



Managing Alaska Soils

Essential Soil Science Topics for the Commercial and Backyard Crop Producer

FGV-00043

Soils are a natural resource with diverse characteristics that influence the potential usefulness for a wide variety of agricultural, engineering and environmental practices. Understanding how to use soils to attain maximum benefit while preserving this natural resource is a prime reason for understanding the basic principles of soils.

Soil Profile and Horizons

Examining a vertical soil section in a roadside cut or in the walls of a pit reveals the presence of several more or less distinct horizontal layers. This vertical soil section is called a profile; the individual layers are called horizons.

The **“A” horizon** is the upper layer of soil. It is the topmost mineral layer, usually higher in organic matter, more biologically active and darker in color than underlying horizons.

The **“E” horizon** is the subsurface layer found directly under the A horizon. This is the layer where maximum leaching, or eluviation, of clay, organic matter, iron and aluminum oxides occurs. Development of this horizon leaves a concentration of resistant minerals, such as quartz, in the sand and silt size fraction. The E horizon is lighter in color than the A or B horizon.

The **“B” horizon** is the subsurface layer in which illuviation (accumulation) of materials takes place from above or even below. It contains much of the clay, organic matter, iron and aluminum oxides that leach from the E horizon. It usually contains less organic matter and more clay, and is brighter in color than the A horizon.

The **“C” horizon** is the unconsolidated material underlying the solum (A, E and B) and is called the soil parent material or the substratum.

The soil profile depth, type and components are used in classifying soils and predicting their value for crop production or other uses.

Soil Components

Mineral soils consist of four major components that include organic matter, mineral particles, air and water. The impact of one component is seldom independent of the others. Organic matter, by binding mineral particles into clusters, increases the number of large soil pores, thereby influencing water and air relationships.

Organic Matter

Soil organic matter is made of partially disintegrated and decomposed plant and animal residues plus other organic compounds synthesized by soil microbes as decay occurs. It binds mineral particles into aggregates that are largely responsible for the loose, easily managed condition of productive soils and increases the soil water-holding capacity.

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In addition to the original plant and animal residues, soil organic matter contains complex compounds relatively resistant to decay. These materials contain living and dead soil microbes plus resistant organic crop residues such as lignin, and are referred to as soil humus. Humus is very fine (colloidal) in nature and usually black or brown in color. Its adsorptive capacity to hold water and nutrient ions greatly exceeds that of clay. Small amounts of humus remarkably increase the soil's capacity to promote plant growth through their effect on the chemical, biological and physical properties of the soil. Humus serves as a storehouse of readily available major nutrients, secondary nutrients and micronutrients.

Organic material makes up less than 10 percent of most soils, yet it is extremely important in terms of plant nutrition. Organic matter has a tremendous amount of surface area that can react with various soil constituents, and it may impart a large influence on soil chemical properties. In addition, because organic matter is composed largely of decayed plant material, it contains plant nutrients which may become available for use by growing plants as the organic matter is decomposed. Thus, the bulk of several nutrients, including nitrogen (N), phosphorus (P), sulfur (S), molybdenum (Mo), copper (Cu), zinc (Zn) and boron (B), may be contained in the organic fraction of a soil. As a result, the available levels of these nutrients are affected by the processes of organic matter decomposition. Organic matter decomposition is dependent upon adequate aeration and moisture and increases with increasing soil temperature. This process is also accelerated when organic matter is incorporated into soil by tillage operations. (See Extension publication FGV-00349, *Organic Fertilizers*.)

Mineral Materials

Mineral particles are separated into groups by sizes that are referred to as soil separates. Clay (<0.002mm), silt (0.002 to 0.05mm), sand (0.05 to 2mm) and gravel (>2mm) are the classifications established by the U.S. Department of Agriculture for soil separates. Minerals that persist with little change in composition since they were formed in molten lava (e.g., quartz, micas, feldspars) are known as primary minerals. They are most prominent in the sand and silt fractions. Other minerals, such as silicate clays and iron oxides, are formed by the breakdown and weathering of less resistant minerals as soil formation progresses. These minerals are called secondary minerals and tend to dominate

the clay and, in some cases, the silt fraction. The colloidal clay and humus particles are important in soils because they hold charged nutrient ions that are available for plants.

Air

Plant roots must have oxygen in order to respire and function normally. Adequate soil aeration is very important in maintaining the best growth and production. Soils with a high proportion of tiny pores tend to be poorly aerated and water-dominated. Water content of soil largely determines the content of soil air since the air occupies the soil pores not filled with water. Soils are roughly 50 percent pore space and 50 percent solids. If the gas exchange between the soil and atmosphere is limited by inadequate aeration, oxygen is depleted and carbon dioxide accumulates from respiration by roots and microorganisms.

Water

Water is held in the soil pores with varying degrees of tightness, depending on the amount of water present and the size of the pores. Together with its soluble parts, including nutrient elements (e.g., calcium (Ca), potassium (K), N and P), soil water makes up the soil solution, which is the critical medium for supplying nutrients to growing plants. An important property of the soil solution is its acidity or alkalinity, or the relative level of hydrogen ions (H^+) and hydroxide ions (OH^-) in the soil. Soil solution acidity, or pH, influences the solubility and, in turn, the availability of several essential nutrient elements, such as iron (Fe), manganese (Mn), P, Zn and Mo, to plants.

The tension or suction with which water is held by soil particles is referred to as soil moisture tension. One unit of expression is the atmosphere (normal atmospheric pressure at sea level), 14.696 lb in². The metric term "bar" is also used; 1 bar is equal to 14.5 lb in². Since bar and atmosphere are essentially the same, they can be used interchangeably for most purposes. The greater the amount of water in a given soil, the lower the soil moisture tension. At the same soil moisture tension, a clay soil holds more water than a sandy soil.

Field tensiometers can be used successfully to measure this tension and determine the need for irrigation. The tensiometer is filled with water, then placed in the soil. Its effectiveness is based on the principle that water in the tensiometer is drawn through a fine porous cup into the soil until equilibrium is reached. At this equilibrium, the tension in

the soil is the same as that in the tensiometer, which is measured by a vacuum gauge above the soil surface.

Water in excess of the field capacity is termed “gravitational.” Gravitational water is of limited use to plants because it is present in the soil only for a short time. While in the soil, it occupies the larger pores, thereby reducing soil aeration. Removing gravitational water from the soil by draining is generally required for optimum plant growth.

During and immediately following a heavy rain or irrigation, pores in the upper soil zones are often filled entirely with water. After a soil has been saturated, moisture will continue to drain away for 24 to 48 hours, after which the soil is at *field capacity*. Field capacity (□ atmosphere) is considered to be the upper limit of available water for plant use. A soil moisture level where a plant cannot regain turgidity in a saturated atmosphere is called the *permanent wilting point* (15 atmospheres). This is considered the lower limit of available soil moisture for plant use. The amount of water in a soil at field capacity and permanent wilting point is a function of soil texture.

Capillary water exists in films around and among soil particles at soil moisture tensions from about □ bar to 31 bars. Essentially all the water taken up by plant roots is capillary water. Capillary forces are at work in all moist soils. Capillarity is due to two forces: (1) the attractive force of water for the solids on the walls of channels through which it moves (adhesion or adsorption) and (2) the surface tension of water, which is due largely to the attraction of water molecules for each other (cohesion).

Hygroscopic water exists as a thin layer around soil particles bound very tightly at tensions greater than 31 bars. It is essentially nonliquid and moves primarily in vapor form. Higher plants cannot absorb hygroscopic water, but some microbial activity has been observed in soils containing only hygroscopic water.

Soil Texture

Soil texture is determined by the relative amounts of various-sized particles that make up a soil. Soil particles are divided into three size categories. The smallest or

finest is clay, followed by silt, and the coarsest or largest particle category is sand. The proportions of sand, silt and clay in the mineral or inorganic portion of a soil determines its texture. There are 12 soil textural classes ranging from sand, which is the coarsest class, to clay, which is the finest. Loamy sand, sandy loam, silt loam and clay loam are common soil textural classes with progressively finer particles. The texture of a soil affects its physical properties (how much water it holds, how difficult it is to till, etc.) as well as its chemical properties. In general, a fine-textured soil has more particle surface area than a coarse-textured soil per given volume of soil. The surfaces of soil particles are chemically active. Fine-textured soils are more chemically active than coarse-textured soils and are able to hold more nutrients; they also have a greater capacity to bind or “fix” nutrients, rendering them unavailable to the plant.

In the field, texture can be determined by the feel of a moist soil sample when rubbed between the thumb and fingers. To determine the textural classification of soil based on the percent of sand, silt and clay, see Figure 1. The percentage of sand, silt and clay may be plotted on the soil textural triangle to determine the textural class of that soil. Example: a soil containing 13 percent clay, 41 percent silt and 46 per-

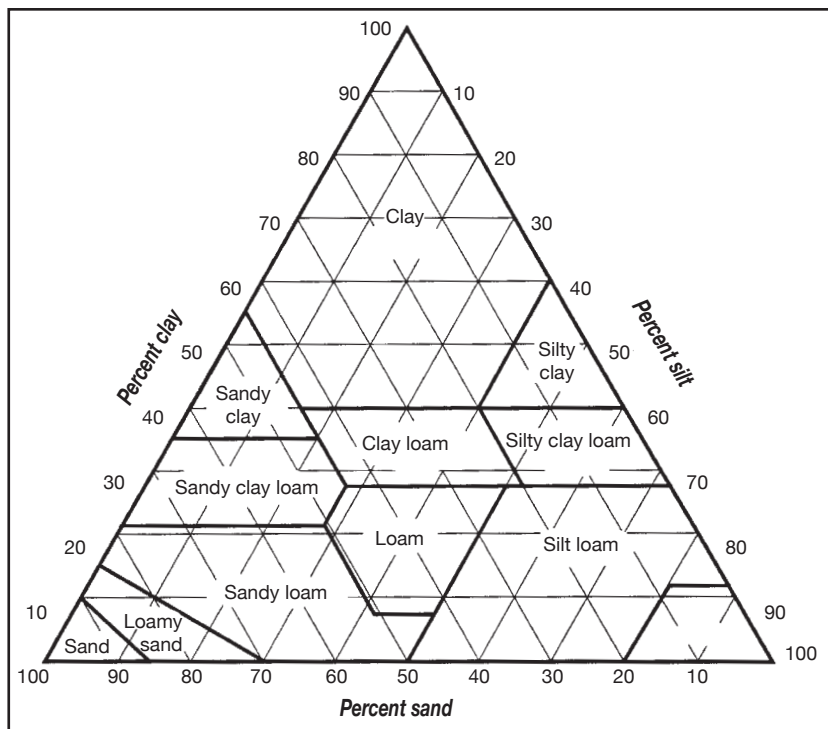


Figure 1. Soil textural triangle (from Brady, N. C. 1990. *The Nature and Properties of Soils*. New York: MacMillan).

cent sand would have a loam texture. Some physical characteristics of the basic textural grades are listed below.

Sand

Sand is coarse and single-grained, and the individual grains can be felt or seen. Squeezed between the thumb and the fingers when moist, it will form a cast, but will crumble when touched. A ribbon will not form.

Sandy Loam

A sandy loam contains mostly sand but has enough silt and clay to make it somewhat cohesive. If squeezed when moist, it will form a cast which will withstand careful handling without breaking; however, a ribbon won't form.

Loam

An ideal loam is a mixture of sand, silt and clay particles that exhibits the properties of those soil separates in about equal proportions. Neither grittiness nor smoothness predominate. A weak ribbon less than 1 inch forms before breaking.

Silt Loam

In a silt loam, over half of the particles are silt size (0.002 to 0.05 mm), with a moderate amount of sand and only a small amount of clay present. When dry and pulverized, it feels soft and floury. When moistened and squeezed between thumb and finger, it will only form a ribbon (less than 1 inch) with a broken appearance that barely sustains its own weight. If moist and kneaded in the hand, it tends to work into a heavy, compact mass.

Clay

A clay soil must contain at least 35 percent of the clay separate, and, in most cases, not less than 40 percent. A clay usually forms very hard lumps or clods when dry, and it is quite plastic and usually sticky when wet. It will form a long, flexible ribbon.

Peat Soil

Peat soil is composed of more than 50 percent organic matter; it is slightly decomposed but highly fibrous, with easily recognizable plant remains.

Muck Soil

Muck soil is an organic soil containing highly decomposed organic matter in which the original plant parts are not recognizable. It contains more mineral matter and is usually darker in color than peat soil.

Soil Structure

Soil texture is important, but by no means does it provide enough information to assess potential soil productivity. Structure is also valuable as it relates to the grouping or arrangement of soil particles. A soil profile may be dominated by a single type of structure. More often, however, several types are encountered in the different horizons. Structure describes the gross, overall combination of the primary soil separates into secondary groupings called aggregates or peds. Soil conditions and characteristics such as water movement, heat transfer, aeration and porosity are influenced by structure. The important physical changes imposed by a farmer on land are structural rather than textural. Texture is a permanent soil property that cannot be altered; structure can be changed by plowing, cultivating, draining, liming or manuring soil.

The four principal types of soil structure are spheroidal, platy, prismatic and blocklike. Two forms of a structureless condition are recognized: single grain (particles are easily distinguishable) or massive (individual particles adhere closely to each other, but the mass lacks planes of weakness).

Spheroidal (granular and crumb subtypes)

This category includes rounded peds or aggregates that usually lie loosely and are separated from each other. Nonporous aggregates are classified as granular; porous granules are classified as crumb. Granular and crumb structures are characteristic of many surface A horizons, particularly those high in organic matter, and are subject to wide and rapid changes.

Platylite

Platylite aggregates are arranged in horizontal plates, leaflets or lenses. These structures may occur in any part of the soil profile and at times are inherited from the parent materials.

Prismatic (columnar and prismatic subtypes)

These structures are characterized by vertically oriented aggregates or pillars that can vary in height and may reach a diameter of 15 cm or more. Prismatic structures are usually found in the B horizon, commonly in soils of arid and semiarid regions. When the tops of the prisms are rounded, the term "columnar" is used. The structural pattern is prismatic when the tops are level and clear cut.

Blocklike (blocky and subangular blocky subtypes)

These aggregates have been reduced to blocks, irregularly six-faced with their three dimensions more

or less equal. The fragments range from 1 to 10 cm in thickness. When the edges of the cubes are sharp and the rectangular faces distinct, aggregates are called blocky. If subrounding has occurred, the aggregates are subangular blocky.

The spheroidal and blocklike structures, particularly granular and blocky types, are desirable for crop production. Organic matter is the major agent that stimulates formation and stabilization of granular and crumb-type aggregates. Plant roots excrete sticky organic chemicals that help bind the soil particles together into aggregates. Microbial decomposition of plant residues produces other organic materials that interact with clays, cementing aggregates together. Thus, organic materials stimulated by microbial processes not only enhance the formation of soil aggregates but also help assure their stability. (See Cooperative Extension publication FGV-00349, *Organic Fertilizers*).

Water Permeability

Structural characteristics most commonly associated with each of the classes of permeability.

Permeability Class (inches/hour)	Type of Structure	
Very slow Slow	0.06 0.06–0.2	Columnar angular, blocky Prismatic, platy angular, blocky
Moderately slow	0.2–0.6	Prismatic, platy angular and subangular blocky
Moderate	0.6–2.0	Prismatic, platy angular and subangular blocky
Moderately rapid	2.0–6.0	Subangular blocky, granular
Rapid	6.0–20	Subangular blocky, single grain
Very rapid	20	Single grain

Bulk Density

An important soil weight measurement is bulk density or the weight of dry soil per unit of bulk volume, including the air space. Silt loams, clays and clay loams generally have lower bulk densities of 1.00 to 1.60 g/cm³. Higher bulk densities occur where essentially no macropores exist, which greatly impairs root growth. Adding crop residue or manure tends to decrease bulk densities of surface soils. In the lower soil profile layers, bulk density is generally higher than in surface horizons, apparently resulting from lower organic matter content, less aggregation and root penetration, and compaction from overlying layers.

pH and Lime Requirements

Reaction, or pH, describes acidity or alkalinity of an aqueous system. Water (H₂O) is comprised of charged hydrogen (H⁺) and hydroxide (OH⁻) molecules or ions. In water there are always some of these free ions that are not combined in the water molecules. If water is pure, the amounts of H⁺ and OH are equal and the system has a pH of 7.0. This system is considered neutral. If a system has an excess of H⁺ ions, it is acidic, and if there is an excess of OH⁻ ions, it is basic, or alkaline. pH is simply a measure of the amount of H⁺ ions in a system, but it is presented as the negative log of the H⁺ concentration. Concentration is expressed in moles per liter (one mole equals 6.02 x 10²³ molecules). Therefore, the relationship is:

pH	4	5	6	7	8
H ⁺ concentration (moles/liter)	.0001	.00001	.000001	.0000001	.00000001

The H⁺ concentration is greater at lower pH values, and diminishes as pH rises. The concentration of H⁺ ions changes by a factor of ten for each change of one pH unit. The pH scale runs from 0 to 14, although the range found in natural soil systems is about 3.5 to 9.0.

pH – Acid Forming Factors

Soils become more acid when excess H⁺ and aluminum (Al³⁺) ions replace basic cations such as Ca²⁺, magnesium (Mg²⁺), K⁺ and Na⁺ on the surface of clays and soil humus. Cations are positively charged ions and anions are negatively charged ions. The basic cations are often leached below the root zone, leaving H⁺ and Al³⁺ behind because they are more strongly attached to the negative charges on the soil surface.

There are various reasons soils become more acid. The slow but persistent solvent action of carbonic acid (H₂CO₃) on mineral constituents in the soil is responsible for removing many base-forming cations (Ca²⁺, Mg²⁺) by dissolution and leaching. Carbonic acid is a product of the reaction of carbon dioxide and water. Microbial decay plus exudates and excretions from plant roots produce organic acids that increase soil acidity. Crop removal takes away base-forming elements such as Ca and Mg from the soil. Wind and water erosion can carry away the fine particles of humus and clay containing adsorbed base-forming elements, leaving more acid silt and sand. Bases leaching from the root zone by the downward

percolation of rain and irrigation waters can also influence soil acidity. Acid precipitation caused by sulfuric and nitric acids formed in the atmosphere over industrialized and heavily populated areas is another consideration. Additionally, most common nitrogen fertilizers, monoammonium phosphate and diammonium phosphate are acid-forming.

pH – Base-Forming Factors

Any process that will encourage high levels of the exchangeable base-forming cations (Ca^{2+} , Mg^{2+} , K^+ , Na^+) will contribute toward an increase in alkalinity. Weathering may release these exchangeable cations from minerals, making them available for adsorption. Liming acid soils increases the supply of base-forming cations. The content of irrigation water should be considered because salts of these cations in the water can be adsorbed by soil colloids to increase soil alkalinity. Recycling of cations by deep-rooted plants as they bring them to the surface and incorporate them in the topsoil can raise the pH of soils.

When the pH of a soil is too high, deficiencies of Fe, Mn and other micronutrients occur. If sodium (Na) is the dominant cation, plant growth can be negatively affected because of high pH as well as the dispersal of soil particles with few micropores present.

pH – Effects on Alaska Soils

Soil acidity is important because it determines solubility of soil minerals, and it affects many microbial processes such as organic matter decomposition and nitrogen fixation. Some soil minerals contain nutrients, and these nutrients may become available for plant growth only when the soil pH is in a favorable range. Additionally, some soil minerals contain elements that are toxic to plants. Primary among these elements is Al, which is a major constituent of all mineral soils. Aluminum may be released when soil pH is allowed to drop below pH 5.2, and many plants will not grow well when soil pH drops below this level. The general relationship between soil pH and nutrient availability is shown in Figure 2. The widths of the bands represent the relative availability of each nutrient. Note that availability of most of the nutrients is maximized in the pH range of 5.5 to 6.5. This is the optimum pH range for many cultivated plants, although the optimum pH level for various plants may differ widely.

When samples are taken frequently or at various times of the year, it is often noted that pH values tend to increase and decrease, seemingly at random. This leads many to question the validity of soil pH

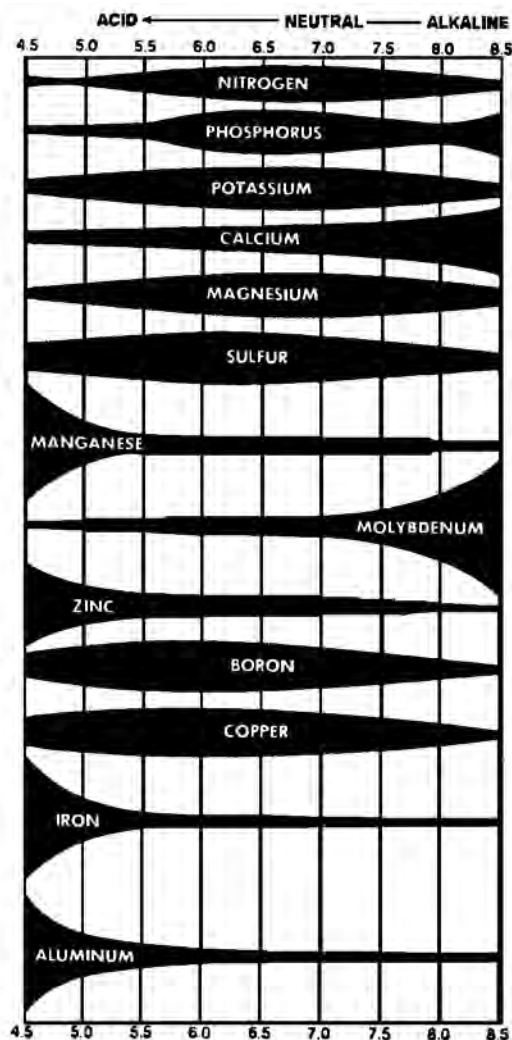


Figure 2. Relationship of soil pH and nutrient availability (from Schulte, E.E. and K.A. Kellig. 1984. Aglime, Key to Increased Yields and Profits. University of Wisconsin Cooperative Extension Service Publication A2240).

measurements, but the fluctuations are often due to changes in salt levels. This does not usually present a serious problem in the use of the analysis. Some laboratories measure pH in a dilute salt solution to mask salt-induced variations. This method gives lower pH values, and the laboratory should provide interpretation guidelines.

Most soils in Southcentral Alaska, in their unlimed condition, have a pH lower than 7.0 (pHs as low as 4 are not uncommon). Some soils in the Interior are neutral to slightly alkaline. Soil pH may be adjusted by the addition of liming materials (to raise pH) or acidifying materials (to lower pH). Plants generally increase soil acidity as they grow. Additionally, many N fertilizer materials add considerable acidity

to soils. Therefore, most corrective action is undertaken to raise pH rather than to lower it. Liming materials are generally calcium oxides, hydroxides or carbonates, which combine with H^+ ions to decrease acidity. All are adequate for liming agricultural soils.

Most commercial lime is simply crushed limestone and may be either dolomitic or calcitic. Dolomitic lime is a mix of Ca and Mg carbonates, while calcitic lime refers to Ca carbonates. Application of dolomitic lime may be desirable where Mg supply is insufficient for crop production.

Since lime is fairly slow to react in soil, recommended amounts should be applied as early as convenient; lime may be applied one to two years before needed for a crop to ensure optimum reaction time. However, some benefit is realized the year of application. Hydrated lime or quick lime will react more rapidly than crushed limestone. One of the best methods of application is to broadcast the lime and thoroughly mix it with the soil during tilling. The better the soil contact with the lime and the finer the lime particles, the quicker soil acidity will be neutralized. (See Extension publication FGV-00348, *Field Crop Fertilizer Recommendations for Alaska: Fertilizer Nutrient Sources and Lime*).

Soils may be acidified by adding elemental S or by direct application of acidic materials such as sulfuric acid (H_2SO_4), aluminum sulfate ($Al_2(SO_4)_3$) or ferrous sulfate ($FeSO_4$). Elemental S produces acidity as it is converted to sulfuric acid by soil microbes. The microbial transformation to sulfuric acid is slow, and elemental S should be applied well in advance of the growing crop. Extreme care should be taken when acidifying soils, since it is easy to reduce soil pH to undesirable levels.

Electrical Conductivity

Salts accumulate in some surface soils from the weathering of rocks and minerals, rainfall, ground waters and irrigation. Once deposited or released into the soil, the salts can be brought to the surface by the upward movement of water, which evaporates, leaving the salts behind. The salts are primarily chlorides and sulfates of Ca, Mg, Na and K. High levels of these salts cannot be tolerated by most crops.

Electrical conductivity (EC) can give an indication of the salt levels. This is determined by measuring the ability of saturated soil to conduct electricity. The more salt in a solution, the higher the EC. Electrical conductivity is expressed as millimhos

per centimeter (mmho/cm) or decisiemens per meter (ds/m); 1 ds/m = 1 mmho/cm. Most crops perform best if the EC is below 1.5 mmho/cm, although salinity tolerance varies with crops.

Cation Exchange Capacity

The nutrient-holding capacity of the soil is largely determined by the cation exchange capacity (CEC). Soil colloids with negative charges attract and hold cations (e.g., Ca^{2+} , Mg^{2+} , K^+ , Na^+ , Al^{3+} , NH_4^+ , H^+). Humus can hold cations in much the same way as clay minerals because of the negative charges on the humus particles. The clay and humus account for most of the CEC, but finer fractions of silt can have a limited number of exchange sites. The CEC is expressed as milliequivalents (meq) of positive charge that can be held (adsorbed) by 100 grams of soil (oven-dry basis) or as centimoles of positive charge per kilogram of soil (cmol/kg); 1 meq/100g = 1 cmol/kg. Sandy soils have a lower CEC than clay soils because the coarse-textured soils are commonly lower in clay and humus content. The texture and organic matter of a soil influence the CEC. The CEC of a loam or silt loam soil could range from 10 to 25 meq/100g.

All higher plants require at least 17 nutrient elements for proper development. Of these, three (carbon, hydrogen and oxygen) are provided by air and water, and the remaining 14 are usually provided by the soil. Six of the 14 elements normally provided by soil are required by growing plants in relatively large amounts and include N, P, K, Ca, Mg and S. The first three (N, P and K) are called primary plant nutrients because they are most commonly limiting in agricultural situations. A complete fertilizer contains the three primary nutrients. The others — Ca, Mg and S — are just as important for normal plant growth but are called secondary nutrients because they are less frequently limiting to crop production than the primary nutrients.

The remaining plant nutrients — B, chlorine (Cl), Cu, Fe, Mn, Mo, nickel (Ni) and Zn — are required in relatively small amounts and are called micronutrients. Plants may contain levels of some micronutrients as high as the primary and secondary nutrients, but the minimum required micronutrient level is generally much lower. Again, these nutrients are just as critical to normal plant growth as the primary and secondary nutrients.

Primary Nutrients

Nitrogen (N)

Nitrogen is one of the more difficult nutrients to analyze. This is because a major portion of soil N may be contained in the soil organic matter. Availability of organic N is dependent on breakdown of organic matter, which is difficult to estimate. Without knowing what soil temperature and moisture is going to be in the future, a prediction of N release from organic matter is no more than a guess. The amount of inorganic N in soils (that which is not contained in organic matter) is fairly easy to determine. However, it may be quickly converted between N forms and is easily lost from the rooting zone of the soil. There is no way to relate inorganic N present in a fall sampling to that which may be present in the spring. An accurate determination of the N available to plants at the time of soil sampling can be made, although even this may not provide reliable information concerning an entire growing season. If soil N analysis is to be used for making fertilizer recommendations, it is important that the sampling be done either shortly before planting time or during the growing season.

A soils laboratory can analyze soil for either total or inorganic N. The total N analysis is not particularly useful for agricultural purposes. Inorganic N analysis provides a measure of N at the time of sampling, but remember, if a soil is overirrigated or if a heavy rainfall occurs, much of this N can be lost, and a re-evaluation of N status may be required.

Nitrogen is generally required in larger amounts than any other plant nutrient. It may be taken up in two forms, nitrate and ammonium. Nitrate (NO_3^-) is an anion, or negatively charged molecule, while ammonium (NH_4^+) is a cation, or positively charged molecule. Because of their charges, these two forms of N behave very differently. Soil particles and soil organic matter generally have a negative charge; therefore they attract positively charged cations and repel negatively charged anions, much like the positive and negative responses observed when two magnets are put together. Nitrate (negative charge), which is not held by soils, is easily lost through leaching, while positively charged ammonium is not. When ammonium fertilizers are applied, soil bacteria can convert the N to nitrate in a process called "nitrification." The rate that nitrification takes place is largely dependent on soil temperature and occurs mainly in the summer months. In waterlogged soils, nitrate may be converted to several gaseous forms of N and lost to the atmosphere. To avoid N loss due to gaseous loss or

leaching, N-containing fertilizers should not be applied in the fall. Most plants are not particular about the form of N they take up, and since the various N forms are easily converted in the soil, the choice of N fertilizer material is usually based on cost.

Roughly 95 percent of soil N is found in the organic material in unfertilized soils. In these situations, organic matter decomposition is critical to N nutrition of plants. Nitrogen applied in inorganic fertilizers is generally very soluble and may be subject to loss by leaching if excessive rain or irrigation is present. However, N moves to plant roots largely through the flow of water. Therefore, providing adequate water for crop plants is critical to maintaining a satisfactory N supply.

Some plants, including legumes and alders, can "fix" N from the atmosphere. Although our atmosphere is 78 percent N, higher (vascular) plants can not directly use this gaseous form of N. It must be captured by microorganisms and converted into usable forms first. This process is carried out to a small extent by free-living soil microorganisms, but it occurs primarily in bacteria growing in conjunction with legumes, alders and a few other higher plants. The bacteria live in lumps of root tissue, called nodules, in the host plant, receive carbohydrates from the host plant and provide "fixed" N in exchange. In legumes properly inoculated with N-fixing bacteria, this process can supply all the N the host plant requires. It may provide enough to supply part or all of the N for a subsequent crop as well.

Phosphorus (P)

Phosphorus is tightly bound to soil particles in many soils. The amount removed during soil extraction is very dependent on soil type and on the specific extractant used. Most laboratories use only a single type of extractant regardless of the type of soil being analyzed. In Alaska, where there are tremendous differences in the P-fixing capacities of various soils, it is difficult for one extractant to accurately evaluate plant-available P in all soils. The extractant currently recommended for an accurate soil analysis of P is called Mehlich-3 extractant, and is the best for a wide range of conditions (see UAF AFES Circular 81, *Relating Mehlich-3 extractable P to Morgan and Bray I extractable P for Alaska Soils*). However, the optimum P soil test value varies substantially in Alaska soils, requiring separate interpretation for each soil type. Phosphorus analysis is one of the most reliable and useful soil tests.

In contrast to N, P is very insoluble in soil systems. Maintaining proper soil pH is critical to providing adequate P for optimum plant growth. When soil pH drops below 5.0 to 5.5, Al becomes soluble and will bind P, making it less available for plant use. Alternatively, if soil pH is above 7.5, Ca may bind P, rendering it less available to crops. Within the range of pH 5.0 to 7.5, P solubility is maximized, but it is still low compared to the other primary and secondary nutrients.

Some types of soil minerals have a very strong affinity for P molecules. Primary among these are volcanic ash particles, which predominate in many Alaska soils, particularly in the Kenai and Susitna Valley areas. In these soils, large amounts of fertilizer may be necessary to provide adequate P. Organic matter decreases the ability of soil mineral particles to fix or bind P, so adding organic materials may reduce the P requirement of volcanic ash soils. Another method of reducing the P requirement in P-fixing soils is to apply P fertilizer in a concentrated band to minimize its contact with soil mineral particles and thus decrease fixation.

Potassium (K)

Although the total amount of K in most soils is quite large, a relatively small portion is generally available for plant growth. Most K is held as part of the soil minerals structure or inside layered clay particles, and it may become available very slowly. The release of K from K-bearing minerals is usually not sufficient for crop plants.

Potassium is held tightly enough to soil particles that K fertilizer may be applied in the fall or spring in all but the sandiest soils. In very sandy soils, K fertilizers should be applied only in the spring.

Potassium availability is not strongly affected by soil pH. However, K uptake by plants can be limited if soil moisture is insufficient. Potassium management consists largely of maintaining soil K levels and providing adequate water to the growing crop. A large amount of K can be taken up by crop plants, and this must be replaced by inorganic or organic fertilizers.

Secondary Nutrients

Calcium (Ca)

Calcium is the dominant positively charged molecule in nearly all soil systems except those with a very low pH. In soils with a pH above about 4.8, Ca is usually present in amounts adequate for crop

growth. In acid soils, however, Ca is subject to leaching, and native Ca levels may be low. This situation can be corrected by using a liming material.

Even when soil Ca levels are satisfactory, supply to growing plants may be interrupted if adequate water is not provided. Calcium moves with water in a plant, and if water flow is interrupted during the formation of certain plant tissues, localized Ca deficiencies may occur. This can result in disorders such as tomato blossom end rot, tip burn in lettuce, cabbage and strawberries, and bitter pit of apples. These and related disorders are more often the result of drought and other plant stresses than of inadequate soil Ca availability.

Magnesium (Mg)

Magnesium is positively charged and, like Ca, is most likely to be deficient in low pH soils. Under acidic conditions, Mg is very soluble and may be lost due to leaching. If an acidic soil is limed with a material that contains little or no Mg, a deficiency of this nutrient may result. When liming a very acid soil (below pH 5.2), it is a good practice to use a liming material that contains Mg or to monitor soil Mg levels closely.

Magnesium and K compete for uptake by plant roots. Plants growing in soils with very high levels of K may exhibit Mg deficiencies when soil Mg is low. This situation can occur in sandy soils that are overfertilized with K, particularly if the soils have been limed with a calcitic material.

Magnesium can be added in fertilizers as well as in liming materials. Using a Mg fertilizer may be desirable where inexpensive sources of calcitic limes are available or where the soil pH level is adequate. Magnesium is held tightly by negatively charged soil particles and can be applied at any time of the year.

The analyses for available K, Ca and Mg are quite reliable. The Mehlich-3 extractant is recommended, although other extractants also produce acceptable results. The main difficulty that may be encountered is when Ca or Mg analyses are conducted on soils with undissolved Ca- or Mg-containing materials. This may be the case if a coarse liming material has recently been applied or in very high pH soils. In these situations, the analytical results may indicate a higher level of plant-available nutrient than actually exists. This is not usually a problem, and K, Ca and Mg tests usually provide excellent estimates of plant available levels of these nutrients.

Sulfur (S)

Sulfur is taken up by plants as the negatively charged sulfate (SO_4^{2-}) molecule. Because it is a negatively charged molecule, or anion, sulfate may be easily leached from the soil. Most S, however, is not present in soil in the anionic form but is tied up in soil organic matter. Sulfur availability, therefore, is controlled largely by the amount and rate of organic matter decomposition. In most soils, adequate S for crop plants is supplied through this process and through rainfall.

In soils with a marginal S supply, insufficient S may be taken up by crops to induce S deficiencies. Crops with pungent sap (onions, cabbage, broccoli) generally have high S requirements. Sulfur may be supplied in many complete fertilizers or may be applied in materials like gypsum (CaSO_4) or elemental S. If elemental S is used, it must be converted to the sulfate anion before being used by the plant. This conversion process produces considerable quantities of acidity. Elemental S is used as a soil acidifying agent more often than as a S fertilizer source.

Micronutrients

Several micronutrients, including Mn, Zn, Fe and Cu, behave similarly. As soil pH increases, the solubilities of these micronutrients decrease. Therefore, deficiencies of these nutrients are most common in high-pH soils.

Even when plants exhibit deficiencies of these four nutrients, they are usually present in the soil in substantial quantities. However, they are unavailable for plant growth because of unfavorable soil conditions, usually high soil pH. Adding fertilizer may not correct the deficiency, because added nutrients will quickly become unavailable as a result of the soil's condition. There are two ways to address this problem. One way is to correct the underlying problem, i.e., acidify the soil if it is too alkaline. The other is to add the nutrient in a "chelated" form, which is more readily available to plants. Chelated micronutrients are complexed with a material that increases the solubility of the nutrients, which reduces the degree of fixation by soil minerals and organic matter. In addition, all micronutrients can be applied as foliar sprays. This is a very effective way of applying micronutrients to growing crops, but it does not address the soil problem. Deficiencies will likely occur in subsequent crops.

Manganese (Mn)

In addition to the effects of soil pH described above, Mn solubility is affected by soil water content. Under waterlogged conditions Mn becomes very soluble and can reach toxic levels. This is most likely to occur in acidic soils with pH levels less than 5.5, although it can happen even when soils are not very acidic. Manganese toxicity can also occur when soils are steam sterilized and is a frequent problem in greenhouse production.

Well-drained, high-pH soils are most prone to Mn deficiency. Manganese deficiency can be induced when acidic, low-lying sandy soils are limed to pH levels above 6.5, or when wet, sandy soils are drained.

Zinc (Zn)

Soil acidity is the primary factor affecting Zn availability. Zinc deficiency occurs in moderate- to high-pH soils and may be more pronounced if soil P levels are high. Zinc deficiency may occur in soils with a pH of 6.0 to 7.0 if they are overfertilized with P. Zinc deficiency is most likely to be found on sandy or high organic matter soils.

Iron (Fe)

Iron deficiencies occur only in high-pH soils. In soils with high pH, most of the Fe is insoluble and therefore unavailable to plants. Reducing the pH with elemental S or some other acidifying agent will correct the problem by solubilizing the Fe in the soil.

Copper (Cu)

Copper solubility also decreases as pH levels increase. Therefore, Cu deficiency can occur in soils with pH levels above 7.5. In contrast to Mn, Zn and Fe, Cu is tightly bound by soil organic matter. As soil organic matter content increases, Cu availability decreases. In some soils with large amounts of organic matter, Cu can be deficient when soil pH is 5.5 or below.

Molybdenum (Mo)

Higher plants require Mo in extremely small amounts. Molybdenum behaves very differently from most other micronutrients. The most common form of soil Mo is anionic, which can be easily leached from sandy soils. Molybdenum is most soluble at high pH levels and is most likely to be deficient in acidic sandy soils. However, Mo deficiencies are sometimes found in moderate-pH, fine-textured soils. This generally occurs where the par-

ent material is low in Mo. Molybdenum is essential to N fixation by legumes, which are very sensitive to Mo deficiencies. The crucifers (broccoli, Brussels sprouts, cauliflower, canola and the forage rapes) all have a high Mo requirement. These plants are sensitive to low Mo levels and also remove substantial quantities of Mo from the soil when harvested.

Boron (B)

Boron is present in soils as an uncharged molecule that is held weakly by various mineral and organic soil constituents; it can be easily leached, particularly from sandy soils. Boron availability is affected by soil pH. It may become unavailable to plants when soil pH is above 6.5.

The crucifers and most of the legumes have high B requirements. The difference between deficient and toxic levels of B is small. Many crops, including cowpeas, lupines, onions and strawberries, are susceptible to B toxicity.

Chlorine (Cl)

Chlorine is rarely deficient in agricultural soils. In fact, there are more problems with excess Cl in saline soils than with deficiencies. The functions of Cl are poorly understood, but it appears that Cl is involved in plant tolerance to both cold and drought. Chlorine deficiencies may also be involved in disease susceptibility (for example, in take-all root rot of wheat in the Pacific Northwest). Adequate Cl is provided by rainfall, air pollution and various fertilizer materials, in most situations.

Soil Analysis

After soil samples are received at a laboratory, a number of tests can be performed. A general understanding of soil testing will help one know how the results can be interpreted and appreciate the accuracy of the analytical results.

Soil supplies most of the mineral nutrition for higher plants through the plant's root system. The root system extracts nutrients from the soil over a long period of time, two to three months for most annual crops, several years for perennial crops. A soil test determines the soil's nutrient-supplying capacity by shaking a soil for a few minutes with a very strong extracting solution (usually a strong acid or a combination of acids). The soil reacts with the extracting solution, liberating some of the nutrients. The solution is filtered and analyzed to determine the concentration of each nutrient. The nutrient concentration is then related to field calibration research that

indicates the yield level reached with varying soil nutrient concentrations. This method works quite well for some nutrients but is less accurate for others, particularly those supplied largely from organic matter decomposition. This is primarily due to the difficulty of estimating or predicting breakdown rates of organic matter.

Standard or routine soil tests vary from laboratory to laboratory, but all include soil pH and available P and K. They sometimes also include available Ca, Mg and lime requirement, and often include an analysis of organic matter content and soil texture. Some laboratories offer analyses of N, S, micronutrients, and soluble salts.

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This publication replaces the following Extension publications: Soil Fundamentals by C.L. Johnson, former Extension Assistant, Palmer Research Station, University of Alaska Fairbanks and Soil Fertility Basics and Soil Sampling and Analysis by J.L. Walworth, former Soil Scientist, Agricultural and Forestry Experiment Station, Palmer Research Center, University of Alaska Fairbanks.

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