Soil Geography

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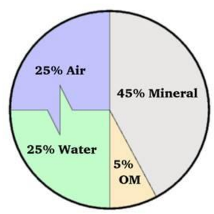
Soil mineralogy and Soil nutrients; Role of physico-chemical properties in soil fertility and productivity.

Soils are composed of clastic particles (mineral matter), organic materials in various stages of decay, living organisms, water (or ice), and gases within pores of various sizes. The absolute amounts of each, and their arrangement into a particular fabric, are the sum of soil morphology. Except in organic soils, most of the soil's solid framework consists of mineral particles. The inorganic part of mineral soils comprises primary silicates derived from rocks; secondary silicates formed from the primary minerals; the uncombined oxides of iron, aluminium and silicon; carbonates and soluble salts. The first two categories constitute the bulk and are found distributed in different size groups of particles. The larger soil particles (stones, gravel, and coarse sands) are generally rock fragments consisting of several different minerals. Smaller particles tend to be made of a single mineral.



Approximate Composition of Soil

Excluding the larger rock fragments such as stones and gravel, soil particles range in size over four orders of magnitude: from 2.0 millimeters (mm) to smaller than 0.0002 mm in diameter. Sand particles are large enough (2.0–0.05 mm) to be seen by the naked eye and feel gritty when rubbed between the fingers. Sand particles do not adhere to one another; therefore, sands do not feel sticky. Silt particles (0.05–0.002 mm) are too small to be seen without a microscope or to be felt individually, so silt feels smooth but not sticky, even when wet. Clay particles are the smallest mineral particles (<0.002 mm) and adhere together to form a sticky mass when wet and hard clods when dry. The smaller particles (<0.001 mm) of clay (and similar-sized organic particles) have colloidal properties and can be seen only with the aid of an electron microscope. Because of their extremely small size, colloidal particles possess a tremendous amount of surface area per unit of mass. The surfaces of soil colloids (both mineral and organic) exhibit electromagnetic charges that attract positive and negative ions as well as water, making this fraction of the soil the most chemically and physically active.

Soil Minerals

Minerals are naturally occurring inorganic compounds that have a characteristic chemical composition and a regular, repeating three dimensional array of atoms in a crystal structure.

Minerals can be classified according to their chemical composition and crystal structure, or according to whether they are primary (inherited from the parent material without chemical alteration) or secondary (formed by chemical weathering of other, pre-existing minerals). Primary minerals tend to dominate in coarser size fractions whereas secondary minerals are most abundant in the clay and fine silt fractions. Primary minerals contain many of the nutrient elements needed by plants. Other minerals, such as silicate clays and iron oxides, which were formed by the breakdown and weathering of less resistant minerals as soil formation progressed, tend to dominate the clay and, in some cases, silt fractions.

Those primary minerals which form the chief constituents of a rock and which are recognized as the characteristic components of that rock are classified as essential minerals, while those which occur only in small quantities and whose presence and absence is of no consequence as far as the character of the rock is concerned, are called accessory minerals.

Essential minerals

The more dominant primary minerals which commonly occur in soils, along with their differentiating characteristics are as follows:

Silicates

Most of the important primary soil minerals are silicates, including quartz, feldspars, micas, pyroxenes, amphiboles and olivines. The clay minerals are the most important silicates in the soil system. Primary silicate minerals are most common in the sand fraction, with the relative abundance of each depending upon the composition of the parent material and the extent of weathering.

Quartz

One of the forms of silica (SiO_2), quartz is abundant in soils. Usually the dominant mineral of fine sand and coarse silt fractions of soils, it is occasionally found in clay fractions also.

Feldspars

A series of monoclinic and triclinic silicates of aluminium with K, Na or Ca are collectively known as feldspars. Orthoclase, $(K, Na)AlSi_3O_8$, and microcline, $KAlSi_3O_8$, are the main potash feldspars but may contain considerable quantities of soda feldspar. Plagioclase feldspars are represented by albite ($NaAlSi_3O_8$)-anorthite ($CaAlSi_3O_8$) series.

Pyroxenes and amphiboles

The pyroxene and amphibole groups include numerous minerals which differ both mineralogically and chemically from one another. These are also called ferromagnesian minerals. They contain Ca, Mg, Fe^{2+} chiefly and Mn, Zn to small extents and are most abundant in soils.The amphiboles are chemically more complicated than the pyroxenes.

Olivines

Olivines constitute a group of continuous series of minerals varying from magnesium orthosilicate Mg_2SiO_4 to ferrous orthosilicate Fe_2SiO_4. Owing to relative ease of weathering, minerals of this group contribute to the nutrient status of the soil.

Micas

Chemically, rock forming micas fall into two main groups: one exemplified by the dark coloured biotite, containing iron and magnesium, and the other of which muscovite is the most prominent member, is devoid of these elements. Biotite, $H_2K(Mg,Fe^{2+})_3$ $(Al,Fe^{3+})(SiO_4)_3$ and muscovite H_2KAl_3 $(SiO_4)_3$ are found in soils. Micas and potash feldspars account for the major portion of potassium in soil.

Accessory Minerals

Important among these minerals are apatite; epidote group; garnets; ilmenite; kyanite, sillimanite, anadalusite; magnetites; pyritesrutile and anatase; sphene; staurolite; topaz; tourmaline; zircon. The primary minerals have complex composition and silicon and aluminium constitute the major elements.

Secondary Minerals

Secondary minerals such as silicate clays and iron oxides form by the breakdown and weathering of less resistant minerals as soil formation progresses. These minerals tend to dominate the clay and, in some cases, silt fractions. Most of the small quantity of organic matter present in soil is sufficiently fine to be included in the clay fraction. The two together form 'soil colloid'. Being fine sized, the inorganic fraction is most reactive, both physically and physico-chemically. In this fraction the following are included:

1. Clay minerals which are crystalline layer silicates
2. Amorphous silicates
3. Oxides of iron, silicon and aluminium and
4. Clay-sized primary minerals

Of these, the layer silicates are the most important and often dominant. The most well known among amorphous constituents of soil is allophane, detected in soils of volcanic origin. The secondary minerals are complex but much less so than the primary minerals which are their source.

Silicates

Silicates, such as kaolinite and smectite, formed by the weathering of primary silicates and are most abundant in the clay fraction.

Oxides

Metal oxides are ubiquitous in soils. Most metal oxides in soils are secondary minerals, formed during the weathering of primary minerals that contain iron or aluminum; only a few oxides are primary minerals inherited from the parent material. Secondary iron and aluminum oxides are major components of the clay fraction of highly weathered soils.

Aluminum oxides

The most abundant aluminum oxide in soils is *gibbsite*, Al(OH)3.

Iron oxides

Iron oxides are more abundant in soils than are aluminum oxides. Several different Fe oxide minerals can be found in soils, depending on the weathering environment. Fe oxides have positively charged surface groups that can bind to negatively charged sites on clays and organic matter, and also possess negatively charged sites that adsorb cations. Hematite forms in strongly weathered soils but it can also be inherited from the parent material. Magnetite is a primary mineral inherited from parent material.

Chlorides, carbonates, sulfates, sulfides and phosphates

Chlorides (mainly halite, NaCl) have a simple structure, are extrememly soluble and occur mainly as salt crusts on the surface of arid soils, particularly soils derived from saline parent material or influenced by saline waters or aerosols.

Carbonates such as calcite ($CaCO_3$) or dolomite $(CaMg)(CO_3)_2$ are less soluble than chlorides, but are nonetheless still typically found only in dry soils or in young soils or soils with calcareous parent material. Calcite is the most common soil carbonate and can be either pedogenic (forming in root zones where CO_2 concentrations are high) or inherited from calcareous parent materials. Soil dolomite is believed to be inherited from calcareous sediments or eolian dust. Sulfates that contain Ca^{2+}, Na^+ or Mg^{2+} are relatively soluble and occur predominantly in dry regions. Gypsum ($CaSO_4.2H_2O$) is the most common sulfate mineral in dry soils and can be either inherited or pedogenic. FeS_2 is the most common sulfide mineral in soils and is rapidly oxidized. Phosphate minerals are not abundant in soils, though apatite ($Ca_5(F,Cl,OH)(PO_4)_3$) has been identified in young soils. In general, phosphate minerals are less soluble than either carbonates or sulfates.

Soil Nutrients

The elements which provide nourishment to the plant and take part in plant metabolism are essential for plants. An element is said to be essential if the plant cannot complete its life cycle without it. Elements essential for the growth of green plants are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, zinc, copper, molybdenum, boron, chlorine, sodium, cobalt, vanadium, silicon, selenium, gallium, aluminium and iodine.

Macronutrients are required in large amounts and normally constitute 1 000 mg kg–1 (0.1%) or more of the dry weight of the plant. Micronutrients are required in relatively small amounts and normally make up less than 500 mg kg–1 (0.05%) of the dry plant weight.

Macronutrients

Besides carbon hydrogen and oxygen, six of the essential nutrients are used in relatively large amounts and are the macronutrients - usually over 500 parts per million (ppm) in the plant. Macronutrients include nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur. Carbon, H, and O are largely obtained by the plant from air and water while N, P, K, Ca, Mg and S come primarily from the soil and are absorbed by the plant through the root system. Nitrogen can be supplied to the plant in relatively large quantities from both the air and soil. Rhizobia bacteria, found in nodules on the roots of legumes, are able to fix dinitrogen (N2) from the air and convert it into inorganic forms for plant use.

Essential Macronutrient Elements and Role in Plants

Nitrogen

It is derived from the atmosphere or dead tissues and in both cases it is transformed by bacteria in the soil into ammonia and nitrate which are taken up by the plant roots. It occurs in great quantities in young plants particularly the leaves. Nitrogen forms a part of every living cell, occurring in chlorophyll and all proteins with many of the latter serving as enzymes. Abundance of nitrogen leads to green succulent growth while nitrogen deficiency causes a loss of colour, reduction in protein production and a gradual yellowing and stunted growth of plants.

Phosphorus

It is a constituent of every living cell and occurs in the protoplasm, with its greatest concentration in seeds thereby increasing their production. Most phosphorus occurs in the mineral *apatite* in igneous rocks and soil parent materials. Fluorapatite is the most common apatite mineral. Apatite weathers slowly, producing the phosphate ion $H_2PO_4^-$. The $H_2PO_4^-$ is immobilized when roots and microorganisms absorb it and convert the phosphorus into organic compounds. This results in a significant amount of phosphorus in soils as organic phosphorus. The availability of phosphorus to plants is determined by the amount of phosphorus in the soil solution. Phosphorus deficiency causes a purplish coloration at the seeding stage, with later yellowing, stunted growth and delayed maturity. The major problem in phosphorus uptake from soils by roots is the very low solubility of most phosphorus compounds, resulting in a low concentration of phosphate ions in the soil solution at any one time.

Potassium

There is a wide range in the potassium content of soils and availability of potassium for plant. Basically, potassium in soils is found in minerals like feldspars and micas that weather and release potassium ions (K^+). These ions are adsorbed onto the cation exchange sites. The exchangeable potassium tends to maintain an equilibrium concentration with the soil solution from which roots absorb K^+. Organic soils tend to be deficient in available potassium because they contain few minerals with potassium. It is essential in all cell metabolic processes. It influences the uptake of other elements and affects both respiration and transpiration. It also encourages the synthesis and translocation of carbohydrates thereby encouraging cell wall thickening and stem strength

Calcium and magnesium

There are many similarities between the behavior of calcium and magnesium with those of potassium in soils. They are all released from minerals by weathering and occur as exchangeable cations. They are the most abundant in young and minimally weathered soils and least abundant in intensively weathered and leached soils. All three elements are absorbed by roots as cations from the soil solution. Some important calcium minerals include calcite, dolomite, gypsum, feldspar, apatite, and amphibole. Important magnesium minerals include dolomite, biotite, serpentine, hornblende, and olivine. Calcium forms part of the cell wall structure and is necessary for cell division. Magnesium is active in enzyme systems and forms part of the chlorophyll. A deficiency causes discoloration and sometimes premature defoliation of the plants.

Sulphur

The three major natural sources of sulphur that can become available for plant uptake are:
(1) *organic matter*, (2) *soil minerals*, and (3) *sulphur gases in the atmosphere.* In natural ecosystems where most of the sulphur taken up by plants is eventually returned to the same soil, these three sources combined are usually sufficient to supply the needs of growing plants Sulphur exists in some soil minerals, including gypsum ($CaSO_4^-.2H_20$). Mineral weathering releases the sulphur as sulfate (SO_4^{2-}) which is absorbed by roots and microorganisms. Sulphur is released as sulphur dioxide (SO_2) into the atmosphere by the burning of fossil fuels and becomes an important constituent of the precipitation. In many locations, more sulphur is added to soils (via precipitation) than plants need. Sulphur accumulates in soils as organic sulphur in plant residues and is then mineralized to SO_4^{2-}. The net effect is the accumulation of sulphur in soils as organic sulphur. Plants, depending on the SO_2 content of the air, may absorb

sulphur through leaf stomata. Sulphur occurs in some amino acids and also in oils of some plants. A deficiency leads to stunting and yellowing.

Micronutrients

Micronutrients are required in very small amounts and function largely in plant-enzyme systems.

Iron and Manganese

Iron and manganese are weathered from minerals and appear as divalent cations in solution; as such, they are available to plants. Generally, in acid soils, sufficient Fe^{2+} and Mn^{2+} exist in the soil solution to meet plant needs. They play a role in enzyme systems and are necessary for the synthesis of chlorophyll.

Copper and Zinc

Copper and zinc are released from mineral weathering to the soil solution. These micronutrient cations can be adsorbed onto cation exchange sites. Little Cu^{2+} exists as exchangeable copper, however, but tends to be strongly adsorbed to the inorganic fraction or complexed with organic matter. As a result, copper is quite immobile in soils and the copper concentration of soil solutions tends to be very low. Even though there is a very low concentration of copper in solution, plants require very little copper, which is generally obtained in sufficient quantity by root interception and mass flow.

Zinc, as Zn^{2+}, occurs as an exchangeable cation, is strongly absorbed onto several soil constitutents, and is complexed by organic matter.

Copper and zinc form part of the enzyme systems and are necessary for the formation of growth promoting substances

Boron

The most abundant boron mineral in soils is tourmaline, a borosilicate. The boron is released by weathering and occurs in the soil solution mostly as undissociated boric acid, H_3B0_3 . It appears to play a role in calcium utilization and the development of the actively growing parts of the plant. It is also essential for the fixation of nitrogen by bacteria in the nodules of legumes.

Chlorine

The chlorine requirement of plants is very small, even though chlorine may be one of the most abundant anions in plants. Chlorine enters the atmosphere from ocean spray, is distributed around the world, and is added to soils via precipitation. The presence of chlorine in fertilizer, as potassium chloride, is an additional source of chlorine for many agricultural soils. Chlorine is responsible for regulating the osmotic pressure and cation balance in plants.

Molybdenum

Weathering of minerals releases molybdenum that is adsorbed to various soil constituents. It is necessary for the reduction of nitrate in the plant, otherwise nitrate will accumulate and interfere with protein synthesis.

Cobalt

Cobalt is required by microorganisms that symbiotically fix nitrogen. This is the only known need for cobalt by plants. It is necessary for the formation of nodules and nitrogen fixation in legumes. It is not required by non-leguminous plants but is taken up by all plants.

Role of Physico-Chemical Properties in Soil Fertility and Productivity

Soil Fertility

The concept of soil fertility is very complex. Soil fertility is the quality that enables the soil to provide proper nutrients in proper amounts and in proper balance for the growth of specified plants, when the other factors, such as light, temperature, moisture and the physical conditions of the soil are favourable. It is thus the capability of soil of producing a plant yield under defined conditions.

From the agricultural point of view soil fertility is best understood by (a) the nutrient requirements of plants, (b) the supply of nutrients in the soils, (c) the ways in which nutrients are lost from the soil, and (d) the methods by which soil fertility is restored and maintained. Soil fertility is usually discussed in the context of crop production but it can be considered from the point of view of inherent soil fertility and induced soil fertility. Nearly every soil has an inherent fertility. Soils that are wet, acid, alkaline or deficient in a particular element will support a specific plant community. Therefore they can be regarded as fertile with regard to the plants growing on them, but when humans want to replace one of these natural plant communities with a crop, the inherent fertility may not be suited to the particular crop. Then it may be necessary to change the soil to induce the type of fertility to suit the needs of the crop. In general terms the plant-soil requirements and the factors affecting these requirements can be identified. The factors affecting plant growth are:

1. Root-room and root-hold (thickness of the soil available for root penetration)
2. Aeration
3. Moisture

4. Temperature
5. Essential elements (macro- and micro-nutrients)
6. pH
7. Stable site (continuous removal of material from the surface means the loss of the most fertile part of the topsoil as well steady gradual reduction of soil thickness).

Soil Productivity

Soil productivity can be defined as the ability of the soil to produce crop under a physically defined set of management practices. It is measured in terms of inputs of production factors in relation to outputs or harvests. Thus productivity is not itself an inherent quality of the soil. All the physical, chemical and biological properties of a soil, together with the associated climate, determine its response to management, inputs of labour and Materials. Thus different physic-chemical properties of soil affect soil fertility and productivity.

Soil Physical Properties

Soil Texture

The texture of a soil refers to the size-composition of elementary grains in a soil. This refers to the relative proportions of clay, silt and sand in a sample of soil. The dominant size fraction is used to describe the texture, for example *sandy loam*, *silty clay*, and *clay loam*. If no fraction is dominant the soil is described as loam. Texture has a profound influence on many soil properties, and it affects the suitability of a soil for most uses. The texture affects productivity in several ways. Sandy soils are said to be “light” and clays “heavy”.

The texture is an important factor determining the amount of pores and the pore size distribution, two properties that are of fundamental importance for water relations, aeration and root penetration and thus for soil fertility.

Sandy soils have large pores so that infiltration rates and permeabilities to water are high, and they retain little water. In contrast, clays have low infiltration rates, low permeability, retain much water in available as well as in unavailable form, and may be poorly drained and waterlogged. Specific surfaces and ion exchange capacities (CEC) of sands are low as compared to clays. Thus they have a low nutrient holding capacity. Aeration is good in sandy soils and fair to poor in clays, depending on their structure. Roots penetrate sands more easily than clays. The very silty soils tend to erode very easily. Soils of intermediate textures such as loams are also intermediate in porosity, water retention, and drainage. The general tendency is for productivity to be better on medium-textured soils consisting of a mixture of sand, silt, and clay than on soils that are light, heavy or mainly silty. The most desirable soils for cultivation are the loams particularly those containing about 5-10 per cent organic matter.The texture is one of the most important soil properties affecting fertility.

Soil Structure

This describes the arrangement of the soil particles, degree and type of aggregation and the nature and distribution of pores and pore space. Soil structure influences plant growth rather indirectly. Formation of structural units leads to the formation of an array of pores of various shapes and sizes. These pores are the controlling factors governing water, air, air and temperature in soil which in turn, govern plant growth. A soil in which particles are unattached to one another is said to have single-grained structure or be structureless; this occurs with coarse grained materials, as in sand dunes. At the other extreme is massive structure where all the mineral particles are packed tightly together, as occurs in some clay soils. More usually the particles form aggregates, which have a size and shape, which are often characteristic of the soil. Aggregates formed by natural processes are called peds. Structure is one of the least permanent properties of soils for it can be altered very rapidly by cultivation or any other type of disturbance. It is just as important as soil texture in governing how water and air move in soils. Soils with a granular or crumb structure allow free percolation of excess moisture and at the same time roots are free to grow in the pore space between peds. Soils with massive or prismatic structure severely restrict root development because there is little pore space into which roots can grow and often they are anaerobic. Farmers very often refer to the tilth of the soil. This is the physical state of the soil in relation to plant growth and s the sum total of particle size distribution, texture, structure, porosity and density. The ideal tilth required by the farmer is one of medium texture, crumb or granular structure, friable and porous.

Consistence – handling properties

When soils are manipulated between the fingers and thumb they exert varying degrees of resistance to disruption and deformation as determined by their mechanical composition, degree of aggregation, content of organic matter and moisture content. Moist sands have a small measure of coherence whereas moist clays are plastic and become very sticky when wet, particularly if the content of montmorillonite is high. The presence of large amounts of humified organic matter in the soil is particularly important for it increases the plasticity of sandy soils but has the reverse effect of clay by reducing the stickiness.

The consistency of a soil is a very important agricultural property and it is essential for the soil to have the correct consistence at the time of cultivation. If it is too dry and hard, undue strain will be placed on implements, on the other hand if it is too wet and sticky the implements may stick and the soil may become puddle thus producing a poor seed bed for crops.

Soil Water

Water is essential for plant growth. Plants need water continuously, but their total water requirement varies depending upon the atmospheric condition and nature of plants. Soil is the main source of water for plants. Soil water relations can be described in stages: water infiltration into, water movement through, and water retention by soil. Two important moisture characteristics are the field capacity and the wilting point. After the soil has been saturated and the excess water drained away the soil is sad to be at field capacity. If plants are growing on the soil they will extract moisture until they cannot extract any more then they will wilt and die if the soil is not rewetted. The point at which permanent wilting starts is known as the wilting point. The actual amount varies from soil to soil and plant to plant. Thus water held between field capacity and wilting point is the water available to plants. The soil air and soil temperature are closely related to water content of soil. Increase in water content is followed by decrease in air-filled pores. Water content of soil has a profound influence on soil temperature. In the summer season, it has a cooling effect and in winter, water checks decrease in soil temperature.

Soil Air

Oxygen is essential for all biological reactions occurring in soil. Its requirement is met from soil air or the gas phase of the soil. In a soil, the volume of gas phase varies indirectly with that of the liquid phase or the water content of the soil. Thus, as a saturated soil becomes unsaturated, the pores which are drained of water are immediately filled with water. On restoration, water replaces air.

Oxygen is required by microbes and plants for respiration. Under anaerobic conditions, gaseous carbon compounds other than carbon dioxide are evolved which may be toxic to plants except rice. The concentration of carbon dioxide may also prove toxic to some plants and needs to be replaced by oxygen. Root elongation is particularly sensitive to aeration conditions. Oxygen deficiency disturbs metabolic processes in plants, resulting in accumulation of toxic substances in plants and low uptake of nutrients. Certain plants such as rice are adapted to grow under submerged conditions where the external source of oxygen for the root is particularly absent. These plants have large internal air spaces which facilitate oxygen transport to the roots. The atmosphere in the soil is constantly circulating and interchanging with that above the ground. If it did not circulate the content of carbon dioxide and other gases would increase to proportions toxic to plant roots. Good aeration is usually facilitated by a granular or crumb structure and free drainage.

Soil Temperature

The main source of heat energy for soil is solar radiation, which determines thermal regime of soil and growth of plants. The other modes of heat transfer in soil are convection, conduction and latent heat transfer.

Soil microorganisms show maximum growth and activity at optimum soil temperature range. The biological processes for nutrient transformations and nutrient availability are controlled by soil temperature and water. Water transport and ion movement also depend on soil temperature.

Soil temperature has a profound influence on seed germination, root and shoot growth, nutrient uptake and crop growth. Even a difference of $1^{o}C$ in soil temperature can have significant effect on plant growth. Seed germination is very sensitive to soil temperature. Seeds do not germinate below or above a certain range of temperature. During winter, seeds of vegetables have to be germinated under favourable condition and then sown in the field. Root elongation is very much dependent on soil temperature for rapid growth and maximum yield.

Most plants have their optimum growth within a specific temperature range. In cool climates germination will not start until the temperature is about 5°C. This restriction becomes increasingly important towards the poles with their long winters and cool spring weather. On the other hand, high soil temperatures may result in an excessive loss of moisture with drought as a consequence.

Soil Colour

Colour of soil is probably the first soil property for the human perception. Even today soil is described by its colour, such as, black, red, and yellow soil. The colour of soil has some relevance to soil constituents, viz. organic matter, oxides of irons of iron. Black colour of organic and peat soils is due to organic matter. Iron oxides occur in several hydrated and coloured forms which may impart red to yellow colour to soil.

Chemical Properties of Soil

Soil Organic Matter

Soil organic matter plays a very important role in the maintenance and improvement of soil properties. Soil organic matter is one of the major sources of nutrient elements for plants. In this respect, nitrogen is probably the most important. Humus has unique properties which very largely determine the character of the upper horizons. It is capable of absorbing large quantities of water thus increasing the water holding capacity of the soil and is therefore important in crop production. The humus portion of soil organic matter with a very high cation exchange capacity is a storehouse of cationic nutrients.Like clays, humus has a Cation Exchange Capacity (CEC), but it is considerably higher and therefore increases the cation holding capacity of the soil. Humus can be dispersed or flocculated depending upon the nature of the cations present and it influences handling consistence. The humus behaves like clay but it is easily destroyed by micro-organisms. It affects soil colour and supplies essential elements when it is decomposed. The reduction in the humus content of the soil is probably the main cause of the deterioration of structure, reduced water and nutrient availability and cultivation problems. Another important property of humus is it chelating power for some trace elements which could have otherwise been lost. Humus adds substantially to the buffering capacity of soil, making it less amenable to pH changes by acids or bases.

Organic matter plays a very important role in improving soil physical conditions. It improves soil aggregation which, in turn, influences infiltration, movement and retention of soil water, soil aeration, soil temperature, soil strength and root penetration. Higher water retention by soils owing to high organic matter content is beneficial for water conservation and water use efficiency for crops.

Organic matter increases the activity of soil microorganisms. As a general rule, the higher the organic matter content, the higher will be the microbial activity and the higher the availability of nutrients to crops.

A summary of the benefits of organic matter is as follows:

a) Improves structure and structural stability
b) Increases water holding capacity
c) Increases CEC
d) Improves conditions for microbial growth
e) Nutrient reserve
f) Decreases toxicity of Al
g) Improves tilth
h) Adsorption/deactivation of organic pesticides

Soil Colloids

A colloid is a two-phase system in which each phase is either solid or liquid or gas and one of the two is present in exceedingly high proportions; the latter is called the dispersion medium, and the other disperse phase.. The commonest colloidal system is one in which the disperse phase is one in which disperse phase is solid and the dispersion medium is liquid, usually water. In soil, both the inorganic silicates in the size range below 2 microns (clay fraction), and the humus, consisting of even smaller sized particles, are capable of remaining in a colloidal state in water as the dispersion medium. The clay particles and the humus and also the clay-humus interaction products are ordinarily present in an aggregated state. These aggregates however, are disaggregated in the presence of a dispersing agent (usually alkali) in a proportionately large volume of a dispersion medium. The clay humus complex is, however, not so easily disaggregated. Soil colloid is the most reactive fraction of soil and governs its chemical and physical properties.

Soil clays (inorganic soil colloid) are composed mainly of secondary minerals, often mixed with small quantities of primary minerals and oxides of iron, aluminium and silicon. Organic soil colloids are humus substances.

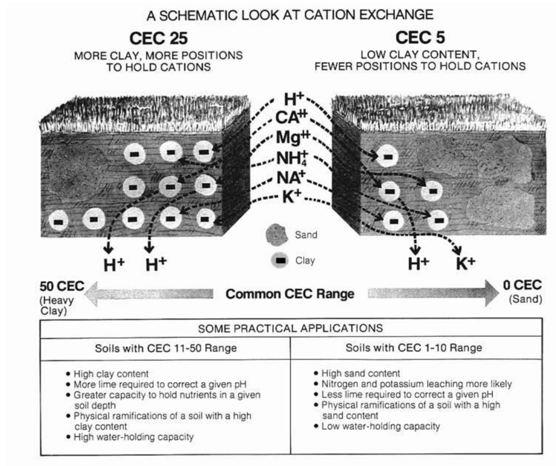
Availability of Essential Nutrients

Soils can be thought of as a reservoir of most of the essential elements for plant growth. Soils that have high contents of primary minerals such as feldspars, amphiboles and pyroxenes contain a large reservoir of elements but strongly weathered soils may have only a small reserve. Although the total reserve of elements is a factor in determining soil fertility, probably more important is the degree of availability of the elements since in a number of cases the elements such as calcium may be tightly locked up within the silicate structure or in undecomposed organic matter and be unavailable or only slowly available to plants.
Elements such as calcium and magnesium when present as carbonates are usually easily available because carbonates are readily soluble in the soil solution. Generally, the available cations occur as exchangeable cations on the surface of the clay particles from which they enter into solution or are taken up directly by plant roots. Thus the higher the base saturation the more cations there are available. The anions essential for plants also vary very much in availability. Nitrogen usually occurs as part of the tissue of organisms and is unavailable until it is transformed by microorganisms into ammonia and nitrate which are easily available. Phosphates which occur principally as calcium phosphates are very slowly soluble and thus not readily available. Therefore in order to know whether a soil is fertile or not it is necessary to know the degree of availability of essential elements.

Ion Exchange Phenomena

The two most important cation exchange properties are the cation exchange capacity (CEC) and the percentage base saturation.

The CEC of the whole soil is a measure of the exchange capacity or negative charges of the clay and humus.The CEC of a soil is expressed in $cmol_c/kg$ (centimol positive charge per kg of soil) or meq/100 g (milli-equivalents per 100 grams of soil). Both expressions are numerically identical (10 $cmol_c/kg$ = 10 meq/100 g). The percentage base saturation is a measure of the extent to which the exchange complex is saturated with basic cations.



The exchangeable cations determine, to a large extent, the chemical and physical properties of soils. The most significant are those of exchangeable hydrogen, sodium and calcium. The relative proportion of hydrogen determines the soil pH. If there is a preponderance of exchangeable hydrogen, the soil is acidic, as a result of which Al^{3+} ions become exchangeable. Soil pH also controls availability of plant nutrient elements. The effect of exchangeable sodium is conspicuous on soil physical properties. The higher the exchangeable sodium percentage (ESP), the more alkaline is the soil. If the ESP is more than 15, the soil is likely to get dispersed, apart from imparting sodium toxicity to plants. Dispersion of soils makes it impervious to water and hence unfavourable for plant growth. Availability of plant nutrients is reduced and crop growth is affected. Exchangeable sodium may react with carbon dioxide of soil or air forming sodium carbonate which on accumulation renders soil alkaline and ultimately infertile.

1. Soil-Na + $H_2O \rightleftarrows$ Soil-H + NaOH
2. 2NaOH + $CO_2 \rightleftarrows Na_2CO_3 + H_2O$

Soil Reaction

Soil Acidity

Soil reaction is measured by pH of soil water. The pH of soil water system is an approximate measure of the active fraction of the hydrogen ions present in the soil phase. Soil acidity is caused by ionizable hydrogen ions or protons. They are displaceable by any cation of high concentration.

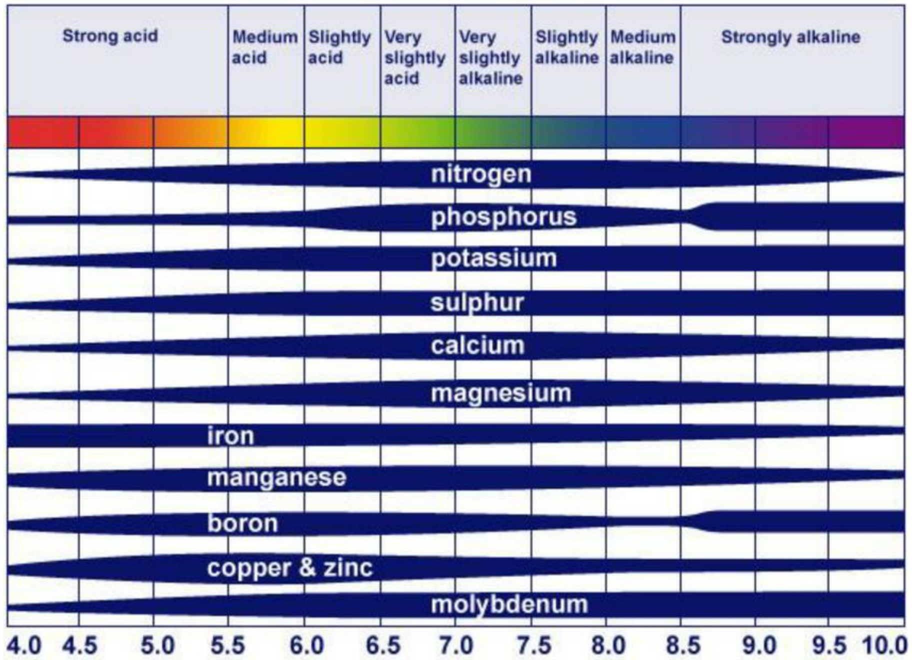
Soil Alkalinity

Soil is alkaline when pH of a soil is more than 7, i.e. when the activity of hydroxyl ions in the soil solution phase is more than that of the hydrogen ions. Soil alkalinity may be due to high base saturation, particularly with sodium, and to the presence of free carbonates of calcium and sodium.

Plants can grow on soils with a wide range of pH. The range for soils is normally from pH 3 to 9. Very low values develop following the drainage of coastal marshes and swamps that contain pyrite which is oxidized, resulting in the production of sulphuric acid. At the other extreme very high values result from the presence of sodium carbonate. Within the normal range the two principal controlling factors are organic matter and the amount and type of cations. Large amount of organic matter induce acidity except when counterbalanced by high concentrations of basic cations. Acidity is also induced by large amounts of aluminium in solution. Generally pH value about neutrality is associated with large amount of exchangeable calcium and some magnesium, sometimes supplemented by free carbonates. The degree of acidity of the soil affects a number of soil properties and processes, more especially the activity of the micro- and meso-organisms. Those that are particularly beneficial to crop production, such as earthworms and bacteria, prefer conditions about neutrality. In some cases acid soils encourage the growth of certain plant pathogens. High acidity may lead to the following:

1. Increasing amount of manganese and aluminium in the soil solution, these can be taken up by plants and are toxic.
2. Little formation of ammonia or nitrate
3. Low availability of phosphhorous
4. Molybdenum may be deficient
5. Reduces root activity
6. Certain diseases thrive.

The other environmental factor is soil physical conditions which are rendered unfavourable under low or high pH. High pH generally lowers availability of all nutrient elements except molybdenum and boron. The last two become available to plants as anions in the alkaline range.



Nutrient Transformation and Fixation

Plants take up nutrients through the roots which are the contact points with the soil. The conditions in soil are, however, not the same. The nutrients are subject to a number of transformations, chemical, physical and biological, before they are available to the plant roots. Moreover, in soil there are a number of competitive reactions, in which the microorganisms play a dominant role, and the soil may contain substances not directly connected with plant nutrition. In such situation plants have to survive by choosing by their root system what is good or what is not. There is a chance that plants may succumb to toxic substances or a large excess of one over others. The transformations may be either release or fixation of nutrient elements, and manner in which they take place is quite complex. Organic matter interacts with the soil components, leading to their transformation and immobilization or fixation. Similarly ammonium, potassium and phosphate are also fixed by several interactions are make them available with difficulty to plants for nutrition.
