Chapter 3. Concepts of Basic Soil Science

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Soil formation and soil horizons

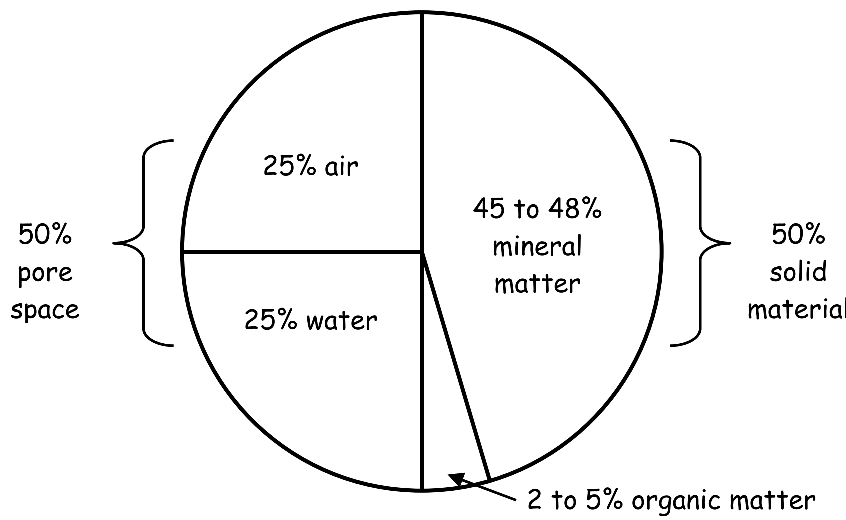
Introduction

Soil covers the vast majority of the exposed portion of the earth in a thin layer. It supplies air, water, nutrients, and mechanical support for the roots of growing plants. The productivity of a given soil is largely dependent on its ability to supply a balance of these factors to the plant community.

Soil composition by volume

A desirable surface soil in good condition for plant growth contains approximately 50% solid material and 50% pore space (Figure 3.1). The solid material is composed of mineral material and organic matter. Mineral material comprises 45% to 48% of the total volume of a typical Mid-Atlantic soil. About 2% to 5% of the volume is made up of organic matter, which may contain both plant and animal residues in varying stages of decay or decomposition. Under ideal moisture conditions for growing plants, the remaining 50% soil pore space would contain approximately equal amounts of air (25%) and water (25%).

Figure 3.1. Volume composition of a desirable surface soil.



Soil formation

The mineral material of a soil is the product of the weathering of underlying rock in place, or the weathering of transported sediments or rock fragments. The material from which a soil has formed is called its *parent material*. The weathering of residual parent materials to form soils is a slow process that has been occurring for millions of years in most of the Mid-Atlantic region. However, certain soil features (such as A horizons, discussed below) can form in several months to years.

The rate and extent of weathering depends on:

- the chemical composition of the minerals that comprise the rock or sediment
- the type, strength, and durability of the material that holds the mineral grains together
- the extent of rock flaws or fractures
- the rate of leaching through the material
- the extent and type of vegetation at the surface

Physical weathering is a mechanical process that occurs during the early stages of soil formation as freeze-thaw processes and differential heating and cooling breaks up rock parent material. After rocks or coarse gravels and sediments are reduced to a size that can retain adequate water and support plant life, the rate of soil formation increases rapidly. As organic materials decompose, the evolved carbon dioxide dissolves in water to form carbonic acid, a weak acid solution. The carbonic acid reacts with and alters many of the primary minerals in the soil matrix to make finer soil particles of sand, silt, and secondary clay minerals.

As soil-forming processes continue, some of the fine clay soil particles (<0.002 mm) are carried, or leached, by water from the upper or surface soil into the lower or subsoil layers. As a result of this leaching action, the surface soil texture becomes coarser and the subsoil texture becomes finer as the soil weathers.

Soil horizons

Soils are layered because of the combined effects of organic matter additions to the surface soil and long-term leaching. These layers are called *horizons*. The vertical sequence of soil horizons found at a given location is collectively called the *soil profile* (Figure 3.2).

The principal master soil horizons found in managed agricultural fields are:

- A horizon or mineral surface soil (if the soil has been plowed, this is called the Ap horizon)
- B horizon or subsoil

- C horizon or partially weathered parent material
- rock (R layer) or unconsolidated parent materials similar to that from which the soil developed

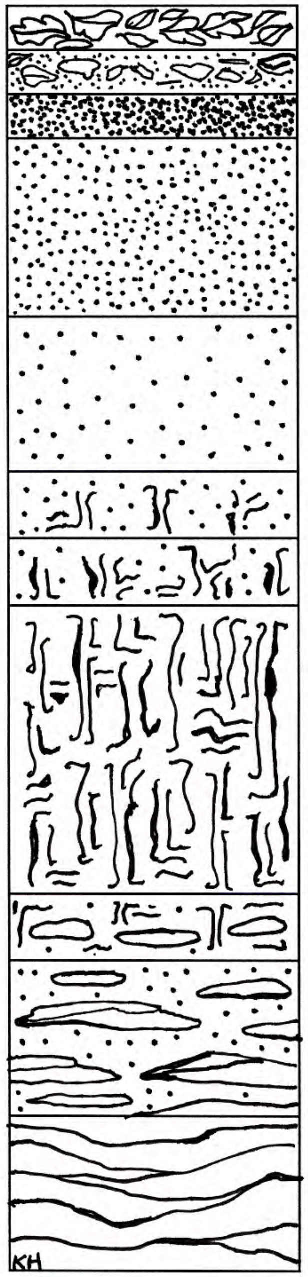
Unmanaged forest soils also commonly contain an organic O horizon on the surface and a light-colored leached zone (E horizon) just below the A horizon.

The surface soil horizon(s) or *topsoil* (the Ap or A+ E horizons) is often coarser than the subsoil layer and contains more organic matter than the other soil layers. The organic matter imparts a grayish, dark-brownish, or black color to the topsoil. Soils that are high in organic matter usually have dark surface colors. The A or Ap horizon tends to be more fertile and have a greater concentration of plant roots of any other soil horizon. In unplowed soils, the *eluviated* (E) horizon below the A horizon is often light-colored, coarser-textured, and more acidic than either the A horizon or the horizons below it because of leaching over time.

The subsoil (B horizon) is typically finer in texture, denser, and firmer than the surface soil. Organic matter content of the subsoil tends to be much lower than that of the surface layer, and subsoil colors are often stronger and brighter, with shades of red, brown, and yellow predominating due to the accumulation of iron coated clays. Subsoil layers with high clay accumulation relative to the A horizon are described as Bt horizons.

The C horizon is partially decomposed and weathered parent material that retains some characteristics of the parent material. It is more like the parent material from which it has weathered than the subsoil above it.

Figure 3.2. Soil profile horizons.



Oi Loose, easily recognizable, organic debris

Oe Partially decomposed organic materials

Oa Fully decomposed organic materials

A Surface mineral horizon; darker and higher in organic matter. If plowed, will be designated Ap

E Eluviated horizon; light colored zone of maximum leaching of clay, iron, aluminum, and soluble organic matter. Often mixed into Ap

EB Transition from E to B; more like E than B

BE Transition from E to B; more like B than E

B Subsurface zone of maximum accumulation of clay, iron, etc. Common features include development of blocky and/or prismatic structure, clay coatings on larger particles, red and yellow colors from accumulation of iron oxides

BC Transition from B to C; more like B than C

C Weathered parent material such as saprolite, oxidized sediments, unconsolidated bedrock, etc.

R Hard bedrock; not always seen

Soil physical properties

Introduction

The physical properties of a soil are the result of soil parent materials being acted upon by climatic factors (such as rainfall and temperature), and being affected by relief (slope and direction or aspect), and by vegetation, with time. A change in any one of these soil-forming factors usually results in a difference in the physical properties of the resulting soil.

The important physical properties of a soil are:

- texture
- aggregation
- structure
- porosity

Texture

The relative amounts of the different soil size (<2 mm) particles, or the fineness or coarseness of the mineral particles in the soil, is referred to as soil texture. Mineral grains which are >2 mm in diameter are called rock fragments and are measured separately. Soil texture is determined by the relative amounts of *sand*, *silt*, and *clay* in the fine earth (< 2 mm) fraction.

- *Sand* particles vary in size from very fine (0.05 mm) to very coarse (2.0 mm) in average diameter. Most sand particles can be seen without a magnifying glass. Sands feel coarse and gritty when rubbed between the thumb and fingers, except for mica flakes which tend to smear when rubbed.

- *Silt* particles range in size from 0.05 mm to 0.002 mm. When moistened, silt feels smooth but is not slick or sticky. When dry, it is smooth and floury and if pressed between the thumb and finger will retain the imprint. Silt particles are so fine that they cannot usually be seen by the unaided eye and are best seen with the aid of a strong hand lens or microscope.

- *Clay* is the finest soil particle size class. Individual particles are finer than 0.002 mm. Clay particles can be seen only with the aid of an electron microscope. They feel extremely smooth or powdery when dry and become plastic and sticky when wet. Clay will hold the form into which it is molded when moist and will form a long ribbon when extruded between the fingers.

Determining textural class with the textural triangle

There are 12 primary classes of soil texture defined by the USDA (Soil Survey Division Staff, 1993). The textural classes are defined by their relative proportions of sand, silt, and clay as shown in the USDA *textural triangle* (Figure 3.3). Each textural class name indicates the size of the mineral particles that are dominant in the soil. Regardless of textural class, all soils in the Mid-Atlantic region contain sand, silt, and clay- sized particles, although the amount of a particular particle size may be small.

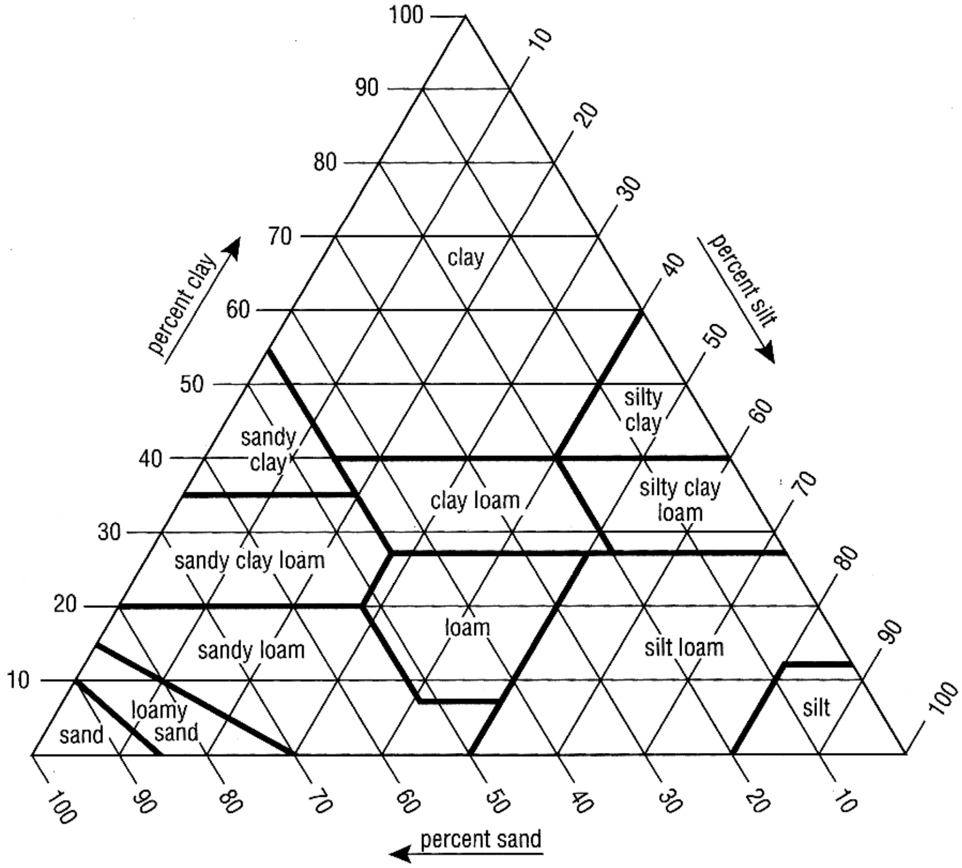
Texture can be estimated in the field by manipulating and feeling the soil between the thumb and fingers, but should be quantified by laboratory particle size analysis.

To use the textural triangle:

1. First, you will need to know the percentages of sand, silt, and clay in your soil, as determined by laboratory particle size analysis.
2. Locate the percentage of clay on the left side of the triangle and move inward horizontally, parallel to the base of the triangle.
3. Follow the same procedure for sand, moving along the base of the triangle to locate your sand percentage
4. Then, move up and to the left until you intersect the line corresponding to your clay percentage value.
5. At this point, read the *textural class* written within the bold boundary on the triangle. For example: a soil with 40% sand, 30% silt, and 30% clay will be a clay loam. With a moderate amount of practice, soil textural class can also be reliably determined in the field.

If a soil contains 15% or more rock fragments, a rock fragment content modifier is added to the soil's texture class. For example, the texture class designated as *gravelly silt* loam would contain 15 to 35% gravels (> 2 mm) within a silt loam (< 2 mm) fine soil matrix. More detailed information on USDA particle size classes and other basic soil morphological descriptors can be found on-line at http://soils.usda.gov/technical/handbook/download.html or in the USDA Soil Survey Manual (Soil Survey Division Staff, 1993).

Figure 3.3. The USDA textural triangle (Soil Survey Division Staff, 1993).



Effects of texture on soil properties

Water infiltrates more quickly and moves more freely in coarse-textured or sandy soils, which increases the potential for leaching of mobile nutrients. Sandy soils also hold less total water and fewer nutrients for plants than fine-textured soils. In addition, the relatively low water holding capacity and the larger amount of air present in sandy soils allows them to warm faster than fine-textured soils. Sandy and loamy soils are also more easily tilled than clayey soils, which tend to be denser.

In general, fine-textured soils hold more water and plant nutrients and thus require less frequent applications of water, lime, and fertilizer. Soils with high clay content (more than 40% clay), however, actually hold less plant-available water than loamy soils. Fine-textured soils have a narrower range of moisture conditions under which they can be worked satisfactorily than sandy soils. Soils high in silt and clay may puddle or form surface crusts after rains, impeding seedling emergence. High clay soils often break up into large clods when worked while either too dry or too wet.

Aggregation and soil structure

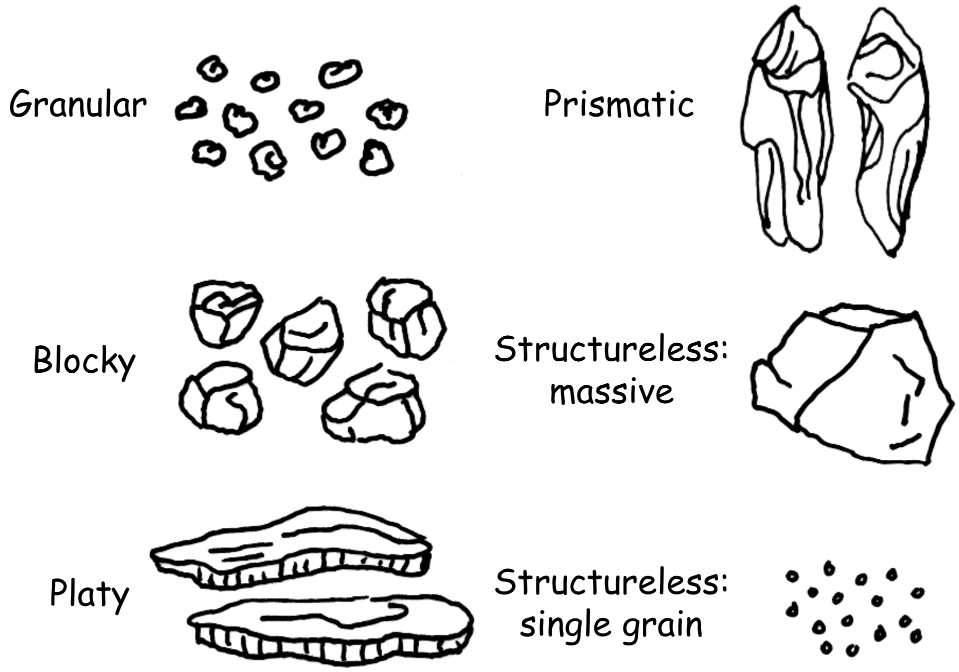
Soil *aggregation* is the cementing of several soil particles into a secondary unit or aggregate. Soil particles are arranged or grouped together during the aggregation process to form structural units (known to soil scientists as *peds*). These units vary in size, shape, and distinctness (also known as strength or grade).

The types of soil structure found in most Mid-Atlantic soils are described in Table 3.1 and illustrated in Figure 3.4.

Table 3.1. Types of soil structure.

Structure type	Description
Granular	Soil particles are arranged in small, rounded units. Granular structure is very common in surface soils (A horizons) and is usually most distinct in soils with relatively high organic matter content.
Blocky	Soil particles are arranged to form block-like units, which are about as wide as they are high or long. Some blocky peds are rounded on the edges and corners; others are angular. Blocky structure is commonly found in the subsoil, although some eroded fine-textured soils have blocky structure in the surface horizons.
Platy	Soil particles are arranged in plate-like sheets. These plate-like pieces are approximately horizontal in the soil and may occur in either the surface or subsoil, although they are most common in the subsoil. Platy structure strongly limits downward movement of water, air, and roots. Platy structure may occur just beneath the plow layer, resulting from compaction by heavy equipment, or on the soil surface when it is too wet to work satisfactorily.
Prismatic	Soil particles are arranged into large peds with a long vertical axis. Tops of prisms may be somewhat indistinct and normally angular. Prismatic structure occurs mainly in subsoils, and the prisms are typically much larger than other typical subsoil structure types such as blocks.
Structureless	Either: • *Massive*, with no definite structure or shape, as in some C horizons or compacted material. Or: • *Single grain*, which is typically individual sand grains in A or C horizons not held together by organic matter or clay.

Figure 3.4. Types of soil structure.



Effects of structure on soil properties

The structure of the soil affects pore space size and distribution and therefore, rates of air and water movement. Well-developed structure allows favorable movement of air and water, while poor structure retards movement of air and water. Since plant roots move through the same channels in the soil as air and water, well-developed structure also encourages extensive root development.

Water can enter a surface soil that has granular structure (particularly fine-textured soils) more rapidly than one that has relatively little structure. Surface soil structure is usually granular, but such granules may be indistinct or completely absent if the soil is continuously tilled, or if organic matter content is low.

The size, shape, and strength of subsoil structural peds are important to soil productivity. Sandy soils generally have poorly developed structure relative to finer textured soils, because of their lower clay content. When the subsoil has well developed blocky structure, there will generally be good air and water movement in the soil. If platy structure has formed in the subsoil, downward water and air movement and root development in the soil will be slowed. Distinct prismatic structure is often associated with subsoils that swell when wet and shrink when dry, resulting in reduced air and water movement. Very large and distinct subsoil prisms are also commonly associated with *fragipans,* which are massive and dense subsoil layers.

Porosity

Soil *porosity*, or pore space, is the volume percentage of the total soil that is not occupied by solid particles. Pore space is commonly expressed as a percentage:

% pore space = 100 - [bulk density ÷ particle density x 100]

Bulk density is the dry mass of soil solids per unit volume of soils, and *particle density* is the density of soil solids, which is assumed to be constant at 2.65 g/cm^3. Bulk densities of mineral soils are usually in the range of 1.1 to 1.7 g/cm^3. A soil with a bulk density of about 1.32 g/cm^3 will generally possess the ideal soil condition of 50% solids and 50% pore space. Bulk density varies depending on factors such as texture, aggregation, organic matter, compaction/consolidation, soil management practices, and soil horizon.

Under field conditions, pore space is filled with a variable mix of water and air. If soil particles are packed closely together, as in graded surface soils or compact subsoils, total porosity is low and bulk density is high. If soil particles are arranged in porous aggregates, as is often the case in medium-textured soils high in organic matter, the pore space per unit volume will be high and the bulk density will be correspondingly low.

The size of the individual pore spaces, rather than their combined volume, will have the most effect on air and water movement in soil. Pores smaller than about 0.05 mm (or finer than sand) in diameter are typically called *micropores* and those larger than 0.05 mm are called *macropores*.

Macropores allow the ready movement of air, roots, and percolating water. In contrast, micropores in moist soils are typically filled with water, and this does not permit much air movement into or out of the soil. Internal water movement is also very slow in micropores. Thus, the movement of air and water through a coarse-textured sandy soil can be surprisingly rapid despite its low total porosity because of the dominance of macropores.

Fine-textured clay soils, especially those without a stable granular structure, may have reduced movement of air and water even though they have a large volume of total pore space. In these fine-textured soils, micropores are dominant. Since these small pores often stay full of water, aeration, especially in the subsoil, can be inadequate for root development and microbial activity. The loosening and granulation of fine-textured soils promotes aeration by increasing the number of macropores.

Soil organic matter

Introduction

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

Soil *humus* is fully decomposed and stable organic matter. Humus is the most reactive and important component of soil organic matter, and is the form of soil organic material that is typically reported as “organic matter” on soil testing reports.

Factors that affect soil organic matter content

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

- **Type of vegetation**: Soils that have been in grass for long periods usually have a relatively high percentage of organic matter in their surface. Soils that develop under trees usually have a low organic matter percentage in the surface mineral soil, but do contain a surface litter layer (O horizon). Organic matter levels are typically higher in a topsoil supporting hay, pasture, or forest than in a topsoil used for cultivated crops.

- **Tillage:** Soils that are tilled frequently are usually low in organic matter. Plowing and otherwise tilling the soil increases the amount of air in the soil, which increases the rate of organic matter decomposition. This detrimental effect of tillage on organic matter is particularly pronounced in very sandy well-aerated soils because of the tendency of frequent tillage to promote organic matter oxidation to CO_2.

- **Drainage**: Soil organic matter is usually higher in poorly-drained soils because of limited oxidation, which slows down the overall biological decomposition process.

- **Soil texture**: Soil organic matter is usually higher in fine-textured soils because soil humus forms stable complexes with clay particles.

Effect of organic matter on soil properties

Adequate soil organic matter levels benefit soil in several ways. The addition of organic matter improves soil physical conditions, particularly aggregation and pore space. This improvement leads to increased water infiltration, improved soil tilth, and decreased soil erosion. Organic matter additions also improve soil fertility, since plant nutrients are released to plant-available mineral forms as organic residues are decomposed (or *mineralized*).

A mixture of organic materials in various states of decomposition helps maintain a good balance of air and water components in the soil. In coarse-textured soils, organic material bridges some of the space between sand grains, which increases water-holding capacity. In fine-textured soil, organic material helps maintain porosity by preventing fine soil particles from compacting.

Soil-water relationships

Water-holding capacity

Soil water-holding capacity is determined largely by the interaction of soil texture, bulk density/pore space, and aggregation. Sands hold little water because their large pore spaces allow water to drain freely from the soils. Clays adsorb a relatively large amount of water, and their small pore spaces retain it against gravitational forces. However, clayey soils hold water much more tightly than sandy soils, so that not all the moisture retained in clayey soils is available to growing plants. As a result, moisture stress can become a problem in fine-textured soils despite their high water-holding capacity.

Field capacity and permanent wilting percentage

The term *field capacity* defines the amount of water remaining in a soil after downward gravitational drainage has stopped. This value represents the maximum amount of water that a soil can hold against gravity following saturation by rain or irrigation. Field capacity is usually expressed as percentage by weight (for example, a soil holding 25% water at field capacity contains 25% of its dry weight as retained water).

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

Tillage and moisture content

Soils with a high clay content are sticky when wet and form hard clods when dry. Tilling clayey soils at the proper moisture content is thus extremely important. Although sandy soils are inherently droughty, they are easier to till at varying moisture contents because they do not form dense clods or other high-strength aggregates. Sandy soils are also far less likely than clays to be compacted if cultivated when wet. However, soils containing high proportions of very fine sand may be compacted by tillage when moist.

Soil drainage

Soil drainage is the rate and extent of vertical or horizontal water removal during the growing season.

Important factors affecting soil drainage are:

- slope (or lack of slope)
- depth to the seasonal water table
- texture of surface and subsoil layers, and of underlying materials
- soil structure
- problems caused by improper tillage, such as compacted subsoils or lack of surface soil structure

Another definition of drainage refers to the removal of excess water from the soil to facilitate agriculture, forestry, or other higher land uses. This is usually accomplished through a series of surface ditches or the installation of subsoil drains.

Soil drainage and soil color

The nature of soil drainage is usually indicated by soil color patterns (such as mottles) and color variations with depth. Clear, bright red and/or yellow subsoil colors indicate well-drained conditions where iron and other compounds are present in their oxidized forms. A soil is said to be well-drained when the *solum* (A+E+B horizon) exhibits strong red/yellow colors without any gray mottles.

When soils become saturated for significant periods of time during the growing season, these oxidized (red/yellow) forms of iron are biochemically reduced to soluble forms and can be moved with drainage waters. This creates a matrix of drab, dominantly gray colors. Subsoil zones with mixtures of bright red/yellow and gray mottling are indicative of seasonally fluctuating water tables, where the subsoil is wet during the winter/early spring and unsaturated in the summer/early fall. Poorly drained soils also tend to accumulate large amounts of organic matter in their surface horizons because of limited oxidation and may have very thick and dark A horizons.

Soils that are wet in their upper 12 inches for considerable amounts of time during the growing season and that support hydrophytic vegetation typical of wetlands are designated as *hydric soils*. Drainage mottles in these soils are referred to as *redoximorphic features.* Further information on Mid-Atlantic hydric soils and redoximorphic features can be found on-line at http://www.epa.gov/reg3esd1/hydricsoils/index.htm.

Drainage classes

The *drainage class* of a soil defines the frequency of soil wetness as it limits agricultural practices, and is usually determined by the depth in soil to gray mottles or other redoximorphic features. The soil drainage classes in table 3.2 are defined by the USDA-NRCS. They refer to the natural drainage condition of the soil without artificial drainage.

Table 3.2. Soil drainage classes.

Drainage Class	Soil Characteristics	Effect on Cropping
Excessively drained	Water is removed rapidly from soil.	Will probably require supplemental irrigation.
Somewhat excessively drained		
Well drained	Water is removed readily, but not rapidly.	No drainage required.
Moderately well drained	Water is removed somewhat slowly at some periods of the year.	May require supplemental drainage if crops that require good drainage are grown.
Somewhat poorly drained	Water is removed so slowly that soil is wet at shallow depths periodically during the growing season.	Will probably require supplemental drainage for satisfactory use in production of most crops.
Poorly drained		
Very poorly drained	Free water is present at or near the surface during the growing season.	

Soil chemical properties

Introduction

The plant root obtains essential nutrients almost entirely by uptake from the soil solution. The chemistry and nutrient content of the soil solution is, in turn, controlled by the solid material portion of the soil. Soil chemical properties, therefore, reflect the influence of the soil minerals and organic materials on the soil solution.

Soil pH

Soil pH defines the relative acidity or alkalinity of the soil solution. The pH scale in natural systems ranges from 0 to 14. A pH value of 7.0 is neutral. Values below 7.0 are acid and those above 7.0 are alkaline, or basic. Many agricultural soils in the Mid-Atlantic region have a soil pH between 5.5 and 6.5.

Soil pH is a measurement of hydrogen ion (H^+) activity, or effective concentration, in a soil and water solution. Soil pH is expressed in logarithmic terms, which means that each unit change in soil pH amounts to a tenfold change in acidity or alkalinity. For example, a soil with a pH of 6.0 has 10 times as much active H^+ as one with a pH of 7.0.

Soils become acidic when basic cations (such as calcium, or Ca^{2+}) held by soil colloids are leached from the soil, and are replaced by aluminum ions (Al^{3+}), which then hydrolyze to form aluminum hydroxide ($Al(OH)_3$) solids and H^+ ions in solution. This long-term acidification process is accelerated by the decomposition of organic matter which also releases acids to soil solution. Most soils of the Mid-Atlantic were formed under high rainfall with abundant vegetation, and are therefore generally more acidic than soils of the midwestern and western United States.

Cation exchange capacity (CEC)

The net ability of a soil to hold, retain, and exchange *cations* (positively charged ions) such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), aluminum (Al^{3+}), and hydrogen (H^+) is called *cation exchange capacity,* or *CEC*. All soils contain clay minerals and organic matter that typically possess negative electrical surface charges. These negative charges are present in excess of any positive charges that may exist, which gives soil a net negative charge.

Negative surface charges attract positively charged cations and prevent their leaching. These ions are held against leaching by electrostatic positive charges, but are not permanently bound to the surface of soil particles. Positively charged ions are held in a "diffuse cloud" within the water films that are also strongly attracted to the charged soil surfaces. Cations that are retained by soils can thus be replaced, or *exchanged*, by other cations in the soil solution. For example, Ca^{2+} can be exchanged for Al^{3+} and/or K^+, and vice versa. The higher a soil's CEC, the more cations it can retain.

There is a direct and positive relationship between the relative abundance of a given cation in solution and the amount of this cation that is retained by the soil CEC. For example, if the predominant cation in the soil solution of a soil is Al^{3+}, Al^{3+} will also be the predominant exchangeable cation. Similarly, when large amounts of Ca^{2+} are added to soil solution by limes dissolving over time, Ca^{2+} will displace Al^{3+} from the exchange complex and allow it to be neutralized in solution by the alkalinity added with the lime.

The CEC of a soil is expressed in terms of moles of charge per mass of soil. The units used are *cmol+/kg* (centimoles of positive charge per kilogram) or *meq/100g* (milliequivalents per 100 grams; 1.0 $cmol^+/kg$ = 1.0 meq/100g). Soil CEC is calculated by adding the charge equivalents of K^+, NH_4^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Na^{+}, and H^+ that are extracted from a soil's exchangeable fraction.

Sources of negative charge in soils

The mineralogy of the clay fraction greatly influences the quantity of negative charges present. One source of negative charge is *isomorphous substitution*, which is the replacement of a Si^{4+} or Al^{3+}cation in the mineral structure with a cation with a lower surface charge. For example, Si^{4+} might be replaced with Al^{3+}, or Al^{3+} with either Mg^{2+} or Fe^{2+}. Clay minerals with a repeating layer structure of two silica sheets sandwiched around an aluminum sheet (2:1 clays, such as vermiculite or smectite), typically have a higher total negative charge than clay minerals with one silica sheet and one aluminum sheet (1:1 clays, such as kaolinite).

Soil pH also has a direct relationship to the quantity of negative charges contributed by organic matter and, to a lesser extent, from mineral surfaces such as iron oxides. As soil pH increases, the quantity of negative charges increases and vice versa. This pH dependent charge is particularly important in highly weathered topsoils where organic matter dominates overall soil charge.

Cation mobility in soils

The negatively charged surfaces of clay particles and organic matter strongly attract cations. However, the retention and release of these cations, which affects their mobility in soil, is dependent on several factors. Two of these factors are the relative retention strength of each cation and the relative amount or mass of each cation present.

For a given cation the relative retention strength by soil is determined by the charge of the ion and the size, or diameter of the ion. In general, the greater the positive charge and the smaller the ionic diameter of a cation, the more tightly the ion is held (i.e., higher retention strength) and the more difficult it is to force the cation to move through the soil profile. For example, Al^{3+} has a positive charge of three and a very small ionic diameter and moves through the soil profile very slowly, while K^+ has a charge of one and a much larger ionic radius, so it leaches much more readily.

If cations are present in equal amounts, the general strength of adsorption that holds cations in the soil is in the following order:

$$\mathbf{Al^{3+} >> Ca^{2+} > Mg^{2+} > K^{+} = NH^{4+} > Na^{+}}$$

Effect of CEC on soil properties

A soil with a **low CEC value** (1-10 meq/100 g) may have some, or all, of the following characteristics:

- high sand and low clay content
- low organic matter content
- low water-holding capacity
- low soil pH
- will not easily resist changes in pH or other chemical changes
- enhanced leaching potential of plant nutrients such as Ca^{2+}, NH_4^+, K^+
- low productivity

A soil with a **higher CEC value** (11-50 meq/100g) may have some or all of the following characteristics:

- low sand and higher silt + clay content
- moderate to high organic matter content
- high water-holding capacity
- ability to resist changes in pH or other chemical properties
- less nutrient losses to leaching than low CEC soils

Base saturation

Of the common soil-bound cations, Ca^{2+}, Mg^{2+}, K^+, and Na^+ are considered to be *basic cations*. The *base saturation* of the soil is defined as the percentage of the soil's CEC (on a charge equivalent basis) that is occupied by these cations. A high base saturation (>50%) enhances Ca, Mg, and K availability and prevents soil pH decline. Low base saturation (<25%) is indicative of a strongly acid soil that may maintain Al^{3+} activity high enough to cause phytotoxicity.

Buffering capacity

The resistance of soils to changes in pH of the soil solution is termed *buffering*. In practical terms, buffering capacity for pH increases with the amount of clay and organic matter. Thus, soils with high clay and organic matter content (high buffer capacity) will require more lime to increase pH than sandy soils with low amounts of organic matter (low, or weak, buffer capacity).

Soil survey

Introduction

The soils of most counties have been mapped by the USDA-NRCS Cooperative Soil Survey Program, and these maps are available in *soil survey reports*. A soil survey report reveals the kinds of soils that exist in the county (or other area) covered by the report at a level of detail that is usually sufficient for agricultural interpretations. The soils are described in terms of their location on the landscape, their profile characteristics, their relationships to one another, their suitability for various uses, and their needs for particular types of management. Each soil survey report contains information about soil morphology, soil genesis, soil conservation, and soil productivity. Soil survey reports are available from county and state USDA-NRCS Cooperative Extension offices and on-line (for certain counties) via http://soils.usda.gov/survey/online_surveys/.

Parts of a soil survey

There are two major sections in a soil survey report. One section contains the soil maps. In most reports, the soil map is printed over an aerial photographic base image. Soil mapping in the past was done at scales ranging from 1:10,000 to 1:50,000, with 1:15,840 being the most common scale used before the 1980's. Current USDA-NRCS mapping is published at 1:24,000 to match United States Geologic Survey (USGS) topographic quadrangle maps.

Each soil area is delineated by an enclosing line on the map. Soil delineation boundaries are drawn wherever there is a significant change in the type of soil. The boundaries may follow contour lines but they also cross contour lines.

The other section of a soil survey report is the narrative portion. Without it, the soil maps would have little meaning. Symbols on each map are keyed to a list of soil mapping units. The nature, properties, and classification and use potentials of all mapping units are described in detail.

Terminology used in soil surveys

- *Soil series* is a basic unit of soil classification, consisting of soils that are essentially alike in all main profile characteristics. Most soil mapping units in modern cooperative soil surveys are named for their dominant component soil series.

- *Soil phase* is a subdivision of a soil series or other unit of classification having characteristics that affect the use and management of the soil but which do not vary enough to merit a separate series. These include variations in slope, erosion, gravel content, and other properties.

- *Soil complexes* and *soil associations* are naturally occurring groupings of two or more soil series with different use and management requirements which occur in a regular pattern across the landscape, but that cannot be separated at the scale of mapping that is used. Soil complexes are used to map two or more series that are commonly intermixed on similar landforms in detailed county soil maps. Soil associations are utilized in more general and less detailed regional soil maps.

- *Map unit*s are the actual units which are delineated on the soil map and are usually named for the dominant soil series and slope phase. Map units generally contain more than one soil series. Units are given the name of the dominant soil series if >85% of the area is correlated as a single soil series (or similar soils in terms of use and management). Soil complexes are used to name the map unit if the dissimilar inclusions exceed 15%. Each map unit is given a symbol (numbers or letters) on the soil map, which designates the name of the soil series or complex being mapped and the slope of the soil. More details on how soil mapping units are developed and named can be found at http://soils.usda.gov/technical/manual/.

Using a soil survey

A user interested in an overall picture of the soils in a county should probably turn first to the soil association section of the soil survey report. The general soil pattern of the county is discussed in this section. A user interested in the soils of a particular farm must first locate that farm on the soil map and determine what soils are present. Index sheets located with the soil maps help the user find the correct section of the map. The map legend gives the soil map unit names for each symbol and assists with the location of descriptive and interpretive material in the report.

Detailed soil descriptions that provide information to those who are primarily interested in the nature and properties of the soils mapped are located in the narrative portion of the soil survey report. The section concerned with the use and management of the soils (*soil interpretations)* is helpful to farmers and others who use the soil or give advice and assistance in its use (e.g., soil conservationists, Cooperative Extension agents). Management needs and estimated yields are included in this section. Newer reports have engineering properties of soils listed in tables that are useful to highway engineers, sanitary engineers, and others who design water storage or drainage projects.

References cited

Soil Survey Division Staff. 1993. Soil survey manual. U.S. Dept. of Agriculture Handbook No. 18. U.S. Govt. Printing Office, Washington, DC.

References for additional information

Note: Although these references are not cited specifically in this chapter, information obtained from them was helpful in writing the chapter.

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