# Nature of Soils

## What is Soil?

Before discussing the analysis of soil it may be helpful to have some understanding of its origin, the components which make up a soil, and the time involved in the soil formation process. Soil may be defined as the naturally deposited unconsolidated material which covers the earth's surface whose chemical, physical, and biological properties are capable of supporting plant growth. Soil is a product of natural decomposition forces acting upon native rocks, vegetation, and animal matter over an extremely long period of time; in some cases literally thousands of years. The factors involved in the formation of natural soils are: (1) living matter (plants, animals, and microorganisms); (2) climate (cold, heat, snow, rainfall, and wind); (3) parent materials (fineness of particle size as well as their chemical and mineralogical composition); (4) relief (slope and land form); and (5) time.

Soils, naturally, vary widely in their composition depending on their origin along with time and the natural forces involved in their formation process. Given the knowledge of the time required to develop a soil, it is of utmost importance that mankind use this natural resource in cooperation with the laws of nature to optimize soil conservation. This involves both chemical and physical conservation implemented by good management practices. Soil analysis is one aspect of soil management which aids in the conservation of this vital natural resource. Soil testing is an important management tool required for maintaining the proper chemical and microbiological balance within a soil necessary to optimize crop production without depleting the nutrient reserves.

Continued survival and dependence of mankind on the soil demands this balance be maintained through good management practices. Wilson stated, "Our soil is not just dirt, it is a factory where everything needed to feed plants, animals, and human beings is made." Hence, it is imperative that we maintain this "factory" in good operating order.

### *Composition of Soils*

For discussion purposes, the soils referred to hereafter will be mineral soils typical of the average farm. Mineral soils are composed of three major constituents: sand, silt, and clay. A fourth component, organic matter, although extremely important in the biological, chemical, and physical aspects of the soil, is not generally considered in the textural makeup of mineral soils. The different components of a soil are referred to as fractions; namely, the sand, silt, clay, and organic fractions.

Soils which contain a high clay content are known as clayey or finely textured soils; the silt loams, loams, clay loams, and silts are medium textured soils; and the sands are called course textured soils. Each soil type has been characterized by field and laboratory tests which are based on certain common chemical and physical properties.

Since the sand, silt, and clay fractions are predominant in the makeup of mineral soils, the texture of a soil, expressed by the use of Class names, i.e., clay, sandy clay, silt loam, loamy sand, etc., is based on the relative proportions of these constituents in a given soil. The different Class names are shown in the textural triangle in Figure 1.

The colloidal portion (sub-microscopic particle size, large surface area) of soils consists of highly decomposed particles of clay and organic matter and accounts for a soil's capacity to hold nutrient elements. These minute clay and organic colloids have a net negative charge and therefore attract and hold iron, manganese, zinc, and copper. The positively-charged metals are called "cations" and the capacity of a particular soil to hold such cations is called the Cation Exchange Capacity (CEC). Hence, the capacity of a soil to hold metal cations varies directly with the CEC of individual soils.

The CEC varies considerably from soil to soil depending on the type and percentage of colloidal clay and organic fractions present in a given soil. For example, a soil in which sand is the predominant

[illegible] component, would have a low CEC as opposed to a clay soil [illegible]EC is relatively high. Soils high in colloidal organic matter have an even higher CEC than clay soils.

Since these metal cations of a soil can be displaced through chemical extraction, the CEC of a particular soil can be determined with the proper soil test. As a result, the native fertility level of the soil can be assayed and evaluated in light of the extractable nutrient content as it related to the CEC of that soil. For example; soils classified as loams, sandy clays, silt loams, etc. have a much higher CEC than sands, sandy loams, or loamy sands and are less subject to nutrient leaching. Consequently, the extractable nutrient fraction from these soil classes is generally much higher, which results in a higher fertility status and residual benefit. In cases where both fertility status and residual nutrient supplies are high, the need for supplemental fertilizer treatment could be reduced or in unique cases eliminated entirely.

Keep in mind, however, that soils have a limited nutrient reservoir and must be replenished periodically in order to maintain levels with a range required for optimum yields. Remember, also, that soil fertility, as such, is only one aspect of the overall soil management program. Crop rotation, tillage practices, limestone needs, varietal differences, insect and weed control, and water management are other key factors involved in maintaining the productivity of a soil.

The clay content, or "colloidal" fraction of soils, has a pronounced effect on the nutrient holding capacity, water retention, and ease of tillage. Soils high in clay have a high water retention which can cause tillage delays during wet periods. Clay soils are not very friable as compared with soils which have a low clay content, namely the silt loams, loamy sands, etc. The latter soil types are also much easier worked through various tillage operations.

The clay fraction performs a very useful function in soils and should be considered a complimentary component of the soil. In addition to enhancing the nutrient and water holding capacity of soils, clay acts as a binding agent in the soil, thereby bringing about a sort of stability in the soil. Without this "binding" agent, many sandy soils would have very limited agricultural value. Since the clay fraction accounts for much of the chemical reactivity in soils, it is beneficial in its effects on texture, structure, and consequently, fertility status of a soil. An "ideal" soil is generally defined as a soil composed of a mixture of sand, silt, and clay - all of which have their unique effect on the chemical or physical aspects of the soil.

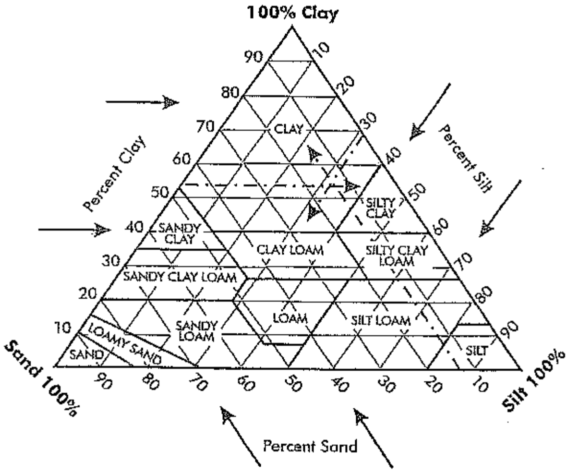

*Figure 1*

### *Effects of Overcropping*

Overcropping of land is analogous to overloading or misusing machinery, its productive life is shortened. Soils, like any other system have a certain production potential and when this potential is exceeded, maximum performance cannot be achieved. In factory management it is a simple matter to inventory the raw materials and determine when they should be replenished. In soil, this inventory is more complex; it must be measured by chemical means and at frequencies that will insure against unexpected shortages. With the advent of high-yielding hybrids and the increasing interest in double cropping systems, the rate of removal of "raw materials" has likewise increased. This has put a much greater demand on the soil and could lead to exhaustion if these reserves are not monitored regularly and replenished periodically.

The larger the crop removed from the soil, the greater will be the rate exhaustion of these raw materials. For example, alfalfa yielding 8 tons/acre will remove approximately 80 pounds of phosphate, 200 pounds of calcium, 480 pounds of potash, and 40 pounds of magnesium and sulfur. Therefore, profitable land use requires that these raw materials be systematically replenished if modern productive agriculture is to survive. A soil test serves as an invaluable tool for monitoring and maintaining these vital nutrient elements at levels required for optimum crop production.

As stated by Professor A.F. Gustafson; "the tillers of the soil are under a definite obligation to society to preserve the productivity of the land that is temporarily under their control." The alternative would overburden the land to the extent that agriculture as an industry would be in jeopardy. As someone stated: "as agriculture goes, so goes the country." With our current knowledge in the area of soil testing technology, the production potential of soils can be maintained through the proper use of this important management tool.

### Organic Matter

Organic Matter is that fraction within soils which results from the decomposition of plant and animal matter through the action of bacteria and fungi. It is an extremely important constituent of soils since it provides the natural home for the millions of bacteriological organisms which are so vital to the many biological and chemical reactions required for sustaining plant life.

*Other equally important benefits of organic matter:*

- Aids in moisture retention in the soil
- Supplies nutrient elements for plant use (particularly nitrogen and sulfur)
- Increases the nutrient holding capacity of soils
- Enhances soil aggregation and aeration
- Improves soil tilth which makes a soil more friable
- Aids in the reduction of soil erosion.

The additive effect of all these factors makes organic matter an extremely important component of a good soil. The beneficial effects of organic matter are often overlooked and in many farming operations little effort is being made to replenish it from time to time. The preservation of organic matter in the soil is of utmost importance without which the biological activity and the rate at which minerals are made available for plant use would be seriously reduced. No other constituent plays such a major beneficial role in the soil environment and gets so little credit as does the organic fraction.

A good soil should have between three to five percent organic matter as a safe margin for continuous rotational cropping use. An examination of soils in many farming areas will show that the organic matter content varies from one percent in the sandy soils to five percent in soils which contain higher levels of silt and clay (peat soils contain much higher levels than this).

Organic matter is the most difficult of the constituents to build up in a depleted soil. It is destroyed by overcropping, burning, and erosion. It can be restored by the application of animal manures, return of crop residues to the soil, and the use of green manure crops in combination with lime and other products which hasten decomposition.

Since organic matter is being used up continuously, every rotational system should be designed to replenish it intermittently to the soil. The very health of a soil and its ability to produce good crops is strongly influenced by the presence of organic matter.

## Macronutrients

### Elements required in large quantities

The major essential nutrient elements supplied through the soil are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). Other major nutrients - carbon (C), hydrogen (H), and Oxygen (O), come from water and atmospheric carbon dioxide.

*Nutrients absorbed from the soil by plants are supplied by several means:*

- Minerals released from the decomposition of native rocks, decomposition of organic matter,
- Deposition with the soil from flood waters
- Application of limestone and commercial fertilizer materials
- Use of animal or plant manures.

Each nutrient element will be discussed in more detail below.

### Nitrogen

Nitrogen is a unique element in that it composes 80% of the earth's atmosphere. Plants are literally submerged in an ocean of nitrogen, most of which reap no benefit because they cannot utilize this form of "free" nitrogen. However, a relatively large group of plants, the legumes, have the capability of converting atmospheric nitrogen into a form which can be utilized by the plant. Nitrogen fixation by legumes is conducted through a symbiotic association between the plant root and Rhizobium bacteria in the soil. The site where the nitrogen-capturing process occurs is in the visible nodules formed on the plant roots. Some of the most common legumes are peanuts, soybeans, lespedeza, alfalfa, clovers, and the vetchs.

The most common sources of nitrogen for non-legumes are through the decomposition of organic matter and application of commercial nitrogen fertilizers.

With the exception of carbon, hydrogen, and oxygen, nitrogen is the most prevalent nutrient element in the makeup of plants. It is a major constituent of essential compounds such as amino acids, nucleic acids, enzymes, and many vitamins. In fact, nitrogen is involved in almost all of the biochemical processes which compose and sustain plant and animal life.

Nitrogen is a component of the chlorophyll (green color) in plants, thus giving plants the rich green color characteristic of a healthy plant. Nitrogen promotes succulence in forage crops and leafy vegetables. When used at the recommended rates, nitrogen improves the quality of leaf crops. It also stimulates the utilization of phosphorus, potassium and other essential nutrient elements. The above-ground growth of plants is enhanced with nitrogen. Nitrogen hastens crop maturity (assuming all other nutrients are adequately supplied and excessive nitrogen rates are not applied). Nitrogen is very influential in fruit sizing.

Given the benefits of nitrogen in crop production, it is important to note that excessive nitrogen can have adverse effects on crops. For instance, excessive nitrogen can delay crop maturity, increase lodging due to weakened stems, produce excessive vegetative growth at the expense of fruitset, and cause potential health hazards for man and animal due to nitrate accumulation in leafy vegetable or forage crops.

Nitrogen is truly an "indispensable" nutrient element, but like many other production items, it must be utilized properly to reap its maximum benefit.

### Phosphorus

Phosphorus is necessary for the hardy growth of the plant and activity of the cells. It encourages root development, and by hastening the maturity of the plant, it increases the ratio of grain to straw, as well as the total yield. It plays an important part in increasing the palatability of plants and stimulates the formation of fats, convertible starches and healthy seed. By stimulating rapid cell development in the plant, phosphorus naturally increases the resistance to disease. An excess of phosphorus does not cause the harmful effects of excessive nitrogen and has an important balancing effect upon the plant.

### *Phosphorus in soils*

Life, either plant or animal, cannot exist without phosphorus, and, of course, the soil is the chief source of this constituent. A lack of phosphorus, therefore, not only retards growth but also lowers the tone and vigor of both plant and animal. Animals secure their phosphorus indirectly by utilizing plants for food, while plants secure phosphorus directly from the soil.

Soil contains less than 0.1% of total phosphorus (available and unavailable) and a large portion of the cultivated areas of the eastern half of the United States contains less than one-half of this amount. The plowed layer of soil on an acre of ordinary loam soil weighs approximately 2,000,000 pounds, and if it contains 0.05% of phosphorus it would have 1000 pounds of phosphorus per acre. Since a 180 bushel crop of corn requires about 100 pounds of available phosphorus, the above-plowed layer has sufficient phosphorus for over 10 crops of corn of 180 bushels each.

### *Cropping depletes soil phosphorus*

The supply of phosphorus in the soil can be quickly exhausted by continuous cropping if provision is not made for the return of phosphorus in the form of farm manure and commercial fertilizers. As soon as the content of phosphorus in a soil goes below a certain level, maximum crop yields drop below a profitable level.

The seeds of plants are relatively high in phosphorus. The bones of animals consist chiefly of calcium phosphate. Milk, likewise is rich in phosphorus. Consequently, when it is considered that grain and livestock are raised and sold, such enterprise gradually depletes the soil of phosphorus unless it is replaced from time to time.

### *Soil phosphates not always in available form*

The phosphorus content in many soils is not only low, but is often present in forms which are not available for effective plant uptake. In acid soils, particularly, phosphorus may be converted into iron and/or aluminum phosphates both of which have relatively lower plant availability. On the other hand, calcium phosphate is more available; therefore, it is desirable to apply phosphates to soils which are properly limed and show slightly acid reaction (see Table 1, page 28). Phosphates applied to properly limed soils are kept in the available form.

This is not meant to infer, however, that iron and aluminum phosphate are entirely unavailable, because plants can feed on these phosphate forms very slowly and given a long growing season they may make a fairly satisfactory growth. For many crops and for maximum yields on practically all crops, however, iron and aluminum phosphates have not been found to supply adequate phosphates for optimum plant growth.

### *How much available phosphorus should soils contain?*

It is extremely important to test soils in order to find out whether or not they contain sufficient readily-available phosphorus for good plant growth. Experience has shown that for general farming in the Northern states, silt loam, sandy loam, and clay soils should contain at least 75 pounds of readily available phosphorus per acre, and sands 50 pounds per acre. More available phosphorus than these amounts is, of course, desirable and beneficial.

The desirable bacteria in soils, such as the nitrogen-fixing bacteria, are greatly stimulated by an abundance of readily-available phosphorus. The best agricultural soils are all high in readily-available phosphorus, since the abundance of readily-available phosphorus favors all the conditions which go to make a fertile soil. A difference of 25 pounds of available phosphorus per acre in the lower range is sufficient to exert a marked influence on the crop-producing power of a soil.

For garden crops and many special truck crops, at least 150 pounds per acre are needed, and higher amounts such as 200 to 300 pounds or more are desirable. In the Southern states, due to the longer growing season, fairly good crops can be secured with about one-half of the amounts just indicate for the Northern States. If the amount of readily available phosphorus found with the LaMotte test is less than the amounts just indicated, the application of phosphate fertilizer is recommended.

## Potassium

Potassium (K+) is a positively-charged basic metal cation whose total content in most mineral soils, except sandy natured soils, is greater than most other major nutrient elements. The average potassium content of the earth's surface is estimated at 2.3 percent, most of which is not readily available to plants because it is either bound in primary minerals or is "fixed" in the interlayers of clay minerals (illite, vermiculite, and other expanding type clay minerals).

Since clay soils develop from the decomposition of potassium-rich primary minerals (feldspars and micas), it follows that soils high in clay content usually have a relatively high potassium content.

*Soil potassium can be divided into three components:*

- Interlayer potassium (trapped between clay layers and relatively unavailable to plants)
- Exchangeable potassium absorbed on the surface of soil colloids
- Potassium present in the soil solution

As potassium in the soil solution is diminished by plant uptake it is replenished by exchangeable potassium from soil colloids. Potassium "fixed" in the interlayers of clay minerals also contributes to the soil potassium supply even though it is not considered as "readily available."

Depending on the type of clay mineral and its resistance to weathering actions, the potassium supply may or may not be adequate for maximum crop production. This evaluation of supply can be made with a soil test, since exchangeable colloids and potassium in the soil solution are the forms of potassium measured by a soil test. In this light, the soil test potassium content reflects that portion of soil potassium which is readily available to plants, and depending on the soil test level may or may not be an adequate supply for good crop yields.

Soils which fix potassium serve as a bank which safeguards against leaching and ultimately, in time, returns potassium to the exchangeable form which can be withdrawn and utilized by plants.

Soils which are predominantly sand with little or no clay have extremely low levels of native potassium and are subject to severe leaching. In most cases, annual potassium applications are required to grow satisfactory crops. Soils of this nature are common throughout the Southeastern region of the United States.

Potassium is not a component of the structural makeup of plants, yet it plays a vital role in the physiological and biochemical functions of plants.

*Importance of Potassium in plant nutrition:*

- Enhances disease resistance by strengthening stalks and stems
- Activates various enzyme systems within plants
- Contributes to a thicker cuticle (waxy layer) which guards against disease and water loss
- Controls the turgor pressure within plants to prevent wilting
- Enhances fruit size, flavor, texture, and development
- Is involved in production of amino acids (the building blocks for protein), chlorophyll formation (green color), starch formation, and sugar transport from leaves to roots.

In short, potassium is an essential element of all living organisms, both plant and animal.

## Calcium

The amount of total calcium in soils may range from as little as 0.1% to as much as 25%. Soils in the arid West have the highest levels of calcium, while acid soil, primarily in the Southeast, has the lowest amounts of calcium. Like potassium, calcium exists as a cation;

however it has two positive charges (Ca++). Exchangeable calcium, as the cation Ca++, is the most abundant form.

Calcium is a structural component of several minerals, such as dolomite and calcite. Gypsum may also be a source of calcium when the soil pH is high but when lime is not required. A calcium deficiency is rarely a problem due to widely-accepted practice of applying lime to soil to raise the pH to the proper range for optimum plant growth.

As an important mineral nutrient, calcium is a component of cell walls in plants and is known to stimulate root and leaf development as well as activate several enzyme reactions involved in plant metabolism. It is responsible for maintaining optimum pH levels in the plant by neutralizing many of the organic acids generated as a result of the plant respiration. Indirectly, calcium influences crop yields by reducing soil acidity and by reducing the toxicity of several other soil minerals such as manganese, zinc, and aluminum.

## Magnesium

Soils have many sources of magnesium. Another divalent cation, (Mg++), is often regarded as the companion to calcium, because the most common source is dolomitic limestone which contains both calcium and magnesium. Many coastal areas along the Atlantic and Gulf states may exhibit magnesium deficiency, which in most cases is easily corrected by the application of pulverized limestone. Neutral soils, those soils having no lime requirement, that are deficient in magnesium may have magnesium applied as magnesium sulfate, magnesium oxide or the double salt of magnesium and potassium sulfate.

The magnesium atom is incorporated into each chlorophyll molecule of all green plants. Without magnesium, photosynthesis would not occur. In plant nutrition, magnesium stimulates the uptake of phosphorus in the plant from the soil solution, and helps in starch translocation. Magnesium is also essential in the formation of fats and oils in the plant.

## Sulfur

Almost all of the sulfur found in soils is located in the organic matter. The amount of sulfur that becomes available to the plant is largely dependent upon the amount of organic matter and the decomposition rate of organic matter by bacteria and other soil organisms. Another major source of sulfur includes the amount and type of rainfall and how much sulfur oxides have been absorbed. Sulfur oxides are produced from combustion of fossil fuels. In the atmosphere, sulfur oxides combine with rain to produce sulfuric acid, a component of acid rain. Sulfur is a component of many commercial fertilizer materials such as ammonium sulfate, potassium sulfate, and super phosphate fertilizers. Certain pesticides also contain sulfur. Gypsum is also a good source of sulfur.

Sulfur is ultimately available to the plant in the sulfate form as an anion ($SO_4$=) where it is readily assimilated by the plant and utilized in the production of plant protein. Sulfur is found in several enzymes and vitamins used in plant metabolism and is known to be important in the formation of chlorophyll.

## Carbon, Hydrogen, and Oxygen

Carbon, hydrogen, and oxygen, in the form of water and carbon dioxide, are required by all plants in macroquantities, but since we are concerned principally with chemicals absorbed from the soil, they will not be discussed further.

# Micronutrients

## Elements Required in Small Quantities

Everyone engaged in the growing of food crops should take an increased interest in the work being done on micronutrients. This research includes studies of their presence or absence in soils, their detection in the plant, but what is more important, the study of the effect of the consumption of these improved plants by the animal world in promoting better health and a higher resistance to disease.

Manifestations of certain diseases in poultry, livestock and humans can be traced to deficiencies in micronutrients, and some cases are almost entirely relieved by their addition to the diet. Iron, copper, and manganese are important performers in the building of vigorous flesh and blood. Boron and zinc with manganese are extremely important in the diet of warm-blooded animals. Some micronutrients can be added to the feed of livestock, but a well-balanced ration could much better come from the soil originally, if these factors were taken care of as needed in the fertilization program. The plant will use them if they are available, and the animal will subsequently get them from plants raised on properly-fertilized soils.

The increasing city population over the entire world and the problem of feeding these millions has alarmed quite a few citizens. The fear seems to be with the quantity of food required rather than the quality needed for proper maintenance of health. There can be no question about the ability of modern American agriculture to raise a sufficient volume of foodstuffs, but if the proper emphasis is not given to the micronutrients in the soil from which this food is to be taken, the tragedy will appear in the lack of good health and well-being of future peoples. Hidden hunger will be encountered under such circumstances even though there seems to be an adequate quantity of food for everyone.

## Manganese

The amount of manganese available to the plant is dependent upon soil pH, the quantity of organic matter present, and the degree of aeration. Manganese deficiency is most likely to occur in neutral or alkaline soils because it is less soluble at elevated pH levels. In extremely acid soils, where manganese is more soluble, toxic levels may exist which may reduce crop yields. In slightly acid sandy soils, manganese may leach past the root zone and not be available for utilization by the plant. Also, it is believed that manganese may form insoluble organic complexes in some soils that have a high humus content. Only soil or tissue tests can determine whether deficient or toxic levels of manganese exist.

Manganese is known to play an important role in many of the metabolic processes in the plant, and is required for the formation of chlorophyll in the plant.

### Iron

While the quantity of total iron in soils may be abundant, only a small fraction is available to the plant. Both solubility and mobility are the keys to iron deficiencies in the plant. Iron readily forms insoluble complexes with carbonates, phosphates, and hydroxides in the soil solution which are not available for uptake by plants. Applications of soluble iron salts such as ferrous sulfate or iron chelates can correct low iron levels in the soil; however, the crop response is generally slow and the possibility exists that the iron salts may form other complexes in the soil and render them unavailable. Fast-acting foliar sprays seem to be a more direct approach to correcting iron deficiencies. Sometimes altering the pH of the soil to a slightly acidic condition may convert some of the insoluble iron to a form where it can readily be assimilated by the plant.

Once absorbed, iron functions as a catalyst in the formation of chlorophyll and is required in many of the oxidation-reduction reactions occurring in the plant.

### Boron

Although boron exists in soils in small quantities, the complete lack of boron results in severe deficiency symptoms and reduced crop yields for citrus, beets, cotton, alfalfa, clover, corn, and many other vegetables. Boron is readily leached from the root zone in coarse textured soils found in many of the humid regions. In arid regions, boron may accumulate to toxic levels, possibly causing as much crop damage as the lack of boron.

The tolerance levels for boron are extremely narrow. It is important to monitor boron levels frequently with soil tests to maintain the optimum levels in the soil. Usually deficiencies are corrected by adding soluble borate such as borax. Boron is essential for seed germination and is required for cell wall formation, and is thought to be involved in sugar transport in the plant and is regarded as essential for protein synthesis.

### Copper

Like many other micronutrients, the amount of available copper varies considerably with the type of soil. Well-drained sandy soils are usually low in copper, while heavy clay-type soils contain an abundant supply of copper. Like manganese, copper may be unavailable in soils that have a high organic make-up because it readily forms insoluble complexes with organic compounds.

Generally from 0.2 - 25 lb/acre of copper is added to the soil to correct a deficient level. Much of the dosage is dependent upon the soil type and the source of copper compound. The soluble copper salts tend to be too mobile in the soil solution and are easily bound to other compounds.

Copper is another metal that is necessary in the formation of the chlorophyll molecule ,and like other metals, e.g., iron, manganese and zinc, acts as a catalyst.

### Zinc

As with most micronutrients, except molybdenum, the availability of zinc in soils decreases with an increase in soil pH. Some soils that are limed above pH 6.0 may show a zinc deficiency, especially in well-drained sandy soils. A nutrient interaction exists between soils that have a high phosphorus level and show a zinc deficiency even though zinc levels were sufficient. This interaction is due to the preferential uptake of phosphorus instead of zinc and the possible formation of insoluble zinc phosphates. Once zinc is applied to the soil it is relatively immobile because it is readily absorbed by organic matter in the soil.

Zinc is essential in promoting certain enzyme reactions in the soil and is required for the production of chlorophyll and the formation of carbohydrates.

### Molybdenum

Unlike micronutrients, the amount of available molybdenum (Mo) increases as the pH increases. Many sandy acid soils show symptoms of molybdenum deficiency. The problem can easily be corrected by the proper application of lime. The amount of molybdenum required by the plants is extremely small, and deficiencies are not generally found with most crops. When required, molybdenum can be applied from 0.5 to 5 oz/acre depending upon soil type and other conditions. An interaction may exist between the application of a high phosphate fertilizer and molybdenum where the levels of phosphate may enhance molybdenum uptake by the plant. A heavy sulfur application, on the other hand, may lower molybdenum uptake. Molybdenum is required for nitrogen fixation by legumes; as a result, the demand for molybdenum is higher for legumes than for other types of crops.

### Chlorine

Chlorine exists in the soil as the chloride anion ($Cl^-$). It is known to be essential for normal plant growth, however, little is known about what it does in the plant. It has been reported to interfere with phosphorus uptake. No known chloride deficiency exists in the soil, but excess chloride may reach toxic levels. Chloride presents special problems in coastal regions where the soil may be subject to salt spray or due to salt water intrusion into ground waters used for irrigation purposes.

## Trace Nutrients

### Elements required in minute quantities

### Cobalt

Lack of cobalt shows a stunted effect upon the plant growth and more particularly upon animals consuming cobalt-deficient vegetation. Pastures grown on soils deficient in cobalt produce characteristic diseases in livestock. These diseases, in practically all cases, are eliminated when the proper amounts of these materials are applied to the diet.

### Iodine

Iodine is essential to good human health and is one of the important regulators of metabolism. Most of the iodine supplied in the human body is related to the thyroid gland, and a deficiency of iodine will cause weakness and faulty growth. The supply of iodine to animals through plants is a distinct advantage in the raising of livestock.

Plants, particularly the larger leafed vegetables, absorb iodine without difficulty. Pastures treated with potassium iodide increase the iodine content of the crops sufficiently to show an improved reproduction rate in the animals consuming it. Since it is not known to be absolutely essential for the normal growth of plants, its absorption will vary with the iodine content of the soil upon which they are grown.

### Fluorine

Fluorine, undoubtedly, has some minor function in the development of certain useful compounds in plant juices. The amounts appearing in the plant are small and do not increase appreciably even when the soil may contain large amounts of the element.

The three elements iodine, chlorine, and fluorine, while not particularly essential to plant life, furnish important body-building materials for both animal and man.

### Sodium and Lithium

Sodium and lithium are two members of the family of alkali metals and their salts are among the most soluble known. Sodium is closely related to potassium and in instances where a limited potash supply in the soil is experienced, much sodium is absorbed as a plant food. Being a very soluble substance, it is extremely active in the soil water and liberates potassium and perhaps other elements which are then taken up by the plant.

The use of lithium to increase the growth of leaf tissue has been reported by some investigators, particularly in connection with the cultivation of tobacco, where it is said to greatly improve the quality of the leaf for use as a wrapper in cigar manufacturing. Both sodium and lithium are prevalent in nature in adequate quantities.

### Aluminum

Aluminum is widely distributed in nature. In some plants it appears to be toxic. The presence of soluble aluminum in the soil is of no great significance except in cases where it may be present in excess quantities. Its solubility is greatly reduced by liming such soils.

## Soil pH, Acidity, and Alkalinity

The term pH refers to the degree of effective acidity or alkalinity (basicity) of a substance. The pH scale ranges from zero to 14 with a pH value of 7.0 being neutral, i.e., neither acid nor alkaline; pH values below 7.0 are acidic and values above 7.0 are alkaline. This relationship is shown in Table 1.

The pH unit is a measure of the hydrogen ion concentration [H+], and is expressed in logarithmic terms (pH = log[H+]). The pH of a substance decreases as the hydrogen ion concentration increases. Since pH is expressed in logarithmic terms, each unit change in pH corresponds to a 10-fold change in acidity or alkalinity. For example, pH 6.0 is ten times more acidic that pH 7.0; pH 5.0 is a hundred times more acidic than 7.0, etc.

*Table 1: Relationship between pH, Acidity and Alkalinity.*

| *← Increasing Acidity* | | | *Neutrality* | *Increasing Alkalinity→* | |
|---|---|---|---|---|---|
| *pH 4.0* | *pH 5.0* | *pH 6.0* | *pH 7.0* | *pH 8.0* | *pH 9.0* |
| Strongly acidic | Moderate to strong acidity | Slight to moderate acidity | Neither acid nor alkaline. | Slight to moderate alkalinity | Moderate to strong alkalinity |
| Acidity and alkalinity compared to pH 7.0 | | | | | |
| X 1000 | X 100 | X 10 | *Neutral* | X 10 | X 100 |

A pH measurement of soil is a measure of acidity that is present in the soil solution and does not address the total acidity present in the soil. Total acidity includes the acidity of the soil solution as well as the hydrogen which is held on the soil colloid. These two forms of acidity have been broken down into two categories, active acidity (measured with a pH meter) and reserve of exchangeable acidity (acidity held on the soil colloids).

The latter form of acidity must be displaced by chemical means (generally a neutral buffered salt) before it can be effectively measured. Since these two forms of acidity are in equilibrium with each other in the soil, a pH depression will be observed as the reserve acidity in the soil increases. The reserve acidity is used in determining the amount of limestone required for optimum plant growth. Since the makeup of soils is alumino-silicates, aluminum is a major contributor to soil acidity. Therefore, the rate of lime required to achieve optimum plant growth can be determined by measuring exchangeable aluminum in the soil. Exchangeable aluminum, like exchangeable acidity, decreases with the increases in soil pH. The pH at which aluminum is rendered ineffective in generating acidity is around pH 5.5.

The pH measurement is a simple means by which the production potential of a soil can be evaluated. For example, soils in which the pH is extremely low have correspondingly low calcium and magnesium levels with high levels of exchangeable acidity. All of the above factors have adverse effects on plant growth.

In addition, at low pH levels, metal cations such as aluminum and manganese are much more soluble and can reach levels which are toxic to plants. These toxic components can be eliminated entirely by application of limestone to raise the pH. In addition to a reduction in the solubility of toxic metals, increased pH levels also enhance microbial activity within the soil.

Hence, the key to good crop production is to maintain the pH within the range where plants and microbiological activity within the soil can function at their optimum level. For most soils this requires a pH between 6.0 to 6.5. Soil pH levels higher than 6.5 can create problems with certain micronutrients, manganese in particular.

Table 1 gave a simple reference scale for the classification of soil according to pH value, which is one of the most important factors to observe in good soil management. The reaction of the soil not only has an important bearing on its bacteriological and chemical vigor, but also greatly affects the tone and characteristics of the growing plant.

In studies at the Rhode Island Experiment Station (1947) the following table was developed to show the relation of pH to yield and scabbiness of potatoes:

| *pH Range* | *%Scab* | *Bushels per acre* |
|---|---|---|
| 4.5 - 5.0 | 0.2 | 439 |
| 5.0 - 5.5 | 1.6 | 403 |
| 5.5 - 6.0 | 17.8 | 423 |
| 6.0 - 6.5 | 97.5 | 387 |
| 6.5 - 7.0 | 62.5 | 385 |

To determine the acidity of soils by the pH method, the LaMotte System employs a series of standardized indicator dyes which show distinctly characteristic color shades when added to soils of different degrees of acidity and alkalinity. Once the result is known, the grower can refer to the tables which follow and find the quantity of lime needed per acre for the various types of soil in order to properly adjust the acidity. In using these tables it will be noted that sandy soils with a pH of 5.0, for example, will require less lime than the other soils shown. This is due to the fact that as the loam and clay fractions increase, the power of soils to resist changes brought about by the addition of lime, increases. In other words, sandy soil has little power to resist the action of lime in changing its reaction and hence less lime is required to overcome this power. Sandy soil has little or no buffer capacity, whereas the loams have much greater buffer action.

This difference in the quantity of lime required for soil reaction adjustment is accounted for in the tables on the following pages.