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THE SOIL DEFINED

Soil is the unconsolidated mineral or organic material on the immediate surface of the earth and serves as a natural medium for the growth of land plants. The soil is characterized by varying types when the unconsolidated mineral or organic matter on the surface has been subjected to and shows effects of formation and environmental factors of climate, macro- and microorganisms acting on parent material over a period of time.

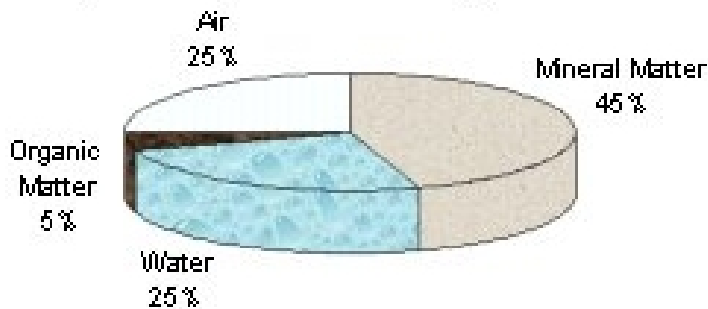


Figure 3.1 Major Components of a Typical Soil

THE SOIL PROFILE

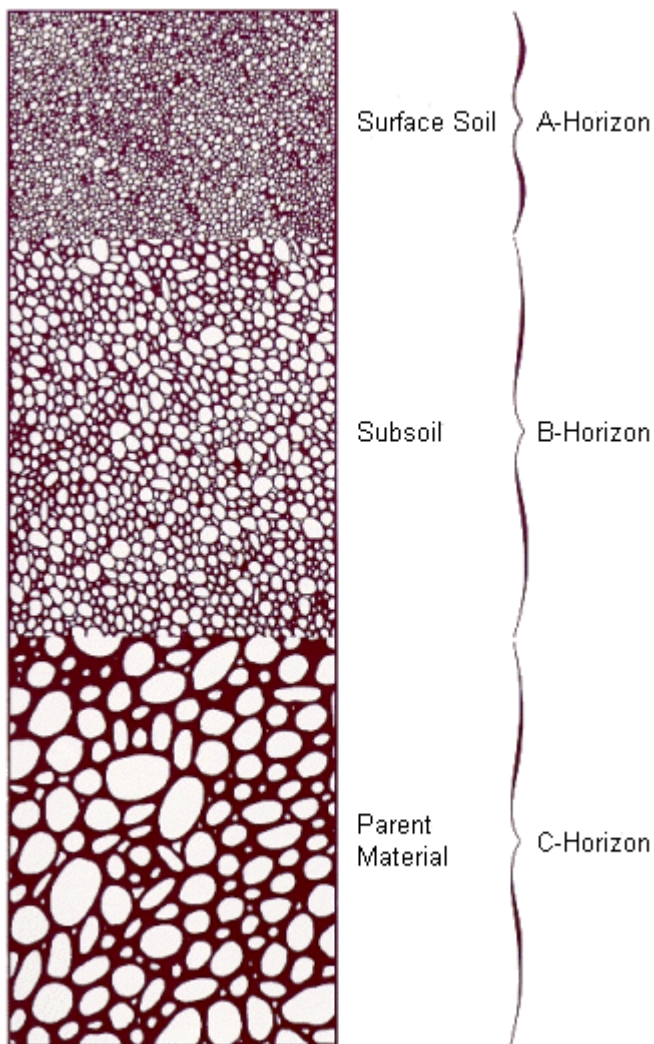
The soil profile is comprised of two or more soil layers called horizons, one below the other, each parallel to the surface of the land. Important characteristics of the various horizons are:

- Soil horizons differ in color, texture, structure, consistence, porosity and soil reaction.



- Soil horizons may be several feet thick or as thin as a fraction of an inch.
- Generally, the horizons merge with one another and may or may not show sharp boundaries. Horizons in a soil profile are like the parts of a layer cake without the clear bonds of frosting between them.

DESCRIPTIONS OF THE THREE MAJOR HORIZONS



The A Horizon...is the uppermost layer in the soil profile or surface soil. It includes the mulch layer and plow layer. Living organisms are most abundant in this horizon consisting of plant roots, bacteria, fungi and small animals. Organic matter is most plentiful, particularly in the mulch layer. When a soil is tilled improperly, the A Horizon may be eroded away.

The B Horizon...lies immediately beneath the A Horizon and above the C Horizon. It is called the subsoil. The B Horizon has properties of both A and C. Living organisms are fewer in number than in the A Horizon but more abundant than in the C Horizon. Color is transitional between A and C as well. It is frequently higher in clay than either of the other horizons.

The C Horizon...is the deepest of the three. This is the material from which the mineral part of the soil forms. It is the parent material of soils. It may have been accumulated in place by the breakdown of hard rock or it may have been placed there by the action of water, wind, or ice. (See Figure 3.2)

Figure 3.2 The Three Major Horizons



A FERTILE SOIL

A fertile soil is one that contains an adequate supply of all the nutrients required for the successful production of plant life. This is important because the full potential of crops is never realized if a shortage of nutrients occur at any time during the growth cycle. This is true even though plants are capable of remarkable recovery from short periods of starvation.

A fertile soil is not necessarily a productive one. The second major requirement is that the soil must provide a satisfactory environment for plant growth. The environmental factors include: texture, structure, soil water supply, pH, temperature, and aeration.

SOIL TEXTURE

Table 3.1: Soil Classes and Textures

Soil Classes	% Sand	% Silt	% Clay
SANDS	85+		0-10
LOAMY SANDS	70-90		0-15
SANDY LOAMS	43-85		0-20
SILT		80+	0-12
SILT LOAMS		50-88	0-27
LOAMS	0-52	0-50	7-27
SANDY CLAY LOAMS	45 +	0-28	20-35
CLAY LOAMS	0-45	0-53	27-40
SILTY CLAY LOAMS	0-20	40 +	27-40
SANDY CLAYS	45+	0-20	35-55
SILTY CLAYS		40 +	40 +
CLAYS	0-45	0-40	40 +

Example: Sands are 85% or more sand and less than 10% clay.

Texture refers to the relative proportions of the various size groups of individual particles or grains in a soil. In other words, the proportions of clay, silt, and sand determine the soil textural class. Clays are the smallest particles in soil, silts are somewhat larger in size, followed by sands which are coarse and the individual particles are easily visible. Note that the term "clay" is used in two different ways when describing soils. The term "clay" is a description of particle size and "clay" is a particular kind of silicate mineral found in soils.



The following table shows the proportion of sand, silt and clay normally found in the various textural classes of soils.

SOIL STRUCTURE

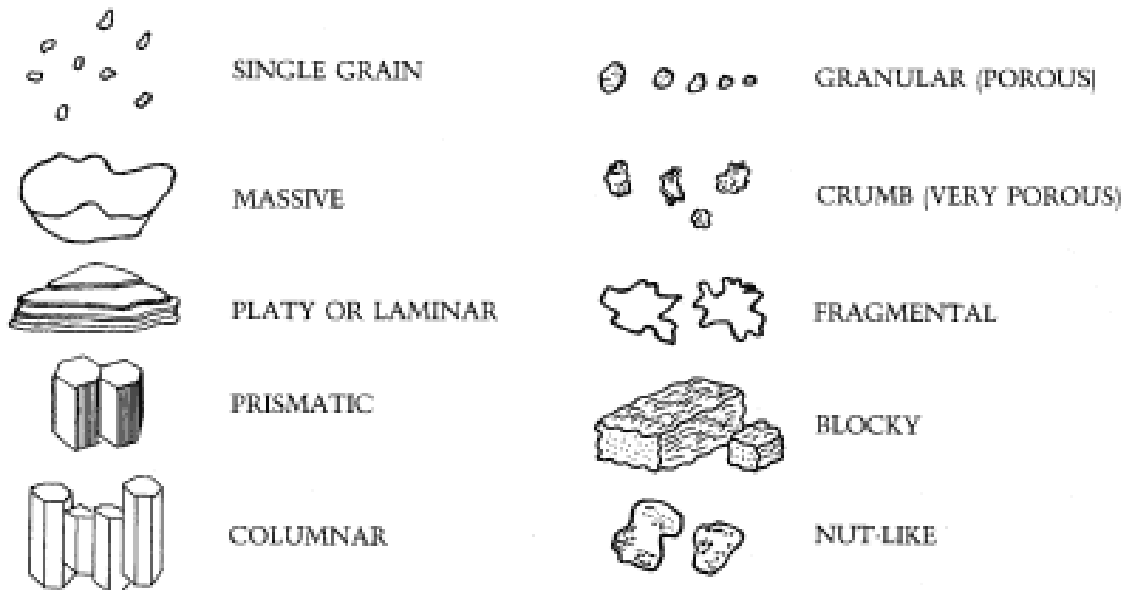


Figure 3.3 Soil Structure

the arrangement of soil particles into groups or aggregates determines the "structure." A single mass or cluster of soil consisting of many soil particles held together in a particular way imparts particular physical characteristics to the soil, such as a clod, prism, crumb or granule. Soil structure is often more important than the texture to the farmer. Soil structure can be changed to produce improved soil conditions for maximum yield and profits. Examples of various types of soil structure are shown in Figure 3.3.

SOIL COLOR

Color in various types of soils is due primarily to the amount of organic matter and the chemical state of the iron and other compounds in the mineral fraction of the soil. Other minerals such as quartz, granite, and heavy black minerals may also influence soil color. Unweathered parent materials tend to be gray in color or else will have the color of the natural minerals from which they are derived.



The color of subsoils can reveal a great deal about the age and drainage conditions in the soil. Iron compounds can exist as oxidized forms, which are red; as hydrated oxides, which are yellow; and as reduced forms, which are gray.

The usual relationship between subsoil color and drainage is shown below:

Table 3.2: Relationship Between Subsoil Color and Drainage

Subsoil Color	Drainage Condition
RED	EXCELLENT
REDDISH BROWN OR BROWN	GOOD
BRIGHT YELLOW	MODERATELY GOOD
PALE YELLOW	IMPERFECT TO FAIR
GRAY	POOR
DARK (BLACK)	VARIABLE

SOIL ORGANISMS

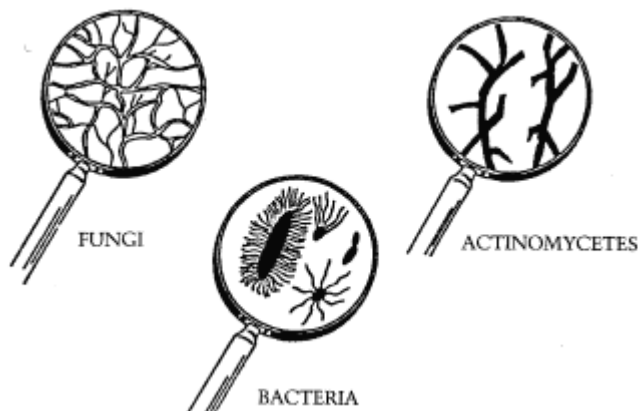


Figure 3.4 Soil organisms

The mineral soil harbors a varied population of living organisms that play a prominent and indispensable role in the changes constantly occurring within the soil. Many groups of organisms live in the soil and range in size from microscopic to those that are visible to the naked eye.

Some of the microscopic-sized organisms are the bacteria, fungi, actinomycetes, algae and protozoa. Most soil organisms depend on organic matter for food and energy. Consequently, they are generally found in the top twelve inches of soil. One of the most important functions of soil microorganisms is the decomposition of organic matter. One of the products formed when organic matter is decomposed is carbon dioxide. Also, nitrogen and other essential plant nutrients are released and made available to growing crops.

Rhizobium is the genus of soil bacteria that is responsible for symbiotic nitrogen fixation in legume plants. These organisms penetrate plant roots causing the formation of small nodules on the roots. They then live in symbiotic relation with the host plant. The beneficial effect of this



process is realized when cultivated legumes, such as alfalfa, clovers, soybeans, etc., are inoculated at seeding with the proper strain of the rhizobium bacteria. The following table shows the approximate amounts of nitrogen fixed annually by selected crops under optimum conditions.

Table 3.3: Nitrogen Fixation by Crop

Crop	lb/acre N Fixed
ALFALFA	196
LADINO CLOVER	178
SWEET CLOVER	116
RED CLOVER	112
WHITE CLOVER	103
SOYBEANS	98
COWPEAS	89
LESPEDEZA	85
VETCH	80
GARDEN PEAS	71
WINTER PEAS	54
PEANUTS	42

Adapted from *Fertilizers and Soil Amendments* by Follett, Murphy and Donahue.

Some soil microorganisms are harmful to soils and growing plants, either directly or indirectly. An indirect harmful effect is *denitrification*. When the supply of air in a soil is limited, certain aerobic soil organisms can get their supply of oxygen by reducing highly oxidized compounds, such as nitrates. This reducing action may continue until free nitrogen is produced and lost to the atmosphere.

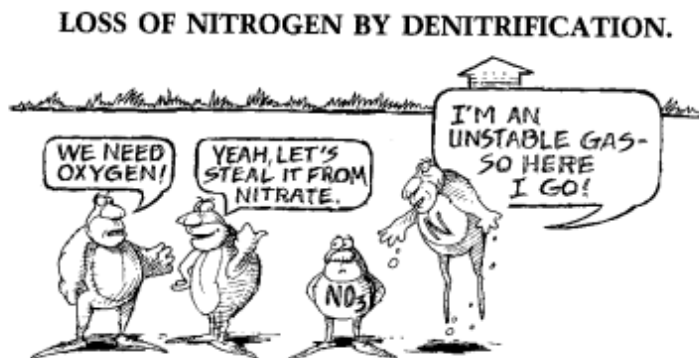


Figure 3.5 Loss of Nitrogen by Denitrification



Another harmful aspect is the onset on plant disease caused by the presence of certain microorganisms. Damping-off and Rhizoctonia (sore shank) of cotton are caused by soil fungi. Actinomycetes also cause some plant diseases. Potato scab, for instance, is caused by a certain strain of actinomycetes. These soil organisms cannot survive at a very low pH. Irish potatoes are grown on acid soils to prevent these organisms from causing potato scab.

Bacteria are responsible for a host of bacterial disease affecting crops, such as bacterial wilt, etc.

ORGANIC MATTER

Soil organic matter represents an accumulation of partially decayed and partially resynthesized plant and animal residues. Such material is in an active state of decay, being subject to attack by soil microorganisms. Consequently, it is a rather transitory soil constituent and must be renewed constantly by the addition of plant residues.

The organic matter content of a soil is small — only about 3 to 5 percent by weight in most topsoils. However, it may actually be less than 0.5 percent in the very sandy soils. Organic matter serves as a "granulator" of the mineral particles, being largely responsible for the loose, friable condition of productive soils. Also, organic matter is a major source of two important mineral elements, phosphorus and sulfur, and essentially the sole source of inherent soil nitrogen.

Through its effect on the physical condition of soils, organic matter also tends to increase the amounts of water a soil can hold and the proportion of this water that is available for plant growth. The capacity of decomposed organic matter (humus) to hold water and nutrient ions greatly exceeds that of clay, its inorganic counterpart. Small amounts of humus thus augment tremendously the soil's capacity to promote plant production.

CLAY AND HUMUS - THE SEAT OF SOIL ACTIVITY

The dynamic nature of soils is generally attributed to the finer portions of the soil-humus and clay. Both of these soil constituents exist in the so-called colloidal state. The individual particles of each are characterized by extremely small size, large surface area per unit weight, and the presence of surface charges to which ions and water are attracted.

The dynamic chemical and physical properties of soils are controlled largely by clay and humus. They act as centers of activity around which chemical reactions and nutrient exchanges occur. Furthermore, by attracting ions to their surfaces, they temporarily protect essential nutrients from leaching and then release them slowly for plant use. Because of their surface charges they are



also thought to act as "contact bridges" between larger particles, thus helping to maintain stable granular structure so desirable in a soil that is easily tilled.

On a weight basis, the humus colloids have greater nutrient and water holding capacities than does clay. Clay is generally present in larger amounts, however. For that reason, its total contribution to the chemical and physical properties will generally equal or exceed that of humus. The best agricultural soils contain a good balance of these two important soil constituents.

CLAY

There are predominately two broad types of silicate clays found in the temperate region which include most of the important agricultural soils of the world, including practically all of the agricultural soils in the United States. The two broad types of clays are montmorillonite and kaolinite. Other types of clays, such as illite, are present in smaller quantities.

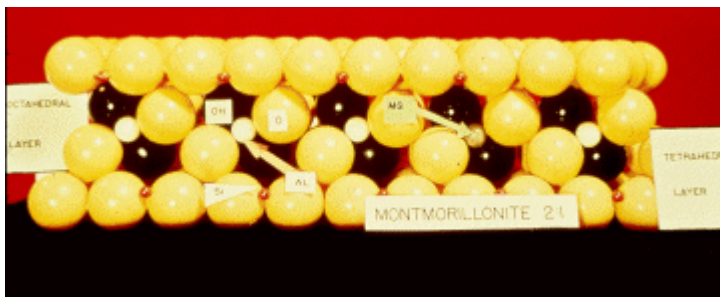
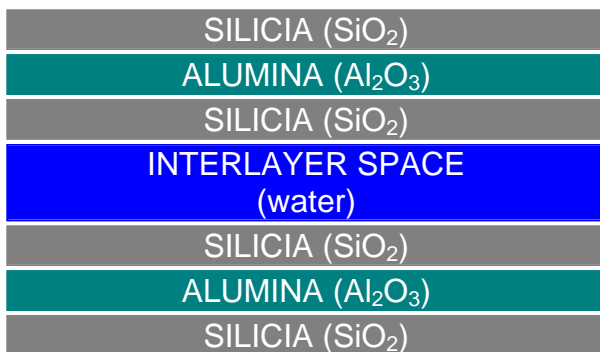


Figure 3.6 Monmorillonite clays are composed of three layers, one alumina layer between two silica layers.

Montmorillonitic clays are less weathered than kaolinitic clays and, therefore, found largely in arid regions and in colder climates such as the western and Midwestern states. They are composed of three layers or sheets, two of silica and one of alumina.

are very difficult to cultivate when wet, being sticky and difficult to manage.

The layers of silica and alumina are not held together tightly and they tend to expand when wet and contract upon drying. Soils containing large amounts of this type of clay



Expands and Contracts

Negative charges on particle surfaces, interlayers and edges.

Figure 3.7 Diagram of a Montmorillonite clay colloid

When these soils dry, cracks appear on the surface. However, because of the tremendous amount of surface area exposed and because of their expanding structural lattice, they have a much higher cation exchange capacity and will hold more water than kaolinitic type soils.



Kaolinite clays are more weathered than montmorillonite clays and are found generally in the more humid and temperate climates, such as the southeastern U.S. These clays are composed of one layer of silica and one layer of alumina and are referred to as a 1:1 type clay.

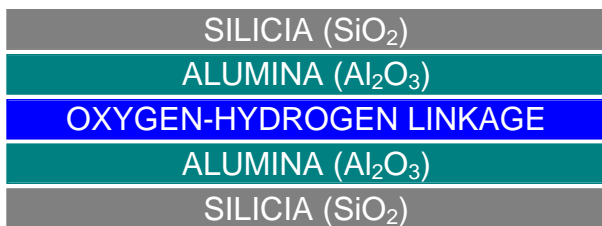


The layers are held together more tightly than montmorillonite and, therefore, do not tend to expand when wet and contract upon drying. As a result, kaolinitic type clay soils are easier to cultivate than montmorillonitic type soils. However, since less surface area is exposed by these clay particles, kaolinite clays have lower cation exchange capacity (CEC) values. They also hold less water than montmorillonite clays.

Figure 3.8 Kaolinite clays are composed of one layer of silica and one layer of alumina.

Each clay or organic colloid contains a net negative electrical charge due to the structural and chemical makeup of the soil colloid. Montmorillonitic and organic colloids have more surface area exposed than kaolinitic type colloids and, therefore, have a higher net electrical charge or cation exchange capacity.

Because of the net negative charges contained by soil colloids, they have the ability to attract and hold positively charged elements by electrical attraction. Most chemical compounds when in solution dissolve into electrically charged particles called ions. For example, common table salt when dissolved in water separates into sodium (Na^+) and chloride (Cl^-) ions. Ions with positive charges are called cations and ions containing negative charges are referred to as anions. Consequently, positively charged cations such as: potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), and ammonium nitrogen (NH_4^+) are attracted and held to the surface of soil colloids much like a magnet attracts and holds iron filings.



Negative charges mainly on broken edges.

Figure 3.9 Diagram of a Kaolinite clay colloid leaching loss than cations.

This phenomenon helps to explain why certain fertilizer elements such as potassium, calcium, magnesium and ammonium nitrogen are not as easily leached from the soil as the negatively charged ions of nitrate nitrogen, sulfates, or chlorides. Negatively charged anions such as nitrates, chlorides, and sulfates have the same negative electrical charge as the soil colloids and are not attracted and held and are more subject to

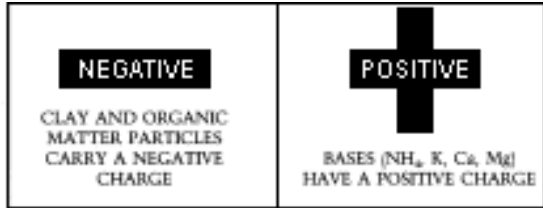


CATION EXCHANGE CAPACITY

The ability of soil colloids to attract and hold positively charged ions is referred to as cation exchange capacity. A knowledge of this phenomenon is basic to understanding how much and how frequently lime and fertilizers should be applied for optimum crop production.

Soils differ in their capacity to attract and hold positively charged fertilizer elements against the force of leaching. This capacity is governed by the type of clay and amount of organic colloids present in the soil. As mentioned previously, montmorillonitic type clays have a higher net electrical charge than kaolinitic type clays; consequently, they have a higher cation exchange capacity. Soils of the west and Midwestern soils contain mostly montmorillonite clay and thus are generally inherently more fertile and will retain more applied fertilizer elements than soils of the southeastern region which contain mostly kaolinitic type clays.

Soils containing a high percentage of organic matter also tend to have high cation exchange capacities. Sandy soils containing a low percentage of clay and organic matter have low exchange capacities. This explains why coarse textured soils require more frequent applications of lime and fertilizer than soils containing more clay and organic matter.



BASES ARE HELD ON CLAY AND ORGANIC MATTER PARTICLES BY MAGNETIC ATTRACTION—Unlike poles attract—like poles repel. This

is characteristic of a magnet. It is this same principle that holds bases (positive charged cations) to the clay and organic matter particles.

Cations held on the surface of soil colloids and contained in the soil solution are available for plant use. Adsorbed cations, however, can be replaced by other cations present in the soil solution through the process of cation exchange. These replaced cations may then combine with an anion and be leached from the soil. For instance, when large amounts of a fertilizer material such as muriate of potash (KCl) are applied to the soil, the KCl when dissolved in soil moisture disassociates into K⁺ and Cl⁻ ions. The potassium cations may replace adsorbed magnesium (Mg⁺⁺) cations. The replaced magnesium ions can then combine with Cl⁻ ions to form magnesium chloride. This compound is soluble and can be leached from the soil when rain occurs.

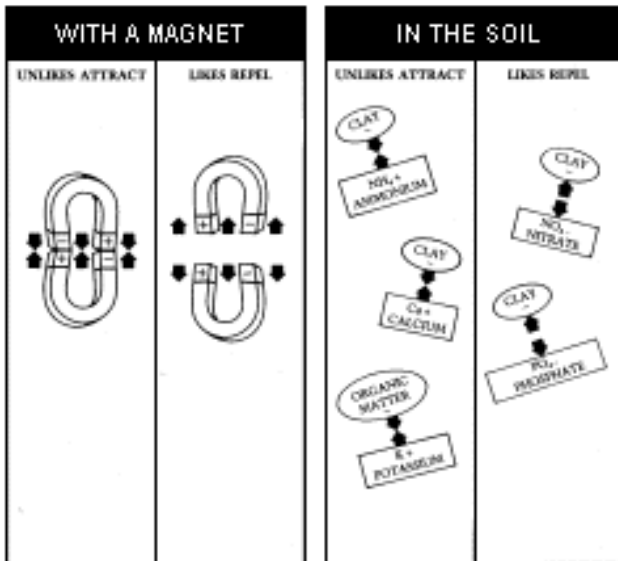


Figure 3.10 Unlike charges attract, like charges repel.

The force by which cations are held by soil colloids will depend upon several factors. The smaller the cation and the less water it has adsorbed, generally the tighter the cation is held on the soil particles. Hydrogen ions, therefore, are more tightly held and more difficult to replace than larger and more hydrated cations such as ammonium, calcium, magnesium, and potassium. Divalent cations (two charges) are generally held tighter by soil colloids than monovalent cations (one charge). Therefore, calcium and magnesium which are divalent cations

are more difficult to replace than the monovalent cations such as potassium and ammonium

DETERMINING SOIL CATION EXCHANGE CAPACITY

The cation exchange capacity of a soil is customarily expressed in terms of milliequivalents. A milliequivalent is defined as "one milligram of hydrogen or the amount of any other element that will displace it." When applied to soils, milliequivalents are generally expressed on the basis of 100 grams of oven dried soil. One milligram of hydrogen per 100 grams of soil equates to 10 parts of hydrogen per one million parts of soil. An acre (top 6-2/3 inches) of soil weighs about 2,000,000 pounds. Therefore, 10 parts per million of hydrogen (whose atomic number is one) equals about 20 lb/acre of hydrogen.



by Dr. Sam Kincheloe

Table 3.4: Conversion Table from Cation Weights to Pounds Per Acre

Cation	Electrical Charge	Atomic Weight	Equiv. Weight	lb/acre of one Milliequivalent (m.e.)
H	1	1	1	20
Ca	2	40	20	400
Mg	2	24	12	240
K	1	39	39	780

Example: Assume soil test results for a particular soil are in pounds per acre and shown in the table below: Hydrogen = 50, Calcium = 800, Magnesium = 120, and Potassium = 250. To arrive at the estimated cation exchange capacity

of this soil, divide the lb/acre of each element as determined by soil test by one milliequivalent (m.e.) in lb/acre of each element. As shown in the following table, for calcium, divide the 800 lb/acre soil test value by the 400 m.e. value which yields a value of 2.0 m.e. per 100 grams of calcium. The sum of the m.e. per 100 grams for each of the four nutrients is the calculated CEC for that soil.

Table 3.5: Soil Test to Millequivalent for Cations

Cation	Soil Test lb/acre	1 m.e. lb/acre	m.e./100 grams
H	50	20	2.50
Ca	800	400	2.00
Mg	120	240	0.50
K	250	780	0.32

CATION EXCHANGE CAPACITY = 5.32

The proportion of adsorbed bases (Calcium, Magnesium, Potassium) to Hydrogen is expressed in terms of percentage base saturation. Generally, the higher the percent base saturation of a soil, the higher the soil pH and fertility level. In the above example, the percent base saturation would be:

$$\text{Ca } 2.0 + \text{Mg } 0.5 + \text{K } 0.32 \div 5.32 = 53\% \text{ Base Saturation}$$



The following table shows the CEC values for representative soils across the United States and illustrates the wide range of values that can occur.

Table 3.6: CEC Values for Representative Soils

Soil or Soil Component	Location	CEC m.e./100 grams
GRUNDY SILT LOAM	IL	23.6
CLARION LOAM	IA	19.1
SAC SILTY CLAY LOAM	IA	35.1
DELTA LIGHT SILT LOAM	MS	9.4
CECIL SANDY LOAM	SC	5.5
NORFOLK SANDY LOAM	SC	3.0
LAKELAND SAND	FL	1.5
KAOLINITE CLAY	--	5-15
ILLITE CLAY	--	10-45
MONTMORILLONITE CLAY	--	60-150
HUMUS	--	140

In summary, the cation exchange capacity of soil is a measure of the ability of a soil to retain and hold positively charged cations against the forces of leaching. The more clay and organic matter a soil contains, the higher its cation exchange capacity. Montmorillonite type clays common in arid and cooler climates have a higher CEC than kaolinite type clays found in the more temperate and higher rainfall areas.

ANION ADSORPTION

Anions are the opposite of cations in that they contain a net negative charge. The most common anions in soils are chloride, sulfate, phosphate and nitrate.

In addition to cation adsorbing capacity, soils also have the ability to adsorb anions, but to a lesser extent than cations. Anion adsorption is pH dependent and increases with a decrease in soil pH. Phosphate and sulfates are adsorbed more strongly than nitrates and chlorides. Anion adsorption is not as important agriculturally as cation adsorption. Most agricultural soils have a pH higher than that at which anion adsorption is at its maximum strength and with the exception of phosphate, and to a lesser degree sulfate, anions are largely lost from the soil by leaching.



Links to other sections of the EFFICIENT FERTILIZER USE MANUAL

[History](#) • [MEY](#) • [Soil](#) • [pH](#) • [Nitrogen](#) • [Phosphorus](#) • [Potassium](#) • [Secondary](#) • [Micronutrients](#) • [Fluid-Dry](#) • [Sampling](#) • [Testing](#) • [Site-Specific](#) • [Tillage](#) • [Environment](#) • [Appendices](#) • [Authors](#)