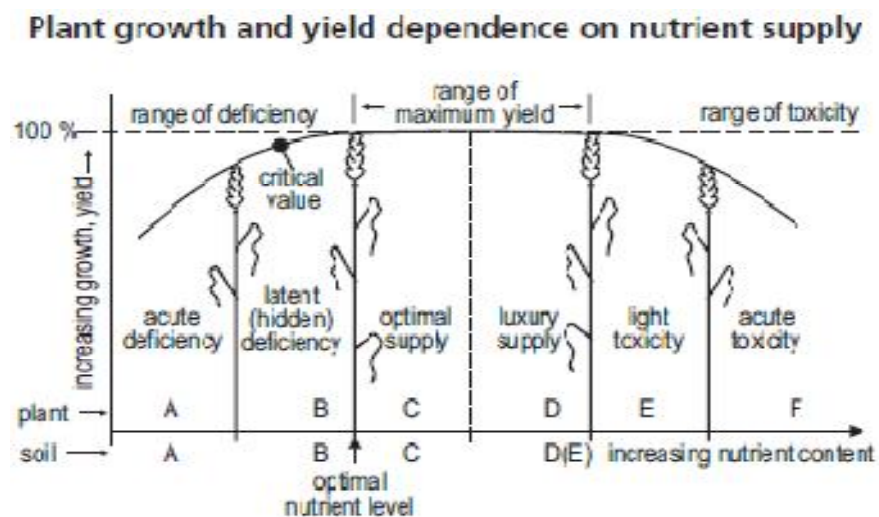


Table 8.1. Role of Nutrients and their Deficiency Symptoms:

Essential Elements	Functions	Deficiency Symptoms
1.Nitrogen NO_3^- , NH_4^+	Proteins, amino acids, purine, pyrimidine, DNA, RNA, chlorophyll, cytochromes, vitamins, hormones, co-enzymes, and ATP	Suppressed shoot growth, older leaves completely pale yellow, <u>flowering and fruiting reduced</u> , <u>leaf purple or red due to anthocyanin</u> , stunt growth, dormancy of lateral bud, symptoms appear first in older leaves then in younger leaves.
2.Phosphorus H_2PO_4^- , H_3PO_4^- , HPO_4^{--}	Nucleic acid, nucleoproteins, phospholipid of membranes, sugar phosphates, healthy root growth, fruit ripennning, ATP, ADP, AMP	Stunted plant, dark blue-green colour leaves, premature falling of leaves, <u>brown necrotic</u> (dead cells) patches on leaves
3.Potassium K^+	Maintenance of cell organization, stomatal movement, chlorophyll and nucleic acid synthesis.	Decolouration of leaves, chlorosis of tips and margins (scorch), <u>shoots may die-back</u> , shorter internodes, plastid disintegration.
4.Calcium Ca^{++}	Cell wall structure, membrane structure, ion transport, cell elongation, turgor of cells	Death of root, stem, leaf tips, <u>chlorosis in younger leaves along the margins</u> , margins curled backward or forward or rolled.
5.Magnesium Mg^{++}	Component of chlorophyll, combines the subunits of ribosomes, synthesis of DNA and RNA	Symptoms develop on older leaves systematically towards younger leaves, <u>mottled chlorosis</u> , <u>necrosis</u> , premature leaf abscission.
6.Sulphur SO_4^{--}	Constituents of amino acids (cysteine, cystene, methionine), vitamin B (thiamine, biotin), chlorophyll synthesis, lipid synthesis and CoA.	Necrosis of young leaf tip and margins, <u>shoot die-back</u> , <u>leaf fall is rapid</u> .
7.Zinc Zn^{++}	Chlorophyll synthesis, RNA synthesis	Seed production and fruit size reduced, leaves show <u>interveinal chlorosis and necrosis</u> , leaf margins distorted.
8.Iron Fe^{+++} Fe^{++}	Chlorophyll synthesis, constituents of cytochrome, leghaemoglobin, ferredoxin, hematin	<u>Chlorosis with green veins</u> , young leaves becomes yellow and white.
9.Manganese Mn^{++}	Chlorophyll formation, maintenance of chloroplast membrane structure	<u>Chlorosis with mottled appearance of leaf</u> , necrotic on younger leaf, <u>chloroplast disintegrate</u> , solubility increases with increasing acid it means crop failure.
10.Copper Cu^{++}	Oxidase enzyme: tyrosinase, ascorbic acid oxidase	<u>Die-back in citrus</u> , necrosis of leaf tips and margins.

Chapter-9 Soil Acidity and Causes of Soil Acidity

9.1. Definition of Soil Acidity: An acid soil has more H^+ than OH^- ions, whereas a basic or alkaline soil contains more OH^- than H^+ ions. The higher the H^+ concentration, lower the pH levels well below 7 (neutral). The degree of acidity or alkalinity in soils, also known as soil reaction, is determined by the hydrogen (H^+) ion concentration in the solution. To characterize these conditions, the term soil pH is used. A solution containing:

- H^+ ions > OH^- ions is acid (acidic)
- H^+ ions < OH^- ions is alkaline (or basic), and
- H^+ ions = OH^- ions is neutral in reaction

Soil Reaction is expressed in terms of soil pH. Soil pH is the negative logarithm (base 10) of the hydrogen ion activity of a soil. The H^+ ion activity or concentration is expressed in gram atoms (or moles) per liter. Thus, pH is given by the formula: $pH = -\log_{10} [H^+]$. In the formula “p” stands for logarithm and the capital letter “H” stands for hydrogen ion concentration or activity.

At neutrality, the hydrogen ion concentration (or activity) has been determined to be 0.0000001 or 1×10^{-7} gram atom or moles per litre. Substituting this concentration into the formula of pH results a pH value of 7 as shown below:

$$\begin{aligned} pH &= -\log_{10} [H^+] \\ &= -\log_{10} 10^{-7} \\ &= 7 \log_{10} 10^1 \\ &= 7 \times 1 = 7 \end{aligned}$$

Table 9.1. pH is an indicator of soil acidity. Classes used are:

Description	pH range
Extremely acidic	<4.0
Very strongly acidic	4.6-5.3
Moderately acidic	5.3-6.0
Slightly acidic	6.0-7.0
Neutral	7.0-7.0
Moderately alkaline	7.1-8.5
Very strongly alkaline	>8.5

9.2. Causes of Soil Acidity: There are following major reasons for soils to become acidic:

1. Rainfall and leaching,
2. Acid rain
3. Acidic parent material
4. Root respiration and Organic matter decay, and
5. Harvest of high-yielding crops.
6. Plant growth
7. Use of nitrogen fertilizers
8. Wet climates have a greater potential for acidic soils.

1. Rainfall and leaching: Acid soils are most often found in areas of high rainfall. Rainwater has a slightly acidic pH (usually about 5.7) due to a reaction with CO_2 in the atmosphere that forms carbonic acid. When this water flows through soil it results in the leaching of basic cations (Ca, Mg/ removal by crops) from the soil as bicarbonates; this increases the percentage of Al^{3+} and H^+ relative to other cations. Too much water results in key nutrients, such as potassium, magnesium, and calcium, being washed out (leached) from the soil. These elements all prevent soil from being acidic, so when they're leached out, the pH level of the soil starts to drop, resulting in acidic soil.

2. Acid rain: The burning of fossil fuels releases oxides of sulfur and nitrogen into the atmosphere. These react with water in the atmosphere to form sulfuric and nitric acid in rain.

3. Acidic parent material furnishing aluminum and silicon ions

Rocks containing an excess of quartz or of silica as compared to their content of basic materials or of basic elements are categorized as acid rocks; for example, granite, felsic and rhyolite. When rocks that are deficient in bases are disintegrated or decomposed in the process of the accumulation of soil material is acidic, despite no loss of base during the process of soil formation. Soils that develop from weathered granite are likely to be more acidic than those developed from shale or limestone. There are large areas of siliceous and sandy soils produced from acid parent rocks, which have always been in need of lime.

4. Root respiration and decomposition of organic matter: Root respiration and decomposition of organic matter by microorganisms releases CO_2 which increases the carbonic acid (H_2CO_3) concentration and subsequent leaching and adds H^+ .

5. Removal of elements through Harvest of high-yielding crops: Harvest of high-yielding crops plays the most significant role in increasing soil acidity. Roots take up basic cations (calcium, Ca^{2+} ; magnesium, Mg^{2+} ; potassium, K^+) and exchange them with H^+ ion.

6. Plant growth: Plants take up nutrients in the form of ions (e.g. NO_3^- , NH_4^+ , Ca^{++} , H_2PO_4^-), and they often take up more cations than anions. However plants must maintain a neutral charge in their roots. In order to compensate for the extra positive charge, they will release H^+ ions from the root. Some plants also exude organic acids into the soil to acidify the zone around their roots to help solubilize metal nutrients that are insoluble at neutral pH, such as iron (Fe).

7. Use of nitrogen fertilizers: Continuous application of inorganic fertilizer without soil test, in the end, can increase soil acidity. This increases soil acidity unless the plant directly absorbs the ammonium ions. The greater the nitrogen fertilization rate, the greater the soil acidification. As ammonium (NH_4^+), converted to nitrate (NO_3^-) in the soil by the process of nitrification, and release H^+ ions.

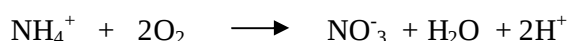


Table 9.2. Acid generating ammonium nitrifying reactions in soil

Ammonium nitrate	$\text{NH}_4\text{NO}_3 + 2\text{O}_2 \Rightarrow 2\text{NO}_3^- + 2\text{H}^+ + \text{H}_2\text{O}$
Urea	$(\text{NH}_2)_2\text{CO} + 4\text{O}_2 \Rightarrow 2\text{NO}_3^- + 2\text{H}^+ + \text{CO}_2 + \text{H}_2\text{O}$
Anhydrous ammonia	$\text{NH}_3 + 2\text{O}_2 \Rightarrow \text{NO}_3^- + \text{H}^+ + \text{H}_2\text{O}$
Ammonium phosphate	$\text{NH}_4\text{H}_2\text{PO}_4 + 2\text{O}_2 \Rightarrow \text{NO}_3^- + \text{H}_2\text{PO}_4^- + \text{H}_2\text{O} + 2\text{H}^+$
Ammonium sulphate	$(\text{NH}_4)_2\text{SO}_4 + 4\text{O}_2 \Rightarrow 2\text{NO}_3^- + \text{SO}_4^{2-} + 4\text{H}^+ + 2\text{H}_2\text{O}$

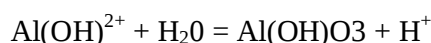
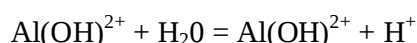
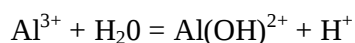
Legumes excrete protons (H^+) strongly from their roots as a result of a greater excess of cations (Ca, Mg, K and Na) uptake during N_2 fixation. This can become a problem where legume products (seed or hay) are exported. Residues of legumes have a high N (NH_4^+) content. Ammonium is converted to nitrate and large amounts of nitric acid (HNO_3) in the soil (nitrification). As these bases are removed and replaced by H ions, soils become more acidic. Legumes like soybeans, alfalfa and clovers tend to take up more cations in proportion to anions.

8. Oxidative weathering: Oxidation of some primary minerals, especially sulfides and those containing Fe^{2+} , generate acidity. This process is often accelerated by human activity.

9. Mine spoil: Severely acidic conditions can form in soils near some mine spoils due to the oxidation of pyrite.

10. Acid sulfate soils formed naturally in waterlogged coastal and estuarine environments can become highly acidic when drained or excavated.

11. Reaction of H⁺ with clay: The hydrogen will cause clay particles to break down, further releasing more toxic aluminium. **Aluminium** also plays a central role in soil acidity. The exchangeable and soluble aluminium ions play two critical roles in the soil acidity story. First, aluminium is highly toxic to most organisms and is responsible for much of the deleterious impact of soil acidity on plants. Second, Al⁺³ ions react with water (hydrolyze) to form H⁺ ions. H⁺ directly reduces the pH of the soil solution, while aluminum participates in hydrolysis reactions, in which H⁺ ions are formed. For this reason, Al⁺³ and H⁺ together are considered **acid cations**.



9.3. Control of Soil Acidity:

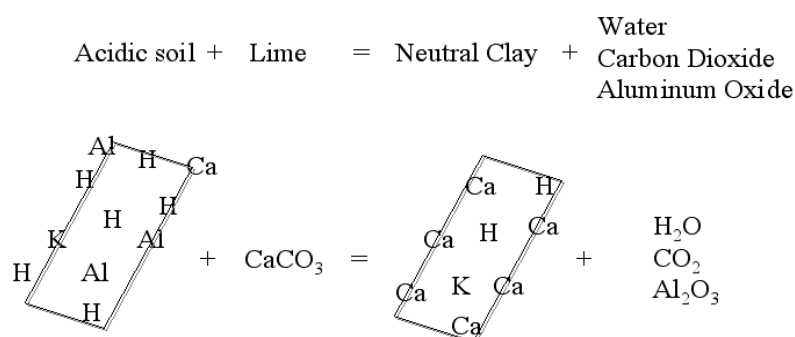
The management of acid soils should aim at improving the production potential by addition of amendment to correct the acidity and manipulate the agricultural practices to obtain optimum crop yields under acid condition. It is most important that soil acidity should be treated at an early stage. If acidity spreads into the sub-soil, serious yield reduction may occur. The first step in managing soil acidity is to diagnose any increase in acidity. Farming practices recommended for minimizing acidification include:

1. The most common way to raise the pH of soil is to add pulverized limestone to the soil. Lime is the cheapest and most effective cure for soil acidity. The carbonate component of lime consumes hydrogen ions present in the soil and reducing their concentration in soil solution and so that raising soil pH. The lime material has to be a calcium or magnesium salt of a weak acid such as limestone (CaCO₃), dolomite (Ca Mg (CO₃)₂), quicklime (CaO), hydrated lime or slaked lime (Ca (OH)₂). The liming of acid soils is regarded as the major solution to soil acidification at present in the western part of Ethiopia. Limestone acts as a soil acid neutralizer and consists of either calcium and magnesium carbonate or calcium carbonate. These are called dolomitic limestone and calcitic limestone respectively.

Table 9.3. Common liming materials and their calcium carbonate equivalent

Name	Chemical formula	Equivalent (%CaCO ₃)
Calcitic limestone	CaCO ₃	90-100
Dolomitic limestone	CaCO ₃ +MgCO ₃	95-110
Oxide/burned lime	CaO	150-175
Hydrated lime	Ca(OH) ₂	120-135
Ground shells	CaCO ₃	80-95
Basic slag	CaSiO ₃	50-80
Wood ashes	Oxides and hydroxides	30-70

Figure 1. How lime neutralizes acidic soil



2. Total soil alkalinity increases with addition of silicate, aluminosilicate and carbonate and bicarbonates minerals to soil containing Na⁺, Ca²⁺, Mg²⁺ and K⁺; this may happen by deposition of material eroded elsewhere by wind or water, or by mixing of the soil with less weathered material (such as the addition of limestone to acid soils).
3. Addition of water containing dissolved bicarbonates (as occurs when irrigating with high-bicarbonate waters).
4. The soil pH usually increases when the total alkalinity increases, but the balance of the added cations also has a marked effect on the soil pH. For example, increasing the amount of sodium in an alkaline soil tends to induce dissolution of calcium carbonate, which increases the pH. Calcareous soils may vary in pH from 7.0 to 9.5, depending on the degree to which Ca²⁺ or Na⁺ dominates the soluble cations.
5. Efficient irrigation management to minimize leaching,
6. Growing deep-rooting perennial species to take-up nitrogen from greater depths,

7. Growing acid tolerant crops or crop varieties that are relatively more tolerant of acid (acid resistant plant) soils such as sugarcane, coffee, papaya and bananas in conjugation with row crops make an important ecosystem on acid soils in Ethiopia. All these are a short-term option to mitigate the soil acidity and associated consequences.
8. **Wood ashes** are used locally, to help control soil acidity.

9.4. Alkaline soils (Alkali): Alkaline soils are clay soils with high pH (> 8.5), a poor soil structure and a low infiltration capacity. Alkali soil is a common name for what are now called sodic or saline sodic soils, those with levels of sodium high enough to be harmful to **plant growth**. Alkaline soils are found on more than half of the earth's arable lands. They dominate most arid and semiarid regions of the world. Salinity and or alkalinity can be developed when salts are naturally accumulated in some surface soils of arid and semiarid regions because of insufficient rainfall to wash salts from upper soil layer or induced by irrigation.

Often they have a hard calcareous layer at 0.5 to 1 metre depth. Alkali soils owe their unfavorable physico-chemical properties mainly to the dominating presence of sodium carbonate, which causes the soil to swell and difficult to clarify/settle. They derive their name from the alkali metal group of elements, to which sodium belongs, and which can induce basicity. Sometimes these soils are also referred to as alkaline sodic soils. Alkaline soils are basic, but not all basic soils are alkaline.

Soil pH is considered a master variable in soils as it affects many chemical processes. It specifically affects plant nutrient availability by controlling the chemical forms of the different nutrients and influencing the chemical reactions they undergo. The optimum pH range for most plants is between 5.5 and 7.5; however, many plants have adapted to thrive at pH values outside this range.

9.4.1. Causes:

The causes of soil alkalinity can be natural or man-made:

1. The natural cause is the presence of soil minerals producing sodium carbonate (Na_2CO_3) and sodium bicarbonate (NaHCO_3) upon weathering. In soils of low rainfall areas, the carbonate and the bicarbonate anions reinforce the tendency towards alkalinity. Moreover, the particular cation associated with carbonate anions also influences the pH level. For example, if adsorbed Na is prominent on the colloidal complex and in the soil solution, and if ample HCO_3^- and CO_3^{2-} are present, NaHCO_3

and Na_2CO_3 will form. Both these salts are water soluble and highly ionised, thus assuring continued high levels of HCO_3^- and CO_3^{2-} ions. The high concentration of carbonate ions can produce pH values as high as 10 or more.

2. Coal-fired boilers / power plants, when using coal or lignite rich in limestone, produce ash containing calcium oxide. CaO readily dissolves in water to form slaked lime— $\text{Ca}(\text{OH})_2$ —and carried by rain water to rivers / irrigation water. Lime softening process precipitates Ca and Mg ions / removes hardness in the water and also converts sodium bicarbonates in river water into sodium carbonate. Sodium carbonates (washing soda) further reacts with the remaining Ca and Mg in the water to remove / precipitate the total hardness. Also water-soluble sodium salts present in the ash enhance the sodium content in water. River water is made devoid of Ca and Mg ions and enhanced Na by coal-fired boilers.
3. Many sodium salts are used in industrial and domestic applications such as Sodium carbonate, Sodium bicarbonate (baking soda), Sodium sulphate, Sodium hydroxide (caustic soda), Sodium hypochlorite (bleaching powder), etc. in huge quantities. These salts are mainly produced from Sodium chloride (common salt). All the sodium in these salts enters into the river / ground water during their production process or consumption enhancing water sodicity. Sodium salt load problem aggravates in the downstream of intensively cultivated river basins located in China, India, Egypt, Pakistan, west Asia, Australia, western US, etc. due to accumulation of salts in the remaining water after meeting various transpiration and evaporation losses.
4. Another source of man made sodium salts addition to the agriculture fields / land mass is in the vicinity of the wet cooling towers using sea water to dissipate waste heat generated in various industries located near the sea coast. Huge capacity cooling towers are installed in oil refineries, petrochemical complexes, fertilizer plants, chemical plants, nuclear and thermal power stations etc. The drift / fine droplets emitted from the cooling towers contain nearly 6% sodium chloride which would deposit on the vicinity areas. This problem aggravates where the national pollution control norms are not imposed or not implemented to minimize the drift emissions to the best industrial norm for the sea water based wet cooling towers.
5. The man-made cause is the application of softened water in irrigation (surface or ground water) containing relatively high proportion of sodium bicarbonates and less calcium and magnesium.

6. **Sources of hydroxide ions:** In arid and semiarid areas, base forming cations (Ca^{2+} , Mg^{2+} , K^+ and Na^+) dominate the exchange complex of soils. These adsorbed cations, enhance the OH^- ion concentration of the soil solution in three ways. First they take place of exchangeable Al and H ions that are the primary sources of H^+ ions already described. This results in a decrease in H^+ ions and an equivalent increase in OH^- ions, since there is an inverse relationship between H^+ and OH^- ions in water based solution. Second, the Ca^{2+} , Mg^{2+} , K^+ and Na^+ , have more direct effect on the OH^- ion concentration in the soil solution. The hydrolysis of colloids saturated with these cations release OH^- ions. In some soils of arid and semiarid regions, accumulated carbonates and bicarbonates offer a third means of increasing the OH^- ion levels. They are subject to hydrolysis through reaction such as the following:



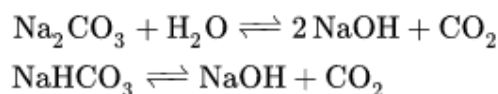
Very high pH value >8 can result from such reactions, particularly if sodium bicarbonate is present.

9.4.1.1. Agricultural problems:

Alkaline soils are difficult to take into agricultural production. Due to the low infiltration capacity, rain water stagnates on the soil easily and, in dry periods, cultivation is hardly possible without copious irrigated water and good drainage. Agriculture is limited to crops tolerant to surface waterlogging (e.g. rice, grasses) and the productivity is low.

9.5. Chemistry:

Soil alkalinity is associated with the presence of sodium carbonate (Na_2CO_3) or sodium bicarbonate (NaHCO_3) in the soil, either as a result of natural weathering of the soil particles or brought in by irrigation and/or flood water.



Sodium carbonate in water can produce carbon dioxide (CO_2), escaping as a gas or absorbed by algae, and sodium hydroxide (Na^+OH^-), which is alkaline (or rather basic) and gives high pH values ($\text{pH} > 8.5$).

9.6. Management of alkali soils:

1. Alkaline soils with solid CaCO_3 can be reclaimed with grass cultures, organic compost, waste hair / feathers, organic garbage, waste paper, rejected lemons/oranges,

etc. ensuring the incorporation of much acidifying material (inorganic or organic material) into the soil, and enhancing dissolved Ca in the field water by releasing CO₂ gas. Deep ploughing and incorporating the calcareous subsoil into the top soil also helps.

2. Plowing the field soon after cutting the crop is also advised to prevent salt migration to the top soil and conserve the soil moisture during the intense summer months. This is done to break the capillary pores in the soil to prevent water reaching the surface of the soil.
3. Using poly-houses or shade netting during summer for cultivating vegetables/crops is also advised to mitigate soil salinity and conserve water / soil moisture. Poly-houses filter the intense summer solar radiation in tropical countries to save the plants from water stress and leaf burns.
4. Clay soils in high annual rain fall (more than 100 cm) areas do not generally suffer from high alkalinity as the rain water runoff is able to reduce/leach the soil salts to comfortable levels if proper rainwater harvesting methods are followed. In some agricultural areas, the use of subsurface "tile lines" are used to facilitate drainage and leach salts. Continuous Drip irrigation would lead to alkali soils formation in the absence of leaching / drainage water from the field.
5. It is also possible to reclaim alkaline soils by adding acidifying minerals like pyrite or cheaper alum or Aluminium sulfate.
6. Alternatively, gypsum (calcium sulfate, CaSO₄·2H₂O) can also be applied as a source of Ca⁺⁺ ions to replace the sodium at the exchange complex. Gypsum also reacts with sodium carbonate to convert into sodium sulphate which is a neutral salt and does not contribute to high pH. There must be enough natural drainage to the underground, or else an artificial subsurface drainage system must be present, to permit leaching of the excess sodium by percolation of rain and/or irrigation water through the soil profile.
7. Calcium Chloride is also used to reclaim alkali soils. CaCl₂ converts Na₂CO₃ into NaCl precipitating CaCO₃. NaCl is drained off by leaching water. Spent acid (HCl, H₂SO₄, etc.) can also be used to reduce the excess Na₂CO₃ in the soil/water.
8. Where urea is made available cheaply to farmers, it is also used to reduce the soil alkalinity / salinity primarily. The NH₄ (Ammonium) present in urea which is a weak cation releases the strong cation Na from the soil structure into water. Thus alkali soils absorb / consume more urea compared to other soils.

9. One way of reducing sodium carbonate is to cultivate glasswort or saltwort or barilla plants. These plants sequester the sodium carbonate they absorb from alkali soil into their tissues. The ash of these plants contains good quantity of sodium carbonate which can be commercially extracted and used in place of sodium carbonate derived from common salt which is highly energy intensive process. Thus alkali lands deterioration can be checked by cultivating barilla plants which can serve as food source, biomass fuel and raw material for soda ash and potash, etc.

9.7. Effect of soil pH on nutrient availability and plant growth

A precise measurement of soil reaction (pH) by determining active hydrogen ion concentration in soils is one of the most useful of soil testing procedures. Accordingly, when crop plants do not grow well, one of the first questions the soil scientist usually asks is **“what is the pH of the soil”**? Because soil pH indicates indirectly a number of soil fertility characteristics. In general soil pH has a significant importance in soil-plant relationships because it determines the:

- Solubility and availability of plant nutrients
- Lime requirement of soils
- Activity of roots of higher plants, and
- Activity of desirable soil micro organisms particularly the nitrogen fixers and nitrifies whose activities are seriously depressed in strongly acid and strongly alkaline soils.

From this, one can understand that soil pH influences nutrient absorption and plant growth in two ways:

- Direct through the toxic effect of H^+ ion on plant root growth and development
- Indirectly through its influence on nutrient solubility and availability and the presence of pH-dependent toxic ions other than H^+ ion.

The indirect effect is of great significance in most soils. Generally, for agricultural purpose, soils with pH values within the range of 5.8 to 7.5 are suitable and more trouble free than those with higher or lower pH values.

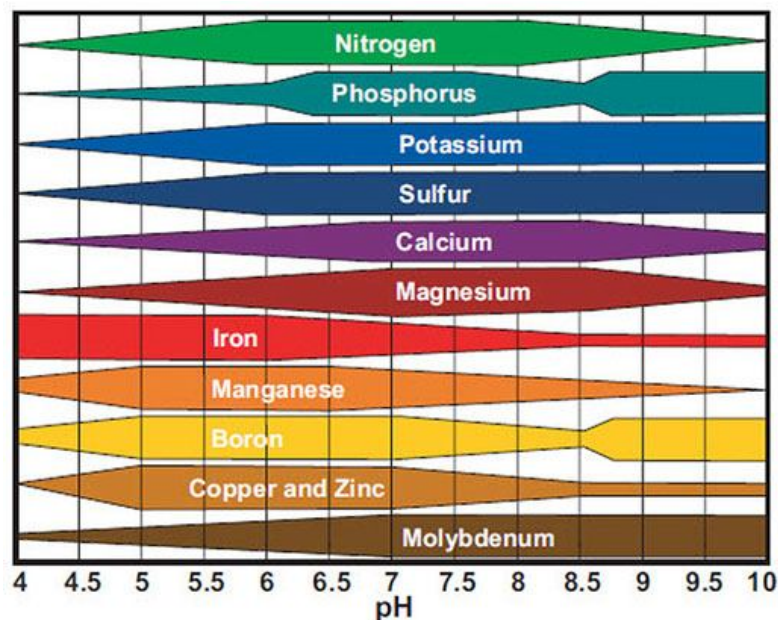


Figure 9.2. Effect of pH on nutrient availability. The width of the line indicates increasing or decreasing availability across a pH range from strongly acidic to strongly alkaline. Note how nitrogen, phosphorous, potassium and sulphur become much less available at low soil pH

9.7.1. Nutrient availability and microbial activity

In strongly acid soils the availability of the macronutrients (Ca, Mg, P, N, S) as well as Mo and B is curtailed. In contrast to and the availability of the micronutrient cations (Fe, Mn, Zn, Cu, Co) is increased by low soil pH. In slightly to moderate alkaline soils, Mo and all macronutrients (except P) are sufficiently available, but level of available Fe, Mn, Zn, Cu and Co are so low that plant growth is constrained. Phosphorous and boron availability is likewise reduced in alkaline soil commonly to a deficiency level. Low pH in topsoils may decrease legume nodulation. Most earthworm species are sensitive to soil acidity, and liming frequently results in a rapid increase in earthworm populations. Some soil bacteria are responsible for many reactions in the soil, such as decomposition of organic matter (contributes nitrogen and phosphorus) and the nitrification process. Those processes are significantly slowed down in acidic soils, and therefore limit nitrogen and other nutrients availability.

9.7.2. Effect of Acid soils on plant growth: Plants grown in acid soils can experience a variety of stresses including aluminium (Al), hydrogen (H), and/or manganese (Mn) toxicity, as well as nutrient deficiencies of calcium (Ca) and magnesium (Mg).

Aluminium toxicity is the most widespread problem in reducing crop yields in acid soils. Aluminium is present in all soils, but dissolved Al^{3+} is toxic to plants; Al^{3+} is most soluble at

low pH; above pH 5.0, there is little Al in soluble form in most soils. Aluminium is not a plant nutrient, and as such, is not actively taken up by the plants, but enters plant roots passively through osmosis. Aluminium inhibits root growth (stunting); lateral roots and root tips become thickened and roots lack fine branching; root tips may turn brown. In the root, the initial effect of Al^{3+} is the inhibition of the expansion of the cells of the rhizodermis, leading to their rupture; thereafter it is known to interfere with many physiological processes including the uptake and transport of calcium and other essential macronutrients (nitrogen, phosphorus, potassium, calcium and magnesium), cell division, cell wall formation, affects the activities of soil microorganisms, enzyme activity, sugar phosphorylation, DNA synthesis and reducing crop growth & yields.

Acid soils, also called ultisols or oxisols, have a pH of 5.5 or lower; they are widely distributed in tropical and subtropical regions, constituting approximately 30% of the total area of the planet and 50% of the arable land in the world, as well as providing between 25 and 80% of vegetable production.

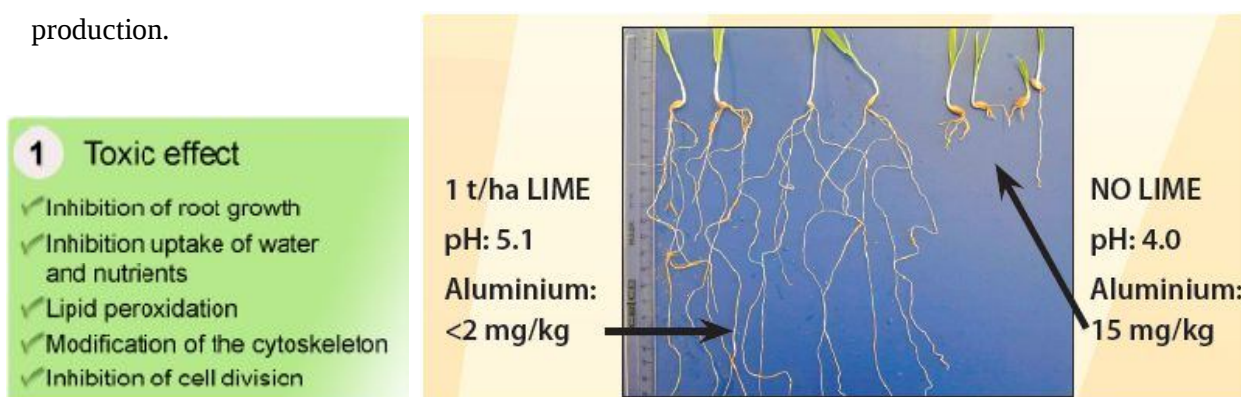


Figure 9.3: Roots of barley grown in acidic subsurface soil are shortened by aluminium toxicity.

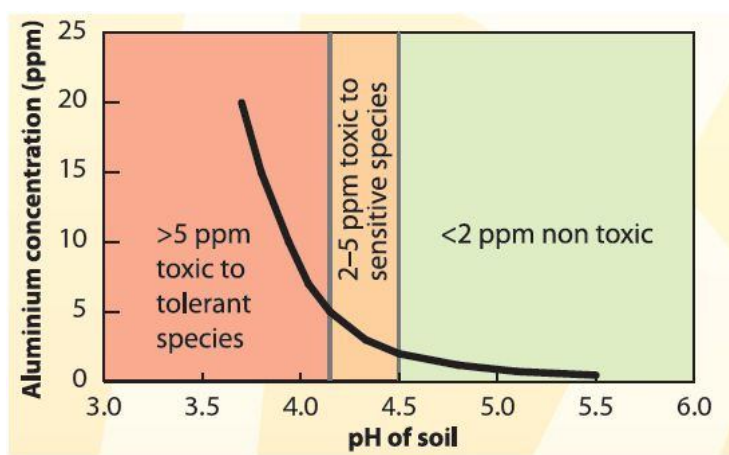


Figure 9.4: Al & pH graph with rule of thumb Al toxicity.

Proton (H^+ ion) stress can also limit plant growth. The proton pump, H^+ -ATPase, of the plasmalemma of root cells works to maintain the near-neutral pH of their cytoplasm. A high proton activity (pH within the range 3.0–4.0 for most plant species) in the external growth medium overcomes the capacity of the cell to maintain the cytoplasmic pH and growth shuts down.

In soils with a high content of manganese-containing minerals, Mn toxicity can become a problem at pH 5.6 and lower. Manganese, like aluminium, becomes increasingly soluble as pH drops, and Mn toxicity symptoms can be seen at pH levels below 5.6. Manganese is an essential plant nutrient, so plants transport Mn into leaves. Classic symptoms of Mn toxicity are crinkling or cupping of leaves.



The growth of faba bean under limed and un-limed condition on acidic soils Welmera Woreda



Growth of barley plants with lime and P, with P alone and without lime in acidic soils of Welmera

9.8. Examples of problems of soil and plant nutrition from Ethiopia

9.8.1. Soil Acidity in Ethiopia

Soil acidity is now a serious threat to crop production in most highlands of Ethiopia. The total area of Ethiopia is 111.8 million hectare out of these only 79 million of hectare is suitable for agriculture. Out of these about 40.9% of area is covered by strongly to weak acid soils. From these 27.7% moderately to weak acids with pH 5.8-6.7 and 13.2% covered by strong to moderate acidic soils (<4.5) and 11 million ha of land of Ethiopia are salt affected soils. Agriculture is the basis of the Ethiopian economy, accounting for 46% of its gross domestic product (GDP) and 63% of the national export earning and employing 85% of the country's labor force. About 85% of the country's population derives their livelihood directly from this sector.

Status of soil acidity and phosphorus concentration in different types of soils from different regions strongly acid soils are found in Oxisols, Nitisols, and Ferralsols. Acid Nitisols (pH <5.5) occur widely in Ethiopian highlands where the rainfall intensity is high and crop cultivation has gone for many years. The most strongly acidic soils are found in western and south western parts of Ethiopia, the central highlands, the high rainfall areas of north western part of the country. Nevertheless, moderately acidic soils (pH 5.5- 6.5) are distributed through much of the rest of the country.

Soil acidity affects the root development and growth crop leading to reduced nutrient and water uptake because acidic soil contain toxic levels of aluminum and manganese. Acidic soils are characterized by deficiency of essential plant nutrients such as P, Ca, K, Mg, and Mo. The net effect of which is reduced growth and yield of crops.

In some barley and wheat growing areas of central and southern Ethiopia, farmers have shifted to producing oats which is more tolerant to soil acidity than wheat and barley. The fertility of most Ethiopian soils has already declined and continued to decline posing an other challenge to crop production.

The use of organic fertilizers such as farm yard manure, compost, green manure and transferred biomass of leguminous trees is an alternative to inorganic fertilizers to improve soil fertility.

1. Hanoqdegem and Anogere Peasant associations kebeles in Degem Wereda in North Shoa Zone of Oromia Regional state.

North Shoa Zone cultivated land and grazing land were strongly acidic ($\text{pH} < 5.5$), whereas eucalyptus plantation and backyard were moderately acidic in both kebeles. The local farmers have understood the problem of soil acidity on their farm land.

In moving from central (West Shoa) to western Ethiopia (West wellega), the degree of soil acidification that is measured in terms of acid saturation percentage is increased ($\text{ASP} > 60$). The acidity problem in east and west Wellega zone of Oromia region is critical. Soils around Asosa and Wellega revealed that in aggregate, some 67 percent had pH values less than 6 and were very strongly to strongly acidic. There are also indications that problems of soil acidity have begun to be visible in the northwestern and northern parts of the country.

2.SNNPR (South): Currently, highland areas of Gamugofa, Sidam, Hadya, Kembata, Guragie and South western areas are affected by soils acidity seriously limiting crop production. Decline in soil fertility is another critical problem to crop production in SNNPR.

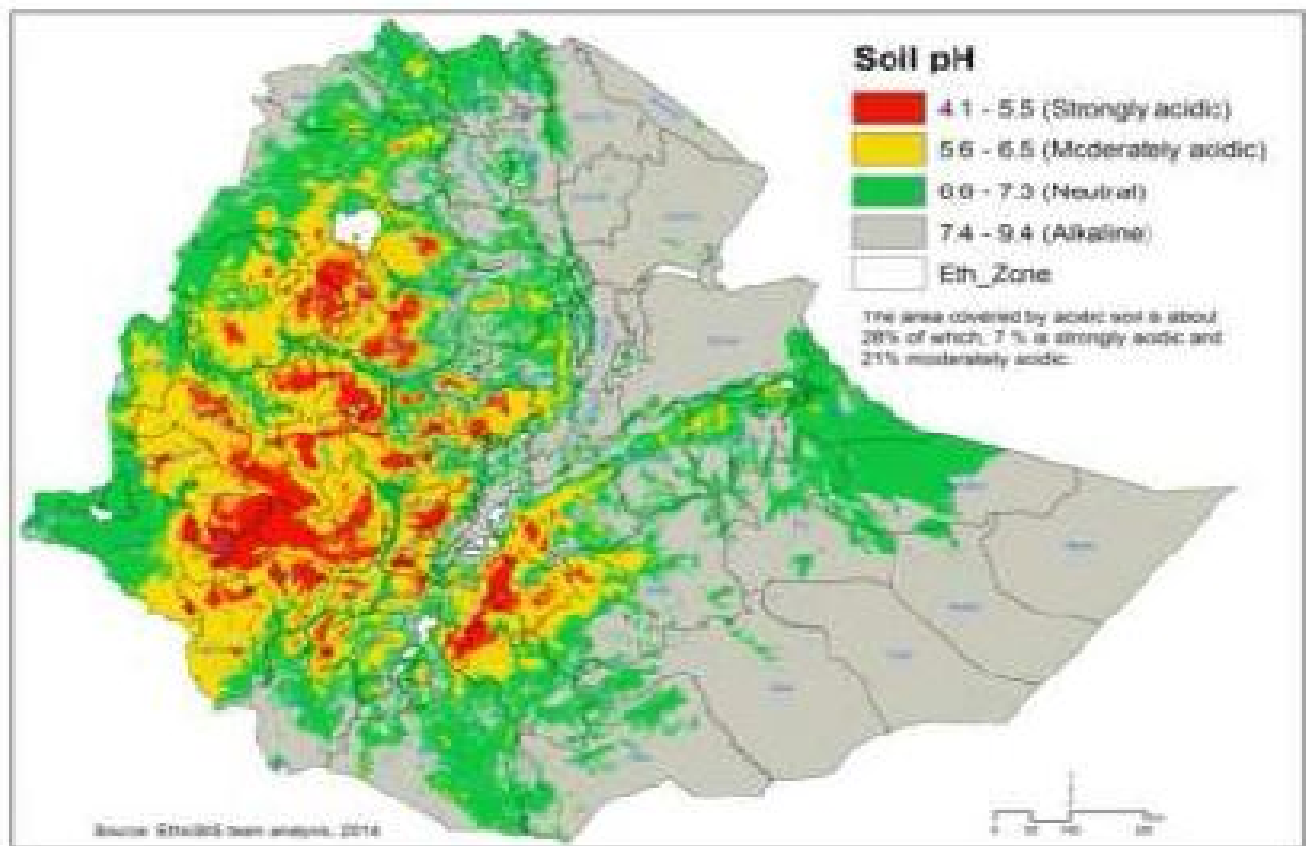


Figure 9.5. Map of Ethiopia showing the distribution of acidity and salinity in different region

Table 9.4: Examples of some acidic soils are given in following table, where it is observed that most of these soils are found in the highlands receiving high rainfall.

Location	Soil Types	Soil pH	P Level (ppm)
Chromic	Vertisol	4.2	19.0
	Pellic Vertisol	5.8	10.0
	Humic Vertisol	4.6	4.0
Metahara	Mollic Andosol	5.4	-
N.Eastern Escarpment	Humic/Mollic Andoso	5.2	8.0
Anno (East Wellega)	Humic Acrisol	4.7	1.0
Aleta Wondo	Nitisol	5.35	4.39
Dale (Yirgalem)	Nitisol	5.49	4.87
Chorra (Illubabor)	Nitisol	5.42	7.04
Metu(Illubabor)	Nitisol	5.24	9.36
Gimbi	Nitisol	5.07	5.82
Haru	Nitisol	5.07	5.17
Anfillo	Nitisol	5.36	18.42
Kosa (Limu)	Luvic Phaeoze	5.8	1.5
	Eutric Nitisol	5.4	1.25
Gumer(Limu)	Eutric Nitisol	5.2	2.8
	Luvic Phaeozem	5.2	2.7
Suntu (Limu)	Nitisol	5.2	0.2
<i>Chencha</i>		4.5	
<i>Nedjo</i>		4.4	
<i>Endibir</i>		4.8	
<i>Melko</i>		5.2	
<i>Bako</i>		6.6	
<i>Melkassa</i>		7.8	
Mecha (West Gojjam)- Enguti	Nitisols	3.79-4.67	
Banja (Awi) -Gashena Akayita	Acrisol (Ultisol)	4.57-5.44	
Gozamin (East Gojjam)- Enerata	Nitisols	4.57-5.49	
Hanoqdegem and Anogere		<5.5	

Effect of Soil Alkalinity and Acidity:

Soil microorganisms are most active and plant nutrients are readily available at optimum soil pH for plant production. At extremes of high (alkaline) and low (acid) pH this delicate balance is disturbed and plant nutrients that were in adequate supply can become either deficient or toxic to plant growth. Some essential nutrients such as phosphorous, calcium, magnesium, and molybdenum become unavailable if the soil pH becomes too acid as shown in figure.

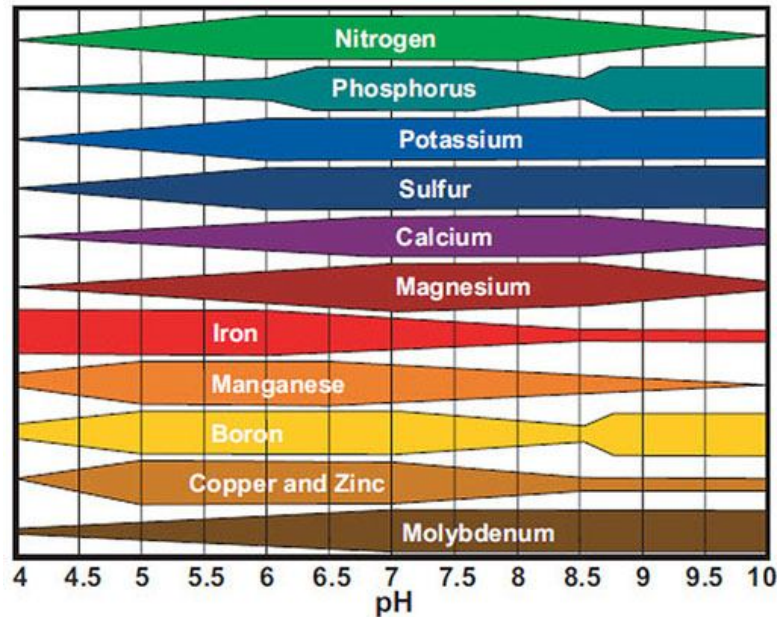


Figure 9.6. Effect of pH on nutrient availability. The width of the line indicates increasing or decreasing availability across a pH range from strongly acidic to strongly alkaline. Note how nitrogen, phosphorous, potassium and sulphur become much less available at low soil pH