

## Lesson 1: Importance of Soil

### What is Soil?

“Soil” is a common word that people use every day. It has several meanings and may be used in various ways. As a transitive verb it means “to make dirty,” for example, to soil dishes or clothing. The noun “soil” is derived from the Latin word *solum*, which means “floor” or “ground.” The farmer has a more practical conception of soil, because it is the medium in which crops grow. The civil engineer, on the other hand, looks at soil as the building material which supports foundations, roads, or airport runways.

Most people do not think about the soil very much. They really do not know what it is made of and where it comes from. It is just “ground” or “dirt.” This reference will describe the origins of soil, its composition, and much more.

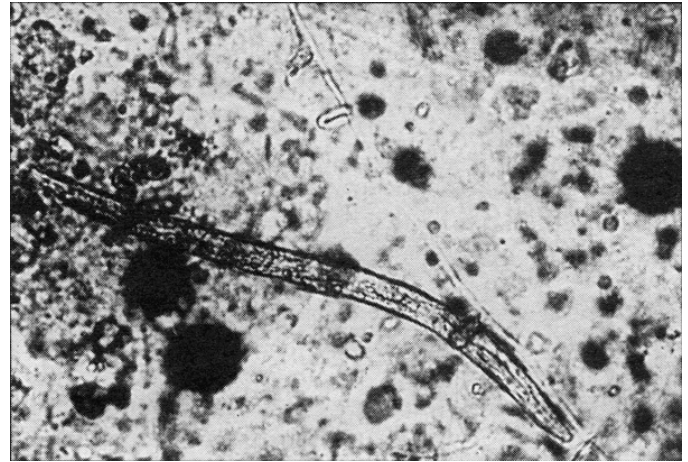
### Definition

**Soil** is a living, naturally occurring dynamic system at the interface of air and rock. Soil forms in response to forces of climate and organisms that act on parent material in a specific landscape (topography) over a period of time.

Soil scientists prefer this definition because each key word says something important about the soil. Why *living*? The soil is living because it is full of living organisms: large and small roots, animals, insects, and millions of microscopic fungi and bacteria. See Figure 1.1. Equally important are the decaying remains of plants and animals. They form organic matter, or **humus**, which is vital for good soil **tilth** (tillage or physical condition of the soil) and productivity.

*Dynamic* means that the soil changes all the time. Missouri soils may change from very wet in the winter to very dry in the summer. Even when irrigation is used, the amount of water in soil can vary widely. The organic matter of the surface soil increases when crop residues are worked in and decreases if the soil is not replenished with fresh plant materials. Soil nutrients increase as soil minerals break down. They decrease as water moving through the soil carries them away. Even soil acidity, or pH, changes seasonally.

Figure 1.1 – Microscopic Worm



*Living, dynamic soil. The microscopic worm shown is called a nematode. A fungus (left) is attacking and invading the nematode.*

The word *system* means that all parts of the soil work together to make up the dynamic whole. A change in one part may cause changes in many parts.

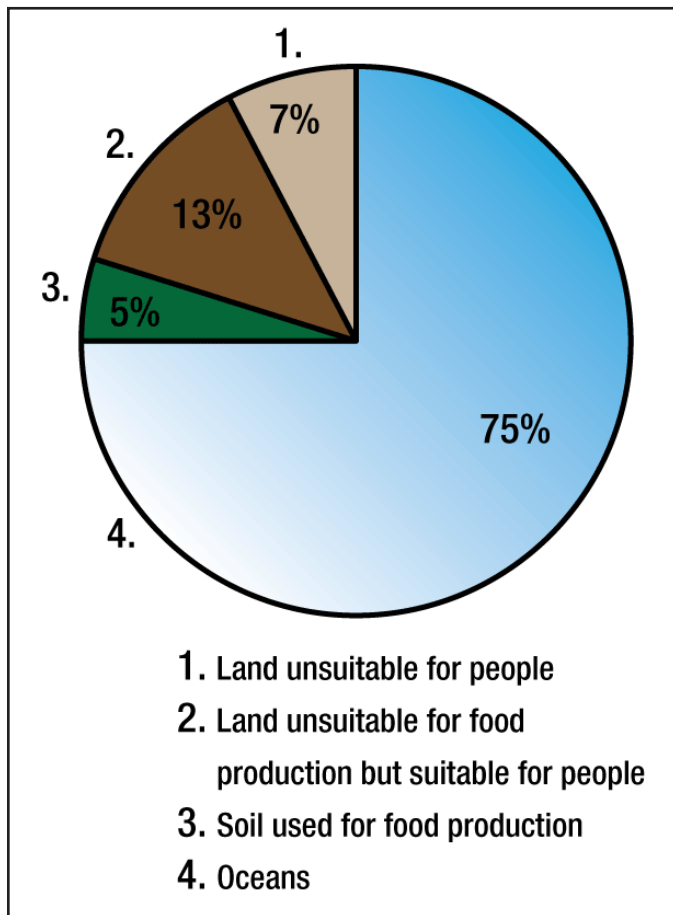
The word *interface* stresses the idea that soil is indeed a very thin rind at the earth's surface. When air meets rock, especially if the air is warm and the rock is moist, the rock begins to change. Some changes are physical. Physical changes break rocks down into smaller pieces. Other changes are chemical. Chemical changes destroy some of the original minerals (primary minerals) and create new ones (secondary minerals).

Physical and chemical changes are called **weathering**. Weather occurs primarily within the first few feet of the earth's surface. Plate 1 (p. 50-A) illustrates a highly weathered soil. Between 2 and 2.5 feet below the surface lies a thin layer of weathered rock remnants not fully changed into soil.

Now consider the size of the earth. The distance from the surface to the center of the earth is about 4,000 miles. Thus, 10 feet of weathered rock out of 4,000 miles is something less than .00005 percent of the thickness. Soil does indeed occur at the point of contact between the earth and the atmosphere. See Figure 1.2.

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Figure 1.2 – Areas of the Earth's Surface



## Reasons for Studying Soil

### Proper Use and Protection

Soil is an essential natural resource, so it is important that people know how to properly use and protect it.

Without a doubt, these are the most important reasons for studying soil. Soil is studied because the characteristics of a soil determine its potential uses and limitations. People depend on soil: it is expected to produce crops, support buildings and highways, grow trees for forests, provide places for recreation and wildlife habitat, and be a safe place for disposal of wastes.

### Resource that Supports Life

Unlike plants, people cannot manufacture their own food from the four primary resources of soil, air, water, and

sunlight. Instead, people depend completely on green plants, which take nutrients and water from the soil and combine them with air and sunlight to provide the food supply for people. Plants convert carbon dioxide into the oxygen that people breathe.

People eat garden fruits and vegetables and products made from plants such as corn, wheat, and rice. However, when people drink milk and/or eat meat products such as beef, pork, and chicken, the nutrients that originally came from plants (such as legumes and warm- and cool-season grasses) were consumed by these animals and indirectly passed on to people. Even fish depend on plants that grow in the sea, using nutrients that have been washed out of the soil and carried to the sea in rivers and streams. People study the soil, then, to increase their understanding of the resource that supports their life. Figure 1.3 illustrates human dependence on the soil.

### Soil Composition

Some people study soil because they are just curious about this unique and fascinating natural resource. When people dig a hole or scrape off a road cut, they discover right away that there is a lot more to the soil than just the top 8 to 10 inches. Soil scientists, in fact, study the soil to a depth of 5 to 6 feet or deeper. They see distinct layers, or **horizons**, in the soil. Together, the horizons make a soil profile.

The horizons in a soil profile are described in terms of their properties. Some properties, such as color and root abundance, can be determined by sight. Other properties, such as structure, require both sight and touch, while texture requires a keen sense of touch.

### Proper Management

Through the study of soil, people can learn how to tailor management practices to the specific needs of each kind of soil. Wet soils, for example, need artificial drainage for crop production. The correct way to drain them depends on just how wet and clayey they are. Many soils require irrigation for maximum productivity. Other soils have a very serious erosion hazard. The proper choice of conservation practices depends, in part, on the texture

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of the surface horizon, and the steepness and length of the slope.

The student, too, can learn how to determine the important properties of soil horizons. Students will be able to make a number of important decisions about drainage, irrigation, crop selection, erosion control practices, areas for building site development, and much, much more.

### Soil Differences

Another important reason for studying soil is to find out how soils differ. Missouri alone has nearly 1,000 different soils, ranging from very deep to very shallow, clayey to sandy, wet to dry, and nearly level to very steep. No two soils are exactly alike, just as there are no two snowflakes or fingerprints that are exactly alike. Some of the differences in soils are so slight (like variations in thickness, percent of organic matter of the surface layer, or the amount of clay in the subsoil) that it is hard to tell them apart except under close examination. Some differences are significant, such as the difference between

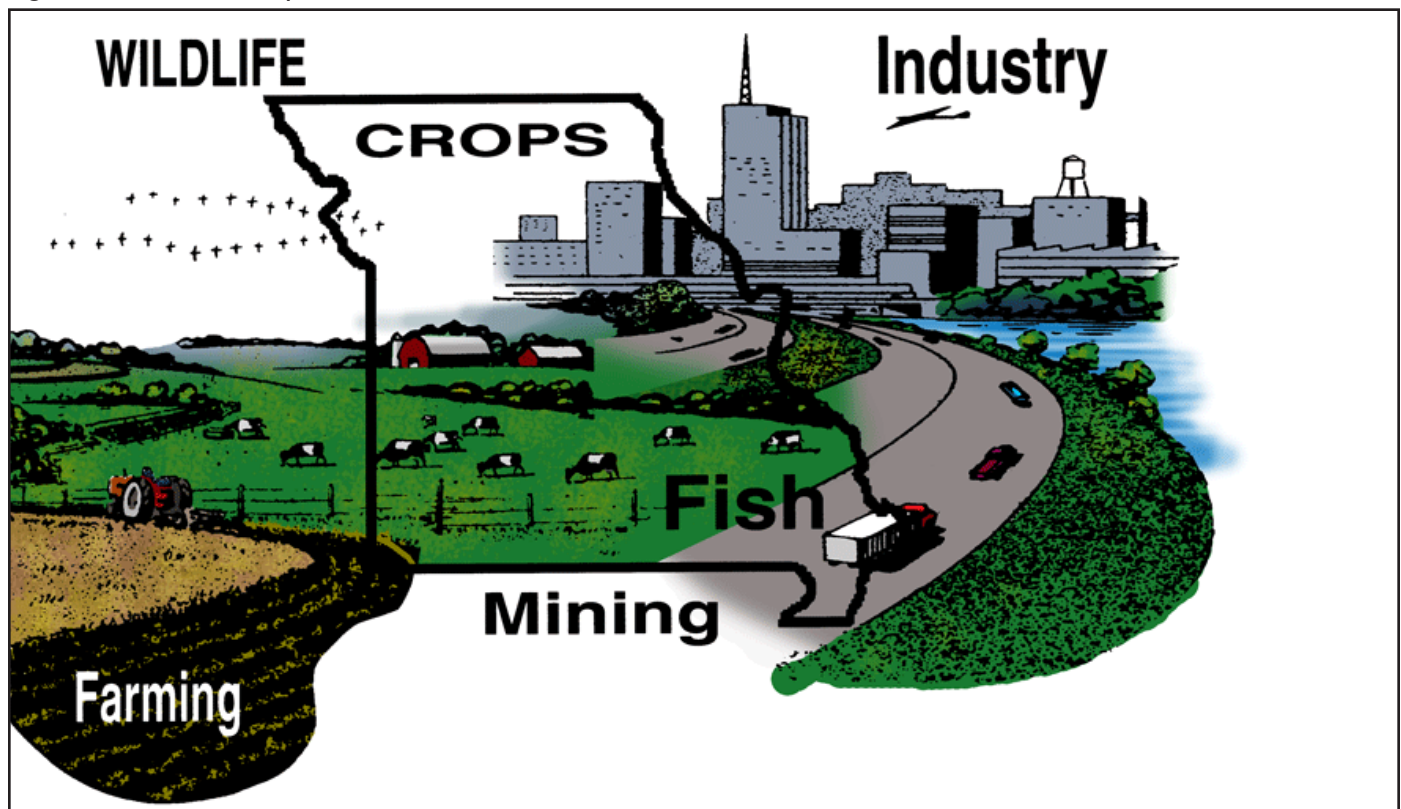
a shallow soil that is 10 inches to bedrock (the solid rock layer under the soil) compared to one that is more than 72 inches to bedrock, or a soil containing 25 percent clay compared to a soil containing 60 percent clay.

It is important to study the soil and note its properties before beginning a construction project or planting a crop. If soil properties are unknown, the results could be disastrous. Some examples:

- ◇ It is nearly impossible to construct a basement or a septic tank filter field in bedrock.
- ◇ Soils containing a high percentage of clay cause basements and highways to crack.
- ◇ Clay soils are difficult to till and crops do not grow well in them.
- ◇ Soils formed in kaolinite clay generally do not hold water for farm ponds.
- ◇ Shallow soils will not produce adequate crop production because of the lack of available water.

Even a person unfamiliar with soils can sometimes detect these differences. There are as many differences in the

Figure 1.3 – Human Dependence on Soil



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soil as there are different soil types in Missouri. Soil maps made by trained soil scientists are available for most of the land in the state. But even with soil maps, on-site evaluation is needed for very small tracts used for building sites and sanitary facilities.

## Career Opportunities in Soil Science

Soil science professionals have a wide array of career opportunities in areas such as agricultural production, natural resources, and environmental sciences.

In the agricultural production industry, soil scientists can serve as farm managers, land specialists for banks, and technical representatives for agricultural chemical companies and fertilizer firms. Soil scientists can also hold positions in government and private research institutions.

Soil scientists may serve the agricultural and natural resource sectors through public service agencies such as the Natural Resources Conservation Service, the U.S. Forest Service, the Department of Natural Resources, the Department of Conservation, and the Highway and Transportation Department. Soil scientists may also serve land based recreational industries as managers of golf courses, parks, and public gardens.

The environmental science area can be served by soil scientists working for government agencies and private consulting firms in areas such as solid waste, wastewater management, reclamation of drastically disturbed lands, and water quality issues.

## Summary

All life depends on the soil resource. People must study the soil so they can learn how to protect it for future use. There is plenty of good soil on this planet as long as people care for it properly. But if people do not protect it properly (by letting it erode, compacting it, or mining it), it will fail to support life.

Farmers are the primary stewards of the soil, for they are the tillers of the land. Everyone, however, shares the responsibility to help protect this valuable resource. If people manage the soil properly, it will continue to nourish the human race for generations to come. If people do not care for it, civilization is threatened. Students need to study the soil to learn about its properties and behavior, so they can manage it wisely and do their part as stewards of the land.

In this chapter, soil is defined, and several reasons for studying the soil are given. Soils can vary greatly, depending on many factors. Some of these differences are noted. Suggestions are made for career opportunities in soil science.

## Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.



## Lesson 2: Soil Formation

Many factors account for the differences in soils throughout the state of Missouri. For example, the climate varies considerably within the state, with the average seasonal rainfall and temperature gradually increasing from northwest to southeast. Also, the parent material from which soil forms varies from northern to southern Missouri. These factors contribute to the scarcity of gravelly soils in the north, and the abundance of gravelly soils in the south.

Soils form through processes that act on accumulated or deposited geologic (relating to the earth's natural crust) material. The characteristics of the soil are determined by the type of parent material, the organisms (plant and animal life on and in the soil), the climate under which the soil-forming factors were (and are presently) active, the topography, and the length of time that the forces of soil formation have been active.

### Factors of Soil Formation

*Soil is a living, naturally occurring dynamic system at the interface of air and rock. Soil forms in response to forces of climate and organisms that act on parent material in a specific landscape (topography) over a period of time.*

The key words in the definition of soil (dynamic, living, system, interface) tell something about how soil forms. Of the five soil-forming factors in Table 2.1, two of them, climate and organisms, are called active factors. They are catalysts that cause soil to form. The other three, parent material, topography, and time, are called passive factors. They respond to the forces exerted by climate and organisms.

Table 2.1 – Five Soil-Forming Factors

Active Factors	Passive Factors
1. Climate	3. Parent Material
2. Organisms	4. Topography
	5. Time

### Climate

Climate affects soil most directly through temperature and rainfall. In warm, moist climates, rocks and minerals weather rather quickly. Temperature affects the rate or speed of chemical activity, the kind of vegetation, and biological (pertaining to living organisms) activity. The temperature and seasonal distribution of rainfall, therefore, have a great influence on the kinds of plants that grow and how rapidly plant residues are decomposed and incorporated into the soil. Average annual rainfall and temperature may or may not be good indicators of soil formation. High intensities of rainfall and high temperature during short periods may be the dominating factors.

Rainfall causes **leaching**, or the removal of soil materials by water flowing through the soil. Free lime is completely leached from most Missouri soils, making these soils acidic. Free lime (calcium carbonate) is still present in some alluvial soils of the Missouri River flood plain and upland soils of northwest Missouri, where there has not been enough rain or time to leach the soil completely. The amount of water moving down through the soil also affects the movement of clay particles into the subsoil.

### Organisms

Organisms are in three significant groups:

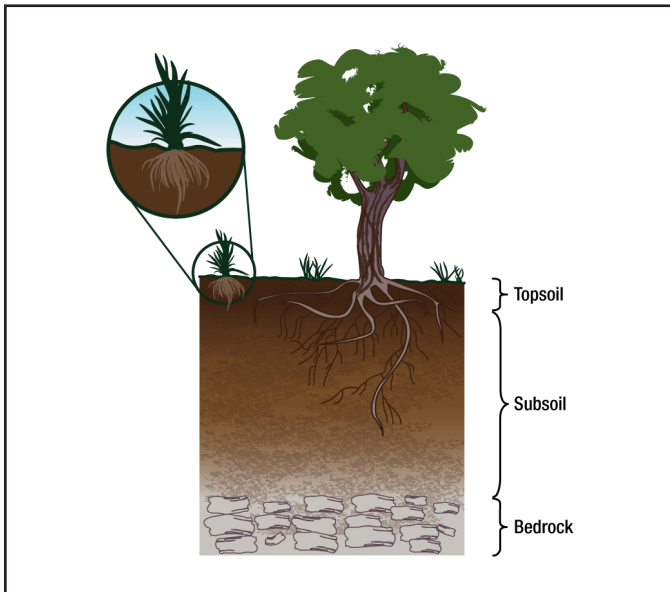
1. Living and dead macroorganisms
2. Living microorganisms
3. Finely divided nonliving material

**Macroorganisms** – Macroorganisms include large plants and animals, both living and dead. Plants die and decay, thereby building up organic matter in the soil. Living macroorganisms are the source of nearly all organic matter. The largest contributors, of course, are plants, such as grasses, woody vegetation, and trees. See Figure 2.1.

The positive effect of organic matter in the soil cannot be overemphasized. Organic matter enhances soil to influence healthy plant growth, although its presence is not considered an absolute necessity.

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Figure 2.1 – Living Macroorganisms



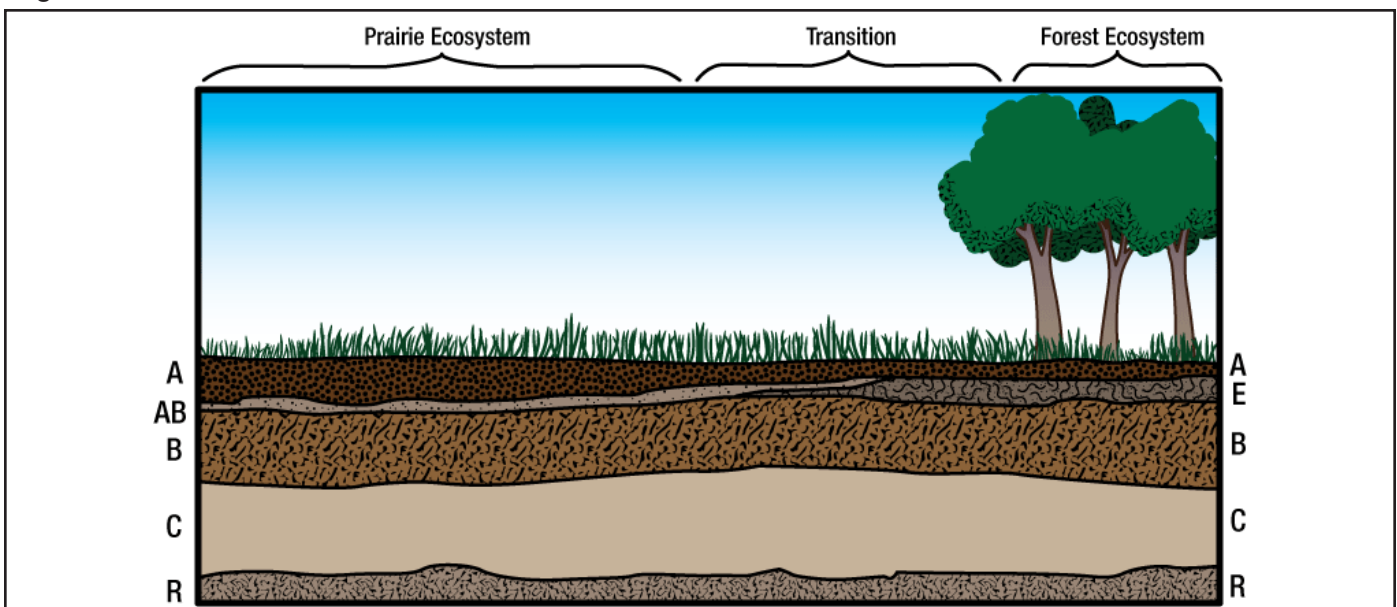
The state of Missouri has a fairly distinctive boundary between native prairie vegetation and native forest. Soils in the prairie regions of Missouri generally are high in organic-matter content because grasses have many fine roots that decay quickly each year. Soils in the forested areas generally have less organic matter because tree roots are large and woody and decay very slowly. Large plants are more than just the source of organic matter. They help break rocks apart and mix soil particles,

and root channels provide pathways for water and air movement through the soil. See Figure 2.2.

Soil animals include large burrowing animals, earthworms, insects, rodents, snakes, and myriapods. Earthworms are the best known animal conditioners of the soil. Each year they ingest and excrete tons of soil per acre. This increases the strength of soil aggregates and leaves channels that increase permeability and aeration. All of these small animals are important because they help mix the soil. Animal mixing carries plant debris that lies on the soil surface down into the topsoil. This makes it easier for the microbes to do their job of changing plant material into humus.

**Microorganisms** – Microorganisms, or microbes, have an extremely important role in soil formation. They are the primary decomposers. The microbes in the soil are made up of many tiny animals and even more tiny plants. They are microscopic in size (they can be seen only with a microscope). Bacteria, fungi, protozoa, nematodes, and algae are the major ones. Microbes cause the organic matter to decompose. They change raw plant material into a complex, dark brown or black substance called **humus**. Plant and animal residues go through many changes to become humus. At the same time, they improve soil tilth and release soil nitrogen, which is an essential nutrient that plants need in large quantities. Thus, many topsoils

Figure 2.2 – Native Prairie and Native Forest

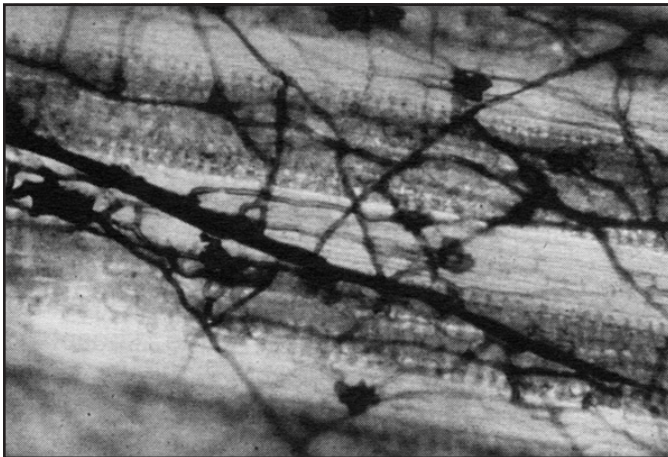


are rich and fertile because they are well supplied with humus. See Plate 2, p. 50-A. Even the earthy smell of moist, rich topsoil is caused by microorganisms.

Microbes and the humus they produce also act as a kind of glue to hold soil particles together in aggregates. Well-aggregated soil is ideal for providing the right combination of air and water to plant roots, as well as improving soil tilth and decreasing susceptibility to erosion. Without microbes, soil would be a virtually inert (lifeless) body. With them, soil is truly a living, dynamic system.

**Finely divided nonliving material** – Organic matter includes plant and animal residues at various stages of decomposition. Humus is the portion of the organic matter remaining after the major part of plant and animal residues have decomposed. It usually is amorphous (formless) and dark brown or black. The finely divided, nonliving materials are the major components of soil humus. See Figure 2.3.

Figure 2.3 – Humus Formation



*Strands of fungus surround a freshly clipped blade of grass. Decomposition is beginning and will soon convert the clipping to soil organic matter.*

### Parent Material

Parent material is the original geologic material that has been changed into the soil of today, or it is the unconsolidated mass in which soil forms. Parent material is passive because it simply responds to the changes brought about by climate and biological activity.

Many parent materials are residual and formed in place from some kind of bedrock, like limestone, shale, or sandstone. This material is called **residuum** (reh-zij-you-um). The kind of bedrock influences the texture of the soil. For example, sandstone produces sandy textures, while shale produces clayey textures. Others are deposits of sediments carried by water, wind, or ice called **transported parent materials**. Alluvium (uh-loo-vee-um), loess (luss), colluvium (kuh-loo-vee-um), and glacial till are all examples of transported parent materials.

### Topography

Topography refers to the relief or landscape. It is frequently called “the lay of the land.” See Figure 2.4. Topography influences soil formation through its effect on drainage, runoff, erosion, and exposure to sunlight and wind. It causes localized changes in moisture and temperature. Soils on south-facing slopes are drier and are also subject to more freezing and thawing than north-facing slopes. Soils on hilltops are drier than soils at the bottom of hillslopes. When rain falls on a hillslope, for example, water runs down from the top of the hill. Excess water collects at the bottom of the hill. The drier soils at the top are quite different from the wetter soils at the bottom, even if both soils form under the same overall conditions of climate, organisms, parent material, and time.

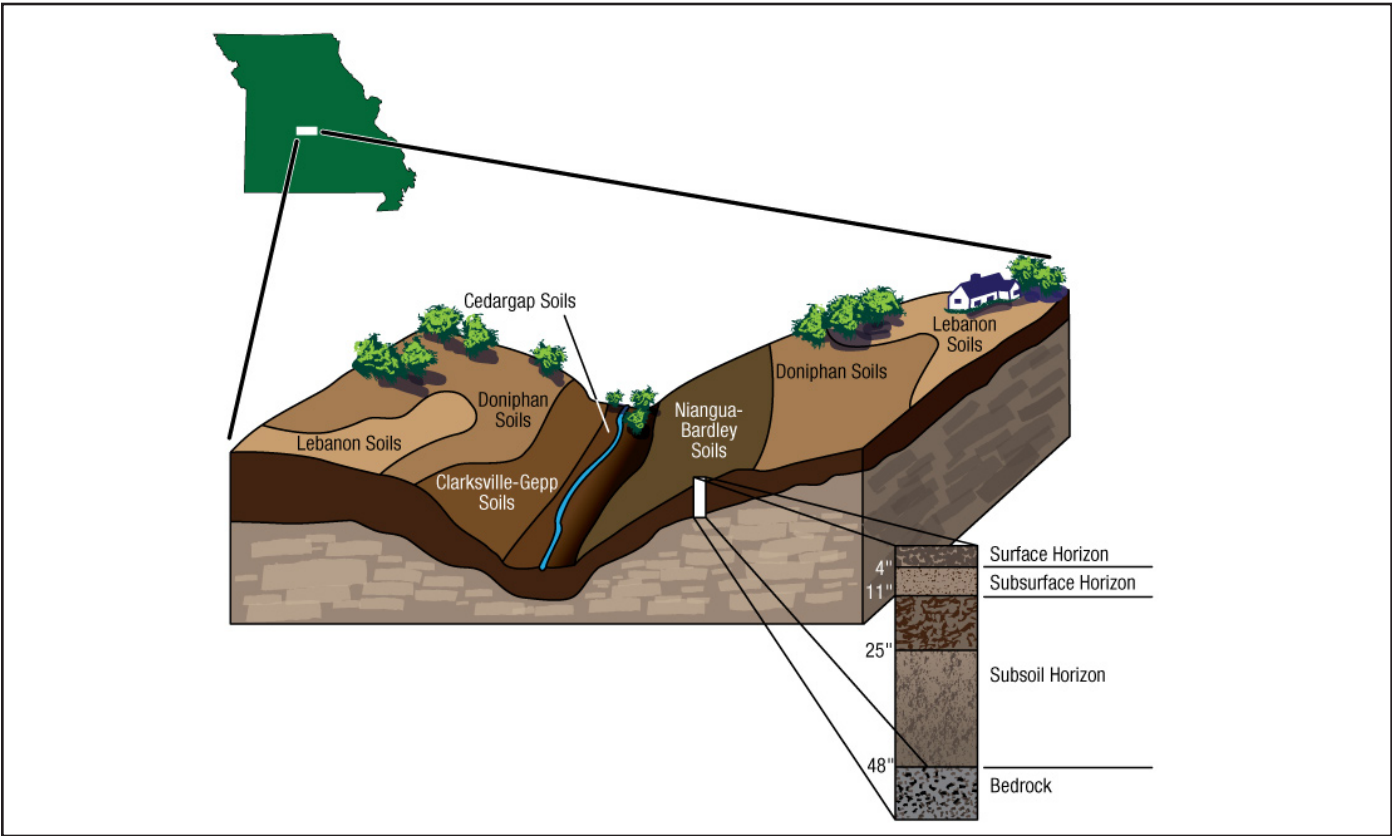
Slope influences the amount of runoff, the rate of water infiltration, the rate of leaching, the movement of clay, and the thickness of the developed soil. In steep areas, runoff is rapid and very little water passes through the soil. As a result, soil formation is slow. In gently sloping areas, runoff is slow, erosion is minimal, and most of the water passes through the soil. The infiltration of water intensifies leaching, translocation of clay, and other soil-forming processes.

### Time

Time is the great equalizer. Young soils inherit the properties of their parent materials. They tend to have the color, texture, and chemical composition of their parent materials. Later on, the influence of parent material is not as evident. The influence of time will vary with the kind of parent material. Some parent materials weather

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Figure 2.4 – Topography



faster than others. Also, climate may change over time. The prairie areas of northern Missouri are a relic of a warmer, drier climate. The youngest soils form in alluvium on flood plains. The parent material is renewed after each flood. Soils on the broad, nearly level uplands have had centuries of weathering and are some of the older soils.

The five factors of soil formation are so closely interrelated in their effects on the soil that few generalizations can be made about the effect of any one factor unless conditions are specified for the other four. Soil-forming factors are not always present in the same intensity and degree; thus, there are many differences in soils.

## Processes of Soil Formation

By the definition of soil used here, there are five **factors** of soil formation and four major **processes** that change parent material into life-sustaining soil. These processes are a result of the catalytic influences of the active factors organisms and climate. See Table 2.2.

Table 2.2 – Processes of Soil Formation

1. Additions	3. Translocations
2. Losses	4. Transformations

### Additions

The most obvious addition to the soil is organic matter. As soon as plant life begins to grow in fresh parent material, organic matter begins to accumulate. Organic matter gives a black or dark brown color to the surface soil. This is why even very young soils may have a dark-colored surface layer.

Other additions come with rainfall. On average, rainfall adds about 5 pounds of nitrogen each year to every acre of soil. Rainfall can also be acidic, especially downwind of industrial areas. Acid rain may alter the rate of some soil processes. Rainfall, by causing rivers to flood, is indirectly responsible for the addition of new sediments to the soil on a river's flood plain.



## Losses

Most losses occur by leaching. Water moving through the soil dissolves certain minerals and carries them out of the soil. Some minerals, especially salts (such as calcium chloride and sodium chloride) and lime (calcium carbonate), are readily soluble. They are removed early in a soil's formation. That is why most soils in humid regions do not contain free lime or salts. Many fertilizers, especially nitrogen fertilizers, are also quite soluble. They, too, are readily lost by leaching, either by natural rainfall or by irrigation water. Other minerals, such as iron oxides and sand grains, dissolve very slowly. They are the residual effects of weathering. They remain in the very old and highly weathered soils.

Losses also occur as gases or solids. Oxygen and water vapor are lost from soil as fresh organic matter decays. When soils are very wet, nitrogen can be changed to a gas and can be lost to the atmosphere. Solids are lost by erosion, which removes both mineral and organic soil particles. Erosion losses are very serious, for the surface soil is the most productive part of the soil profile.

## Translocations

Translocation refers to the movement from one place to another (*trans* is Latin for “across” or “through”; *locus* is Latin for “place”). Usually the movement is out of a

horizon near the soil surface into another horizon that is deeper in the soil.

One kind of translocation involves microscopic, very thin clay particles. Water moving through the soil can carry these particles from one horizon to another, from place to place within a horizon, or from the surface soil to the subsoil. See Figure 2.5.

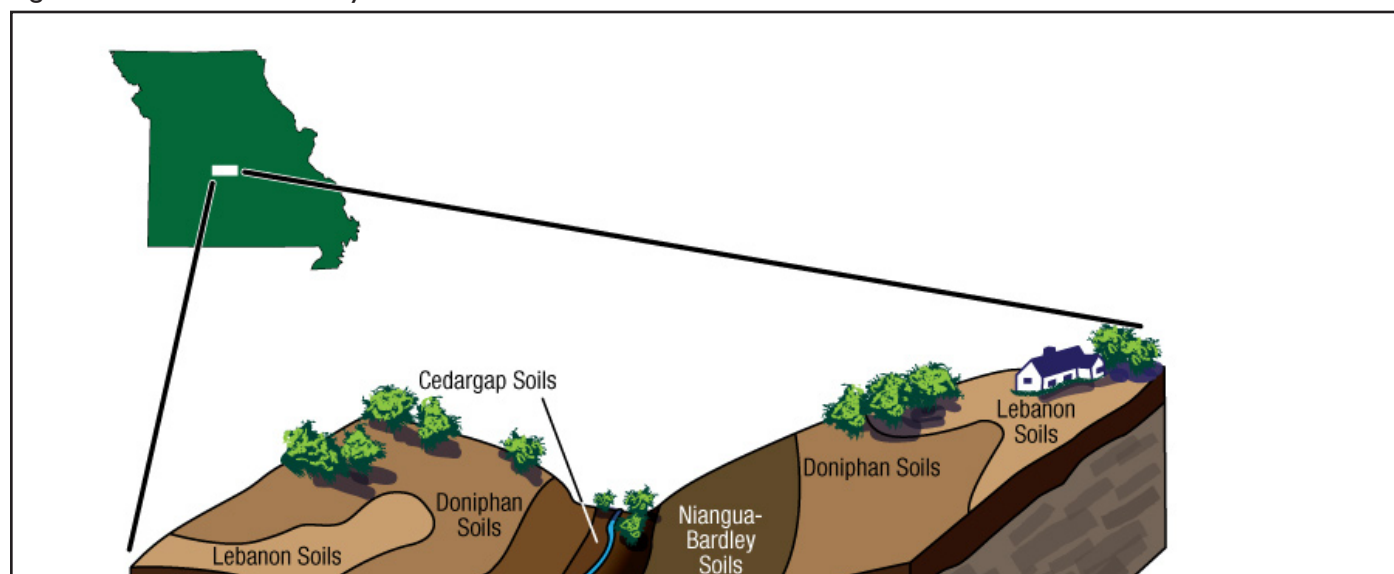
When the water stops moving, clay particles are deposited on the surface of soil aggregates. These coatings are called clay films. They have a dark, waxy appearance. A clay flow is shown in Plate 3, p. 50-A.

In low rainfall areas, leaching often is incomplete. Water moving through the soil dissolves soluble minerals. But there is not always enough water to move the soluble materials all the way through the soil. When the water stops moving and evaporates, the minerals (carbonates) are left behind. That is how subsoil accumulations of free lime are formed. A few of the soils in northern Missouri that formed in deep loess on uplands or in alluvium on flood plains have free lime throughout the soil.

## Transformations

Transformations are changes that take place in the soil (from the Latin *trans* for “across” or “through” and *formis* for “form”). Microorganisms that live in the soil feed on

Figure 2.5 – Translocated Clay



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fresh organic matter and change it into humus. Chemical weathering changes the primary minerals of parent materials. Some minerals are destroyed completely. Others are changed into secondary minerals. Many of the clay particles in soils are actually new minerals that form as a result of chemical changes.

An obvious transformation is the formation of definite structure. The rearrangement of individual soil particles into aggregates (granular, blocky, prismatic) allows greater porosity for water movement and root penetration.

Still other transformations change the form of certain elements. Iron oxide (ferric oxide) usually gives soils a yellowish-brown, reddish-brown, or red color. This process is called **oxidation**. See Plate 5, p. 50-B. In water-logged (saturated) soils, however, iron oxide changes to a different form (ferrous oxide). This process is called **reduction**. Reduced iron oxide is quite easily lost from the soil by leaching. After the iron is gone, the soil has a gray or white color. See Plate 6, p. 50-B.

Repeated cycles of wetting and drying in the soil causes oxidation or reduction of iron and manganese. See Plate 7, p. 50-B. Part of the soil is gray because of the reduction of iron, and part remains yellowish brown, reddish brown, or red where the iron oxide is not reduced.

## Processes Work Together to Form Soil

How do all these processes work together to form soil? Climate starts acting on a fresh parent material immediately. Physical weathering first decreases the size of the parent material and increases the surface area per unit volume. Chemical weathering begins to change minerals. Leaching removes salts first, then the free lime.

As soon as plants begin to grow, they add organic matter to the soil. Biological activity increases and humus forms. Soon a dark-colored surface horizon is present. This increases porosity and allows the leaching process to begin.

Weathering and leaching continue to change soil minerals and remove soluble components. More horizons develop beneath the surface. The upper part of the soil becomes

more acidic. Clay minerals begin to form. Clay is translocated and clay films become visible.

As the amount of clay in subsoil horizons increases, the rate of water movement through the soil decreases. Weathering continues, but leaching is not as rapid. After a while, further change is very slow and the whole soil-plant-landscape system is in equilibrium.

## Summary

The active factors of soil formation (climate and organisms), together with the passive factors (parent material, topography, and time) are so closely interrelated in their effects on the soil that few generalizations can be made unless conditions are known for all of them. The soil-forming processes (additions, losses, translocations, and transformations) add further variability.

Soils that formed at the same time from the same parent material can be different. For example, soils at the bottom of a hill are different from soils at the top or sides of a hill. Rainwater infiltrates the soil at the top of the hill, but the slope causes the water to rush down the sides of the hill as runoff. Soils at the bottom of the hill will be wetter and more developed than soils on the top or the adjacent slopes. Another factor to consider is the aspect of the hill. Soils on southerly aspects will be drier than those on northerly aspects. Additionally, in areas with both high rainfall and hot temperatures, soil materials weather faster than those in cool, dry areas. This explanation provides insight to the many differences in soils throughout the state.

## Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

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## Lesson 3: Soil Color

Color is one of the most noticeable properties of the soil. The organic matter content, climate, soil drainage, and mineralogy affect soil color. Most soil minerals are naturally white or light gray. Color is strongly influenced by humus and iron compounds. They change the outer color of the soil much like a coat of paint.

### Importance of Soil Color

Soil color gives clues about the nature of the root zone (the normal depth of root penetration into the soil). Dark colors mean favorable amounts of humus. Gray colors suggest unfavorable wetness. Brown and red colors indicate favorable air-water relations.

### Soil Matrix Color

The **soil matrix** refers to the main body of soil in a horizon. In uniformly colored horizons, all the soil in the horizon has the same matrix color. Some horizons, however, have two or more colors. The matrix color is the dominant color, the one that covers the greatest area and gives an overall impression of the horizon's color.

The color of most soils depends on whether the soil is moist or dry. Moist soil is nearly always darker than dry soil. One can always moisten a dry soil, but one might not always have time to wait for a moist soil to dry out to determine the color. To be consistent, therefore, always evaluate the color of the soil when it is moist. One or two drops of water will be enough to moisten a small sample of the soil.

The apparent color of a moist soil may also depend on the amount of sunlight striking the sample. The color may seem to be a little darker on an overcast day or in a shadow than on a sunny day or in open sunlight. Some variation is unavoidable, but the soil color always should be determined using the greatest amount of light available. Shades of brown, red, yellow, and black make up the majority of soil colors.

Soil color can be grouped into four broad classes: 1) dark brown, very dark brown, black; 2) light brown, brown,

yellowish brown; 3) red, reddish brown; and 4) dark gray, light gray, white.

Descriptive names are used for these classes because everyone sees colors a little differently. There is a fairly accurate way to describe soil color, but it requires a Munsell soil color chart that is quite expensive. This method is described briefly at the end of this lesson.

### ***Dark Brown, Very Dark Brown, Black***

These colors are caused by accumulations of organic matter in soils. Humus coats the soil particles, giving them a dark color. Usually, the darker the color, the more organic matter the soil contains, and the more fertile and productive is the soil.

Dark colors are typical of A horizons (the surface layer of soil). See Plates 2 and 8, pp. 50-A and 50-B. In northern Missouri soils, nearly all A horizons have this color.

That is not the case in much of southern Missouri. Organic matter content is lower; therefore, the soils are lighter in color. In general, if the lighter-colored soils have been cultivated, and much crop residue has been mixed into the Ap horizon (plow layer), then the color is probably brown or very dark brown. If the soil has not been cultivated and there is not much native vegetation, then the A horizon is likely to have a light brown color.

Some soils have black colors extending well down into the subsoil. That is usually an indication of wetness. In wet soils, organic matter breaks down very slowly and the soil is darkened by the partially decomposed organic matter that accumulates.

Some very clayey, sticky soils may be black, too. In these soils, organic matter is mixed throughout the entire soil, and the soil is black, even though the organic matter content is not particularly high.

### ***Light Brown, Brown, Yellowish Brown***

These are the colors of well-aerated soils. **Well-aerated** means that air moves freely into and out of the pore spaces of the soil. As microbes and plant roots use up

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oxygen in soil pores, oxygen from the air above the soil moves in to replace it. Well-aerated soils, therefore, provide a healthy environment for plant roots.

Brown colors are due to iron oxide coatings on mineral grains (soil particles). Chemically, they are the same as a coating of rust on a piece of iron. These iron oxide coatings require plenty of oxygen in soil pores. If water should fill soil pores and remain there for a long time, oxygen cannot reach the iron coatings, causing the soil to turn gray. That is why brown colors indicate that the soil has good air-water relations and has not been saturated for long periods of time.

Brown colors are typical of B and C horizons (lower horizons) that are well-aerated. See Plates 2 and 8, pp. 50-A and 50-B. This is true all over Missouri. As long as there is not enough organic matter to darken the soil and there is plenty of oxygen to maintain iron oxide coatings, the soil will nearly always be brown or red.

### **Red, Reddish Brown**

These colors are also caused by iron oxide coatings, and they also indicate well-aerated soil. The soil is red, rather than brown, only because the chemical form of the iron oxide is a little different.

Most red soils are very old soils and are very strongly weathered. See Plates 5 and 9, pp. 50-B and 50-C. They are more leached, more acidic, and less fertile than soils having brown colors.

Red soils occur on some of the uplands of southern Missouri. Except for the A horizon, all the other horizons in these soils usually are red. Red soils are rare in northern Missouri, but there are a few areas where the soils formed in limestone residuum and have red subsoils.

### **Dark Gray, Light Gray, White**

Dark gray soils are wet soils. When soil pores are full of water, oxygen cannot get in. Gradually the yellow-brown coatings are removed from mineral grains and are leached away. The gray color is the natural gray color of the uncoated mineral grains, darkened a little by organic

matter. Dark gray is typical of B and C horizons in wet soils. See Plates 11 and 12, p. 50-C.

E horizons (subsurface layers) are always lighter in color than the horizon above them because E horizons have lost organic matter and are leached. Some E horizons occur in wet soils. See Plates 11 and 13, pp. 50-C and 50-D. Iron is reduced and leached from the soil by water moving horizontally on top of a clayey subsoil. Other E horizons may occur in well-drained soils. In these soils, different chemical processes cause the loss of iron oxide coatings from mineral grains. These E horizons have bright-colored B horizons below them.

There are some parent materials (loess and glacial till) common in northwest Missouri that are naturally gray. It should be noted that this color is not a result of wetness. See Plate 30, p. 50-H.

## **Mottling**

Some soil horizons have spots of one color in a matrix of a different color. The spots are called **mottles**, and the soil is said to be **mottled**. Some mottles appear as splotches of reddish-brown color in a gray matrix. See Plate 7, p. 50-B. Others appear as gray mottles in a brown matrix. See Plate 14, p. 50-D. In either case, mottles show that the soil has a seasonal high water table some time during the year, usually during winter and spring months.

### **Mottling Caused by Water**

A **seasonal high water table** is the top of a zone of water-saturated soil. In this zone of saturated soil, all the soil pores are full of water. Without a supply of air, iron oxide coatings are removed from soil particles, and gray colors develop.

When the water table drops, oxygen enters the soil through root channels and large pores. Iron changes back to the yellow-brown form and coats the soil particles in contact with the air. The result is a yellowish-brown mottle surrounded by gray soil.

The depth to mottles and the abundance and brightness of the mottles are keys to the degree of wetness of the



soil. This will be discussed more fully in the section on internal soil drainage in Lesson 11. There are, however, situations in which mottles do not indicate wetness.

In recent USDA soil guides, mottles caused by soil wetness are called **Redoximorphic features**. Redoximorphic features are of several kinds. Two of the more important ones are the bright-colored mottles of yellowish brown to red that are caused by oxidation, or iron, and gray mottles that are caused by the reduction of iron. See “Transformations” in Lesson 2. Redoximorphic, often referred to as Redox, is from the words “reduction” (red), “oxidation” (ox), and “amorphous” meaning not having a definite form or shape.

In technical soil descriptions, the bright-colored mottles will be referred to as iron accumulations and the gray mottles as iron depletions. They are described by giving the Munsell color notation, size, and abundance.

### ***Mottling Caused by Chemical Weathering***

One situation in which mottles do not indicate wetness is caused by the chemical weathering of rocks. Each different mineral that makes up a rock reacts differently to chemical processes. Some minerals turn yellow, some turn red, some turn gray, and some are destroyed. The result of rock weathering can be a mixture of colors that may look like mottles caused by wetness, even though the soil is quite well drained. Many Cr horizons (soft bedrock) have this kind of mottling.

The key to correctly interpreting causes of soil mottling is to study other factors of the soil and the landscape very carefully. Concave (bowl-shaped) depressions, low-lying areas, or broad, flat terraces are landscapes that are likely to have wet soils. Mottles in these soils probably are mottles caused by wetness. Soils that have horizons that restrict water movement are also likely to have mottles caused by wetness.

Soils on rounded hilltops and sloping hillsides shed water. They are likely to be well drained. Many of these soils are not very deep to bedrock. In these soils, the lower horizons may very well contain weathered rock fragments

that look like mottles. The closer one gets to bedrock, the more mottled it might look. Brown colors throughout the soil (in addition to the shape of the landscape) indicate that these mottles are not from wetness. Remnants of original rock layering might be seen, which is another clue indicating that color variations are not caused by wetness.

### ***Coatings on Soil Aggregates***

One false interpretation of color patterns is caused by coating on soil aggregates. Organic matter coatings, clay coatings, or moisture films darken the surface of soil aggregates, particularly in B horizons.

Do not confuse these coatings with mottles. Do not judge the color of the soil matrix by the color of the coatings. Always break open a soil aggregate, and judge the color of both the matrix and the mottles from a freshly exposed surface.

Mottle patterns in soil are described in Figure 3.1 using four properties: abundance, size, contrast, and color.

## **Technical Descriptions of Soil Colors**

The more technical method of describing soil color uses Munsell color notations. These notations use three variables: hue, value, and chroma.

- Hue** – Color, such as red or yellow, or an intermediate color.
- Value** – Relative darkness or lightness of a color, from black to white.
- Chroma** – Relative purity of a color, from dull to bright.

The Munsell color notation uses symbols like 10YR 4/6. The first part (10YR) designates the color, yellowish red. The numerator of the fraction (4) is the value. This is the relative darkness of the color on a scale of 0 to 10 (0 = black, 10 = white). The denominator (6) is the chroma. It is an index of the brightness of the color on a scale of 1 to 8 (1 = dull, 8 = bright). Therefore, 10YR 4/6 denotes a dark, yellowish-brown soil.

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Figure 3.1 – Guide for Describing Mottles

**ABUNDANCE** – The percentage of exposed surface area occupied by mottles.

Classes

- ◊ *Few*: Less than 2 percent of the exposed surface
- ◊ *Common*: 2–20 percent of the exposed surface
- ◊ *Many*: More than 20 percent of the exposed surface

**SIZE** – The approximate diameter of individual mottles.

Classes

- ◊ *Fine*: Diameter less than 5 mm
- ◊ *Medium*: Diameter 5–15 mm
- ◊ *Coarse*: Diameter more than 15 mm

**CONTRAST** – The relative difference between the mottle color and the matrix color.

Classes

- ◊ *Faint*: Mottles are evident only on close examination. Mottle color and matrix color are very nearly the same.
- ◊ *Distinct*: Mottles are readily seen, though not striking. Mottle color and matrix color are different, though not widely so.
- ◊ *Prominent*: Mottles are so conspicuous that they are the outstanding visible feature of the horizon. Mottle color and matrix color are widely different.

**COLOR** – Mottle colors are described the same way as the soil matrix colors. The most common mottle colors are yellowish brown, dark reddish brown, red, and gray.

The Munsell Color Company makes small color chips for each combination of hue, value, and chroma. See Plate 15, p. 50-D. Chips of those colors that are most frequently observed in soils are arranged in special books of soil color charts. To determine soil color in the field, simply match the color of a soil aggregate with a chip of the same color. Then record the symbol for that chip. Technical descriptions of Missouri soils published either in soil survey reports or as single-sheet Official Soil Descriptions (OSDs) use this more precise method to consistently record soil colors.

## Summary

This chapter discusses the importance of soil color and describes how the matrix color of soil is identified. Soil color can be grouped into four broad classes: 1) dark brown, very dark brown, and black; 2) light brown, brown, and yellowish brown; 3) red and reddish brown; and 4) dark gray, light gray, and white. The presence of organic matter has an effect on soil color, usually making it darker. Other factors also can have an effect on soil color.

Mottling, spots in a soil matrix of a different color, is described. Causes of mottling are discussed, and ways to identify mottles are given. Mottle patterns in soils are described according to abundance, size, contrast, and color. Lastly, the Munsell color notation system is briefly described.

## Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

Soil Survey Division Staff. *Soil Survey Manual, Handbook #18*, rev. Washington, DC: U.S. Government Printing Office, U.S. Department of Agriculture, Soil Conservation Service, 1993.

Vepraskas, Michael J. *Redoximorphic Features for Identifying Aquic Conditions*, Tech Bulletin 301. Raleigh: North Carolina State Agricultural Research Service, May 1994.

## Lesson 4: Soil Texture

Soil texture is a way to describe the particle sizes of the minerals present in the soil. It has an effect on the passage of air, water, and roots through the soil. Sandy materials usually cause little restriction of air, water, and root movement through the soil, whereas clayey materials often reduce movement. Every particle makes its contribution to the nature of the soil as a whole. A good blend of soil particle sizes makes the most ideal soil.

### What Is Soil Texture?

Most soils are made up of a combination of sand, silt, and clay. **Soil texture** refers to the percentage by weight of sand, silt, and clay in a soil. Depending on how much sand, silt, and clay are present, the soils are given names like sandy loam, clay loam, or silty clay loam. Soils that also contain gravel or cobble may have names like gravelly loam or very cobbly clay.

Texture is an important soil property because it is closely related to many aspects of soil behavior. The ease of tilling and plant root development within the soil are both influenced by soil texture. Texture affects the amount of air and water a soil will hold and the rate of water movement through the soil.

Plant nutrient supplies are also related to soil texture. Tiny silt and clay particles provide more mineral nutrients to plants than large sand grains. Sandy soils require a high level of management to improve their productivity; they require more fertilizer and more frequent irrigation or rain than silty soils.

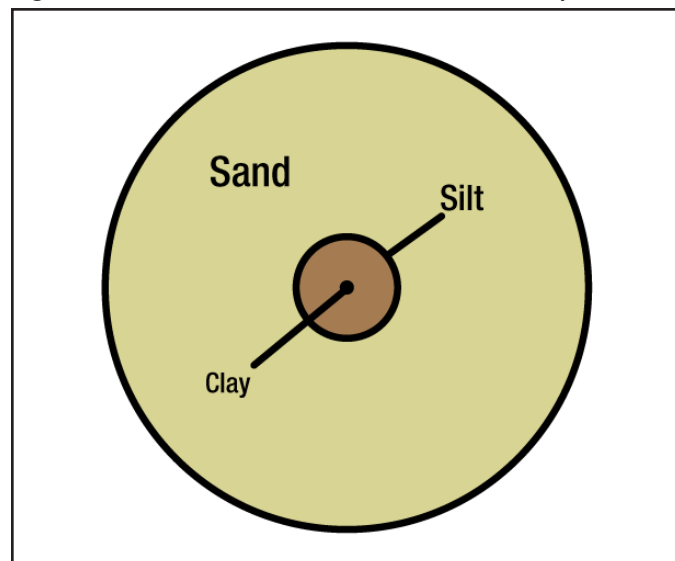
### Particle Size in Soils

The determination of soil texture begins by separating the fine earth from the rock fragments.

#### *Fine Earth*

Fine earth includes all particles smaller than 2 mm in diameter. This is the soil fraction that passes through a number 10 sieve. Sand, silt, and clay are all smaller than 2 mm and are the components of fine earth. Sand, silt, and

Figure 4.1 – Relative Sizes of Sand, Silt, and Clay



clay are called the **separates** of the fine earth. Figure 4.1 shows the relative sizes of sand, silt, and clay.

**Sand** particles range in size from .05 mm to 2 mm. They generally are spherical (rounded) and large enough to be seen without magnification. They feel gritty.

**Silt** particles range in size from .002 mm to .05 mm. They cannot be seen without a hand lens or microscope. Silt has a smooth feel, like flour or corn starch. It is not sticky.

**Clay** particles are less than .002 mm in size. They are usually flat, or plate-shaped, and can be seen only with high-powered microscopes. Clay feels sticky and can be molded into ribbons or wires.

### Classes of Soil Texture

Every soil contains a mixture of sand, silt, and clay. A textural triangle is used to show all the possible combinations. The triangle is also used to form groups of soil textures, which can then be identified with a textural name. See Figure 4.2.

Any soil textural name will have a specific range of sand, silt, and clay. For example, a soil that is nearly all sand would lie close to the sand corner of the triangle. Its textural class name would simply be sand. A soil dominated by clay

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would be near the clay corner of the triangle. It would simply be named clay.

Now consider a balanced mixture of sand, silt, and clay. All three separates are present, though not in exactly equal proportions (Actually, it takes less clay to balance the mixture than either sand or silt). These soils lie near the center of the triangle and are called **loams**.

If more sand is added to a balanced mixture of sand, silt, and clay, the sand would begin to dominate. The mixture would move away from the center of the triangle toward the sand corner. The texture would change from loam to sandy loam, and ultimately to a sand.

If clay is added to a loam, first the texture would change to a clay loam, then to a clay. If both silt and clay are added, the texture would move away from sand toward something intermediate between silt and clay. The texture becomes a silty clay loam.

Precise boundaries between textural classes are shown in Figure 4.3. Each side of the triangle is a base line, or zero point, for the separate in the opposite corner. A scale runs from zero percent at the middle of each base line up to 100 percent at the corner. If the amount of sand, silt, and clay is known, the location on the triangle can easily be plotted and the textural class can be identified.

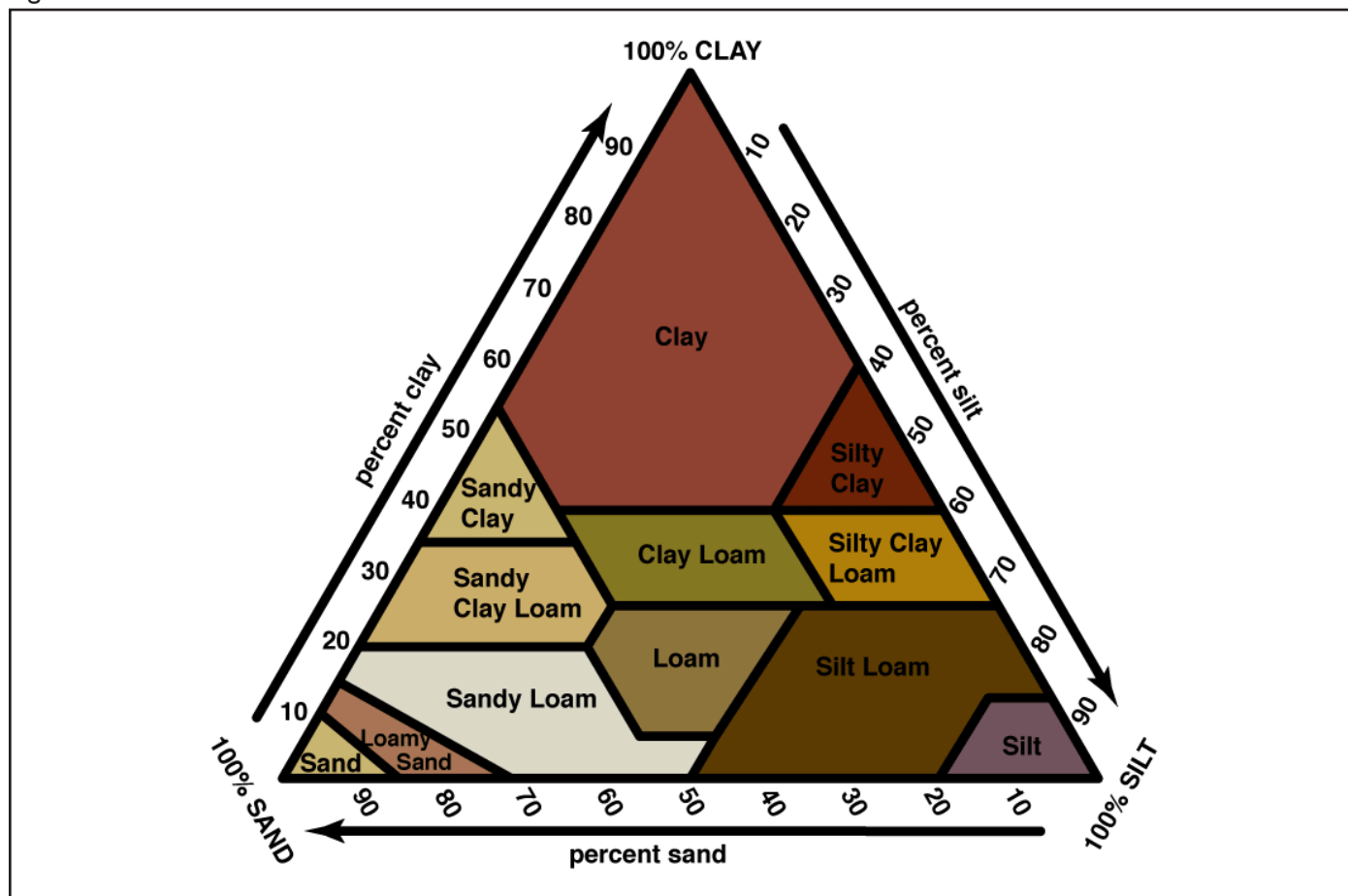
### Determining Soil Texture

Soil texture can be determined from the results of a laboratory analysis or from a field estimate. Both methods are as follows.

#### Laboratory Analysis

Suppose the laboratory analysis shows that a soil contains 40 percent sand, 45 percent silt, and 15 percent clay. For this example, start with the clay content (although one could start with either silt or sand). Go to the midpoint

Figure 4.2 – USDA Soil Textural Classes





of the baseline running from sand to silt. Then go up to the horizontal line at 15 percent. Every soil along this line contains 15 percent clay.

Next, go to the midpoint of the baseline running from silt to clay. This line represents zero percent sand. Move along the sand scale, down and to the left, until the 40 percent line is reached. Then move down the 40 percent sand line until it intersects the 15 percent clay line. Mark that point. One can find the 45 percent silt line and track it to the same point. This sample is a loam. Note, however, that it only takes two points to determine the texture.

## Field Estimate

Actually, one needs to learn only four key points on the textural triangle: 27 percent clay, 40 percent clay, 20 percent sand, and 45 percent sand. See Table 4.1. These points do not exactly match the textural class boundaries

in Figure 4.3, but they are close enough to make good estimates.

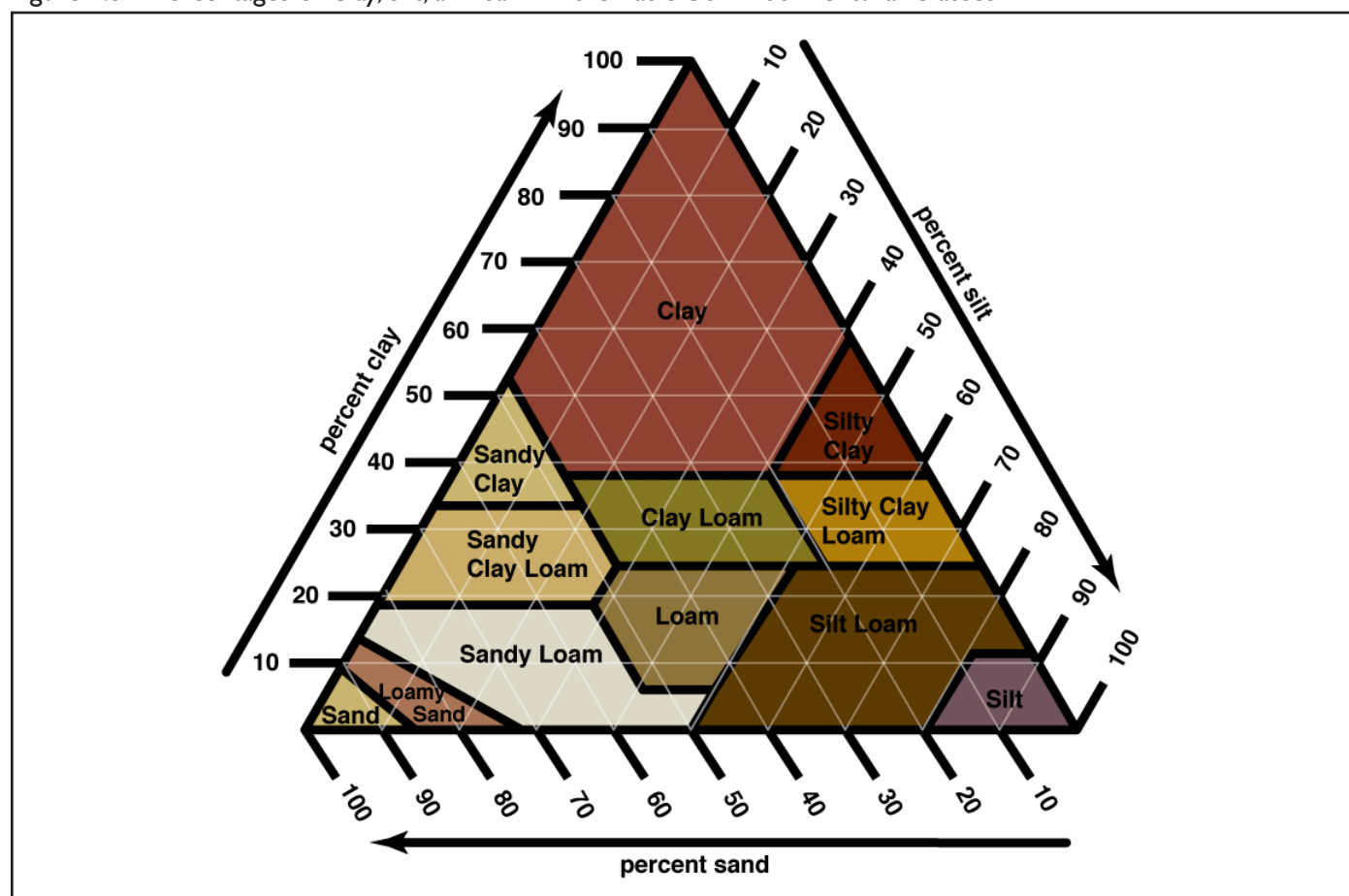
Table 4.1 – Four Key Textural Points

45 percent sand	27 percent clay
20 percent sand	40 percent clay

Study the locations of these key values in Figure 4.3 very carefully. Note that none of the texture names below 27 percent clay contain the word “clay.” Texture names between 27 and 40 percent clay contain both the words “clay” and “loam.” Texture names above 40 percent clay contain on the word “clay” unless it contains very little sand on one side or very little silt on the other side. Texture names above 60 percent clay contain only the word “clay.”

Similarly, clayey soils having more than 45 percent sand all have names that include the words “sand” or “sandy.”

Figure 4.3 – Percentages of Clay, Silt, and Sand in the Basic USDA Soil Textural Classes



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If there is less than 20 percent sand, then “silt” or “silty” is usually part of the name. If the soil contains between 20 and 45 percent sand, “sand” is not part of the name. There is one exception between sandy loam and loam, which is 52 percent.

Additional clues to the way each kind of soil texture feels are given in Figure 4.4. The effect of these different textures on permeability, available water capacity, and erosion hazard will become clearer when specific interpretations of soil behavior are discussed.

Field estimates are determined by working the soil between the thumb and fingers and estimating the amounts of sand, clay, and silt. First, estimate the amount of sand by the grittiness. Next, estimate the amount of clay by the length of the ribbon formed. The rest of the content is silt. For example, if the amount of grittiness indicates sand content of less than 20 percent, the amount of ribbon formed indicates clay content greater than 40 percent, the rest of the content is silt (perhaps 35–40 percent). A step-by-step procedure for estimating the soil texture by feel is given in Figure 4.5.

Figure 4.4 – Clues to the Feel of Textural Classes

### **SAND**

- ◇ Moist sample collapses after squeezing.
- ◇ Your hands don’t get dirty working the sample.

### **LOAMY SAND**

- ◇ Sample has very little body.
- ◇ Moist soil barely stays together after squeezing.
- ◇ Just enough silt and clay to dirty your hands.

### **SANDY LOAM**

- ◇ Sand dominates noticeably.
- ◇ Enough silt and clay to give the sample body.
- ◇ Moist soil stays together after squeezing.
- ◇ Hardly forms any ribbon at all.

### **SANDY CLAY LOAM**

- ◇ Feels gritty and sticky.
- ◇ Forms ribbon 1–2 inches (2.5–5 cm) long.

### **SANDY CLAY**

- ◇ Feels definitely sandy.
- ◇ Forms ribbon 2–3 inches (5–7.5 cm) long.

### **LOAM**

- ◇ Sand noticeably present, but doesn’t dominate.
- ◇ Sample works easily between thumb and fingers.
- ◇ Contains enough silt and clay to give sample good body.
- ◇ Sample only forms short, broken ribbons.

### **SILT LOAM**

- ◇ Feels smooth, like flour or corn starch.
- ◇ Tends to be nonsticky.
- ◇ Only forms short, broken ribbons.

### **CLAY LOAM**

- ◇ Noticeably gritty, but sand doesn’t dominate.
- ◇ Noticeably sticky.
- ◇ Noticeably hard to work between thumb and fingers.
- ◇ Forms ribbon 1–2.5 inches (2.5–6 cm) long).

### **SILTY CLAY LOAM**

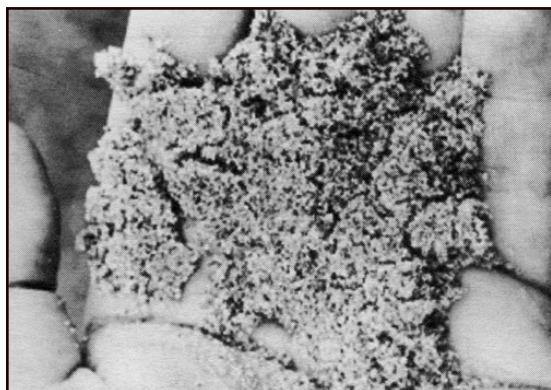
- ◇ Feels smooth and sticky.
- ◇ Contains very little sand.
- ◇ Forms ribbon 1–2.5 inches (2.5–6 cm) long.

### **CLAY AND SILY CLAY**

- ◇ Dry sample absorbs a lot of water before it is moist enough to work.
- ◇ Sample very hard to work between thumb and finger.
- ◇ Forms ribbon 2.5–4 inches (6–10 cm) long.

Figure 4.5 – Estimating Texture by Feel

1. Fill the palm of your hand with dry soil.
2. Moisten the soil enough so that it sticks together and can be worked with the fingers. Do not saturate it to runny mud. If the soil sticks to your fingers, it is too wet to texture. Add more dry soil.
3. Knead the soil between your thumb and fingers. Take out the pebbles, and crush all the soil aggregates. You may need to add a little more water.
4. Continue working the soil until you crush all the aggregates.
5. Estimate the **sand** content by the amount of textural grittiness you feel. Use the following chart on estimating sand content.
  - a. More than 45% sand. Sand dominates. The textural name contains the word *sand* or *sandy*. See photo A.
  - b. 20–45% sand. Sand is noticeably present, but not dominant. The texture is most likely *loam* or *clay*



**Photo A** – Sand texture: Individual sand grains are evident and little or no fine soil particles are present in this moist sand sample.



**Photo B** – Loam texture: This moist loam soil clings together well but small cracks, a rough surface, and shiny, fine sand grains are evident when pressed between the fingers.

- c. Less than 20% sand. Silt and clay dominate. The textural name is *silt loam*, *silty clay loam*, or *clay*.
6. Estimate the **clay** content by the size of the soil ribbon formed by pushing the sample up between your thumb and index finger.
  - a. Clay is less than 27%. A ribbon is not present or it is less than 1 inch (2.5 cm) long. Textural names contain the word *loam* but not the word *clay*. See photo B.
  - b. Clay is 27–40%. The ribbon is 1–2.5 inches (2.5–6 cm) long. Textural names contain both the words *clay* and *loam*.
  - c. Clay is more than 40%. Clay dominates. The ribbon is more than 2.5 inches (6 cm) long. Textural name contains the word *clay* but not the word *loam*. See photo C.
7. Combine your estimates of sand and clay.

These are general and will not fit every possibility on the textural triangle. An alternate way of estimating soil texture is given in the flowchart in Figure 4.6.

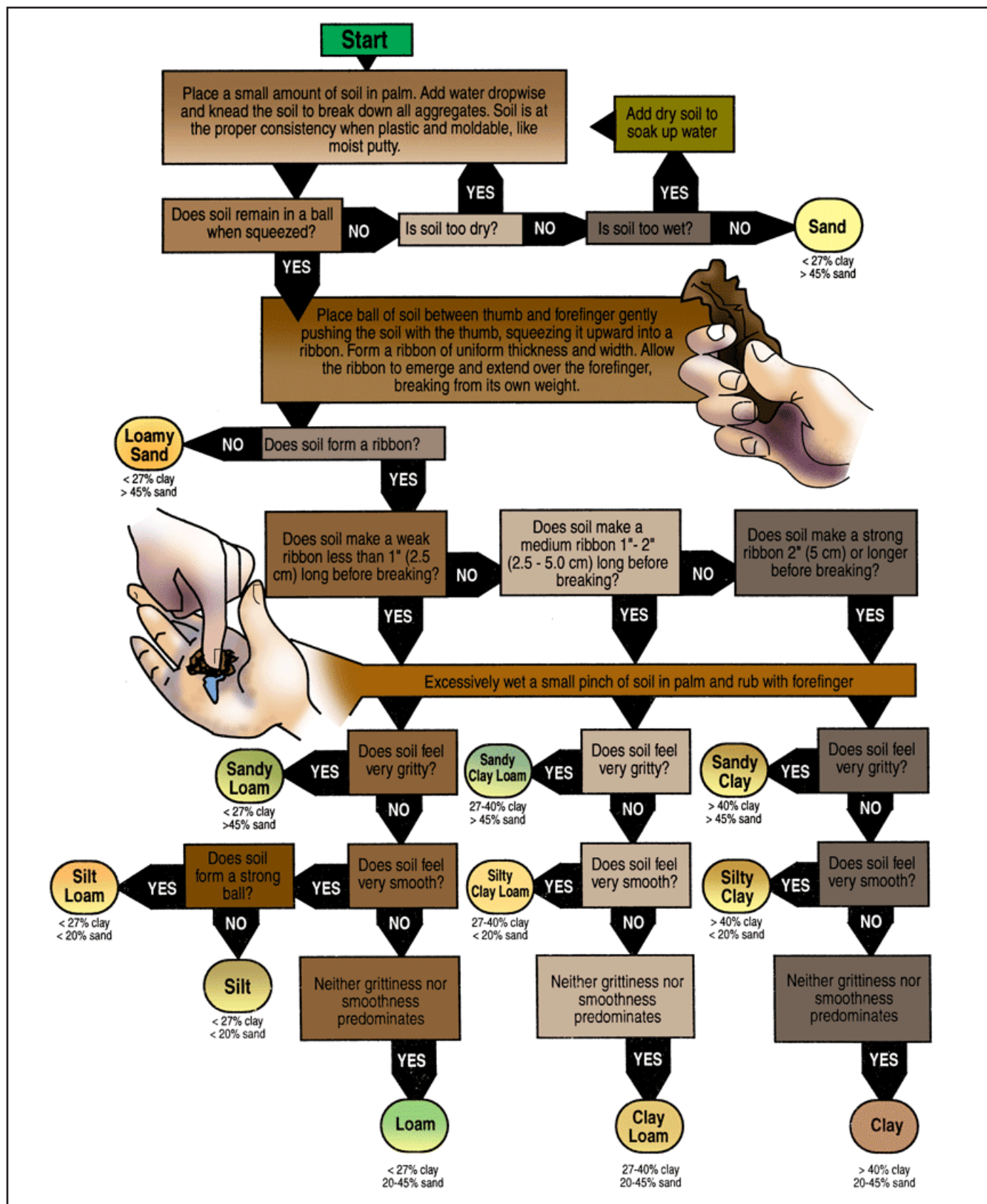


**Photo C** – Clay texture: A firm ribbon of soil with a slick, shiny surface is clearly evident when pressed between the fingers.

		SAND		
		>45%	20-45%	<20%
CLAY	>40%	Sandy clay	Clay	Silty clay Clay
	27-40%	Sandy clay loam	Clay loam	Silty clay loam
	<27%	Sandy loam Loamy sand Sand	Loam	Silt loam

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Figure 4.6 – Flowchart for Estimating Textural Classes



Flowchart courtesy of Dr. Steve J. Thien.



## Rock Fragments

**Rock fragments** include all fragments larger than 2 mm including boulders. Rounded rock fragments 2 mm to 25 cm (10 inches) are called gravel and cobbles. Flat rock fragments 2 mm to 37.5 cm (15 inches) long are called channers and flagstones. In USDA engineering guides, gravel, cobbles, channers, and flagstones are used differently in some soil interpretations than those which are more than 10 inches (25 cm) in size (rounded) or more than 15 inches (38 cm) in size (flat). Rounded rock fragments larger than 10 inches (25 cm) and flat rock fragments larger than 15 inches (38 cm) are called **stones** and **boulders**. They are described as characteristic of the site and are discussed in Lesson 11. The quantity of rock fragments in the soil greatly affects the available water capacity and ease of tillage. It should be noted that the term “coarse fragment” is not in common use in the most recent literature.

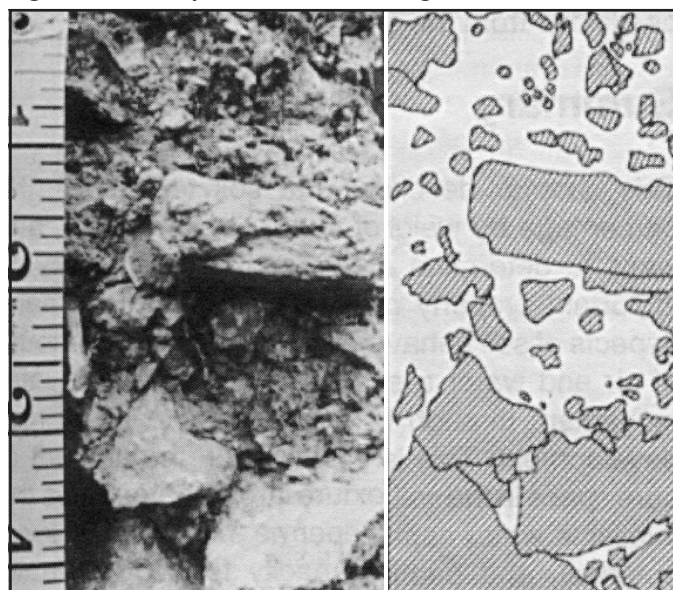
## Rock Fragments Used to Modify Texture

Soil textural names based on the fine earth must be modified if the soil contains a significant amount of gravel or cobbles. The two most common kinds of rock fragments in Missouri soils are gravel and cobbles. **Gravel** refers to rounded rock fragments with diameters between 2 mm and 3 inches (7.5 cm). **Cobbles** are rounded or partly rounded, with diameters of 3–10 inches (7.5–25 cm). See Plate 16, p. 50-D. Rock fragments that are more nearly flat than rounded are measured differently than gravel or cobbles and are called channers or flagstones, depending on their size. A **chanter** is 2 mm to 6 inches (15 cm) in length. **Flagstones** range from 6 to 15 inches (15–38 cm) in length.

Rock fragment names depend on the volume of the soil mass occupied by the fragments. See Figure 4.7.

One can estimate the volume by looking at the vertical surface exposed in a soil profile. If 50 percent of the surface consists of fragments, then 50 percent of the soil volume is fragments as well. See Plates 9, 17, and 18, pp. 50-C and 50-E.

Figure 4.7 – Fifty Percent Rock Fragments



*A section of rocky silt loam surface soil. The adjacent diagram outlines exposed rock fragments in a vertical cut.*

Once both the percentage by volume and the dominant size of fragments are known, the correct modifier can be found in the key in Table 4.2. If a soil contains both gravel and cobbles, at least 60 percent of the fragments must be gravel to use the gravelly term. If more than 40 percent of the fragments are cobbles, use the cobbly term. The same calculations are made if the rock fragments are channers or flagstones.

## Pore Space (Soil Porosity)

The soil is made up of solids (for example, soil particles such as sand, silt, and clay) and pore space. Texture is the distribution of sand, silt, and clay particles. **Pore space** is the space between the soil particles. One might think of pore space as just open space, but that really is not true. Pore space contains air and/or water. See Figure 4.8.

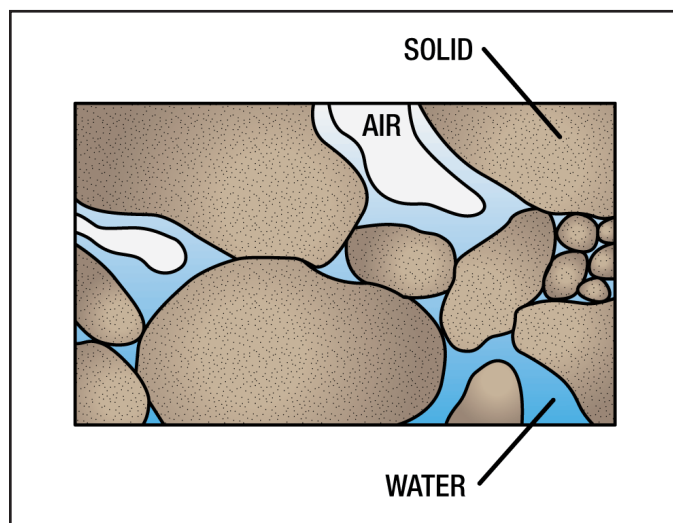
The A horizon (surface soil) contains approximately the same amounts of solids and pore space. The B and C horizons (lower layers) usually contain somewhat less than one-half pore space because of the finer soil

## Soil Science

Table 4.2 – Key to Naming Rock Fragment Modifiers

PERCENT BY VOLUME	GRAVEL (2 mm–3 inches, 7.5 cm) CHANNER (2 mm–6 inches, 15 cm)	COBBLE (3–10 inches, 7.5–15 cm) FLAGSTONE (6–15 inches, 15–38 cm)
<15	No modifier	No modifier
15–35	Gravelly/channery	Cobbly/flaggy
35–60	Very gravelly/very channery	Very cobbly/very flaggy
>60	Extremely gravelly/extremely channery	Extremely cobbly/extremely flaggy

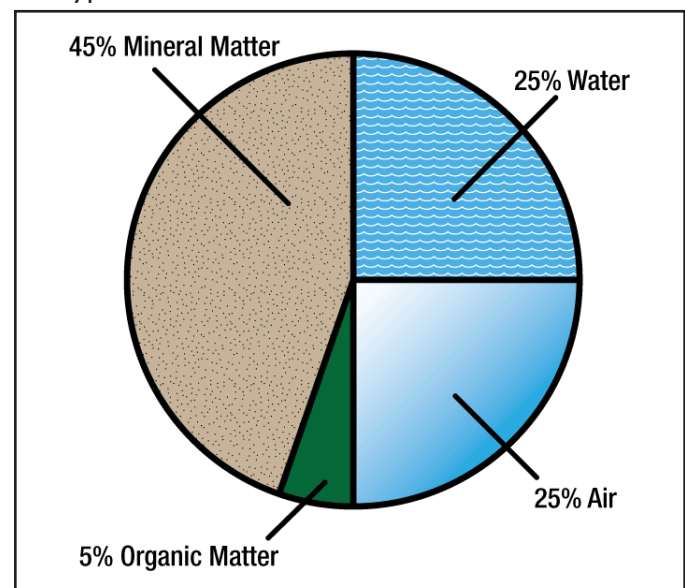
Figure 4.8 – Pore Space Filled With Water or Air



particles. This relationship depends on the size of the soil particles and the soil structure. The pore space in clayey soils is so small that it is always filled with a very thin film of water that is unavailable to plant roots. Also, the pore space available for air is too little for adequate soil aeration. A mixture of large and small pores is the most desirable in the soil. Pore space often is referred to as **soil porosity**. The relative amounts of solids, air, and water in the soil are very important for good plant growth. See Figure 4.9.

Also important to soil porosity is a good mix of the soil separates (sand, silt, and clay). A sandy soil has mostly large pore spaces but cannot hold the water as it passes on through the profile; therefore, the soil is droughty (very low water capacity). Clayey soil has many tiny

Figure 4.9 – Relative Volumes of Solids, Air, and Water in a Typical A Horizon



pore spaces that are completely filled with a thin film of hygroscopic water that will not allow good aeration or infiltration of water through the profile. Soils that have a good balance of particle sizes will have the best balance of pore space size, and thus will have the best soil properties for maximum plant growth. See Lesson 10 for more information.

Excessive tillage will cause compaction and reduce pore space. Minimum tillage will leave more plant residue and allow for an increase in root growth, organic-matter content, and better aeration. Without adequate pore space, the soil would not be a good place for roots to grow.

### Factors Affected by Soil Texture

When soil is wet, it can swell, and when it dries, it can shrink. This phenomenon is called **shrink-swell**. Soil texture affects the shrink-swell potential of the soil, which in turn affects how buildings and highways are designed to prevent damage from cracking. See Plate 19, p. 50-E.

Soil texture in relation to the content of rock fragments greatly affects the bearing capacity of the soil for roads, heavy buildings, and earthen dams. Soil texture affects the functioning of septic tank filter fields and sewage lagoons. It affects the available water capacity, tillage of crops, and the leaching of pesticides from the soil.

### Summary

This chapter describes what soil texture is (the percentage by weight of sand, silt, and clay), and ways to determine soil texture. Texture is a very important property of soil, and is related to many aspects of soil behavior. Texture affects the amount of air and water a soil will hold, the rate of water movement through the soil, and the ease of root development. This is dependent on the amount of pore space in the soil. Texture largely determines the available

water capacity, permeability, shrink-swell potential, and bearing capacity for roads, heavy buildings, and dams.

Soil texture can be determined by laboratory analysis or by an estimate in the field by working the soil between the thumb and fingers. Textural class names are determined using a textural triangle. Soil textural names based on the fine earth must be modified if the soil contains a significant amount of rock fragments.

### Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*, Corvallis: Oregon State University Extension Service, 1984.

Soil Survey Division Staff. *Soil Survey Manual, Handbook #18*, rev. Washington, DC: U.S. Government Printing Office, U.S. Department of Agriculture, Soil Conservation Service, 1993.

Soil Survey Division Staff, Lincoln, Nebraska. *National Soils Survey Handbook* (Title 430-VI). Washington, DC: U.S. Department of Agriculture, Soil Conservation Service, 1993.



### Lesson 5: Soil Structure

Two soils with the same texture may have distinctly different physical properties because of the arrangement of soil particles. The arrangement of individual soil particles into different size units or peds is called **soil structure**. Topsoil structure is the most observable and is easier to amend or destroy than the subsoil structure.

#### What is Soil Structure?

Weathering converts parent material into soil. Shrinking and swelling (caused by wetting and drying, freezing and thawing) and root penetration cause shifting, loosening, and forming of pore space. Microbes, plants, and animals produce cementing agents that bind and stabilize the soil into units. This is a never-ending process, unless interfered with by cultivation. As a result, soil structure becomes stronger and more distinct with time.

Soil structure forms when individual grains of sand, silt, and clay are bound together physically and/or chemically. Plant roots, organic matter, and clay particles all provide physical and chemical binding agents. These bound particles form larger units called **peds**. A ped is a single unit of soil structure. A ped ranges in size from about 1 mm to 10 cm. The shape of the peds formed determines the type of structure: granular, platy, blocky, or prismatic. See Figure 5.1.

#### Importance of Soil Structure

Soil structure is important because it modifies some of the desirable and undesirable effects of texture on soil behavior. Structure creates relatively large pores, which favor water entry into and movement within the soil. Even clayey soils, which tend to have tiny pores, can have good rates of water infiltration if they have a well-developed A horizon structure. Good soil structure also means good aeration and a favorable balance between pores that contain air and pores that store water for plant use. Soils with good structure are easy to till and provide ideal environments for plant root growth. In short, good structure means better tilth in the topsoil.

Soil structure can be destroyed by over-tilling or tilling when the soil is wet. Over-tilling destroys the soil structure because aggregates are crushed. Tilling when the soil is wet compacts the soil and causes it to puddle, or run together. The pore spaces collapse and the soil structure is destroyed. Structure can also be destroyed when organic matter is reduced through burning or removing residues.

In poor soil structures, the pore space is reduced. Infiltration rates and aeration are adversely affected, making it difficult for plants to grow.

#### Formation of Soil Structure

Organic matter is vital to the formation and maintenance of good soil structure. Organic matter tends to aggregate (clump) tiny soil particles, especially clay, into small clumps that have definite shapes. Some topsoils of northern Missouri are naturally high in organic matter. The structure in these areas tends to be well developed, and the soil resists breakdown from tillage and raindrop impact. Many southern Missouri topsoils are naturally low in organic matter. The soil structure tends to be weakly formed and unstable. These soils have a higher erosion hazard.

Maintaining the organic-matter content is essential to sustain good soil structure. Mixing animal wastes and crop residues into the soil is an excellent way to do this. One of the real benefits of conservation tillage programs is the use of crop residues to form stable soil structures.

#### Types of Soil Structure

Common types of soil structure include granular, platy, blocky, and prismatic. Soils that do not have peds are said to be either **massive** or **single grain**. “Massive” and “single grain” do not refer to structure; they are terms used if the soil is structureless. Each of the common structure types is illustrated and described in Figure 5.1.


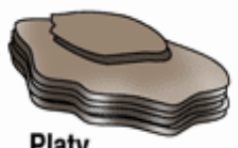




#### Compound Structure

Some soil horizons have large structural aggregates that can be further subdivided into smaller aggregates of a different shape. Examples are blocks that break into



# Soil Science

Figure 5.1 – Types of Soil Structure

STRUCTURED	
 <p><b>Granular</b></p>	<p><b>GRANULAR</b></p> <p>Granular structure is roughly spherical, like Grape Nuts™ cereal. The structure is usually 1–10 mm in diameter. It is most common in surface horizons (A horizons) where plant roots, microorganisms, and sticky products of organic matter decomposition bind soil grains into aggregates.</p>
 <p><b>Platy</b></p>	<p><b>PLATY</b></p> <p>Platy structure consists of flat peds that lie horizontally in the soil. Most are less than 2 cm thick. Platy structure is not common, but occurs mostly in subsurface horizons or dense layers (E and Bx horizons).</p>
 <p><b>Angular</b></p> <p><b>Subangular</b></p>	<p><b>BLOCKY</b></p> <p>Blocky structure consists of peds that are roughly cube-shaped with generally flat surfaces. Blocky structures are divided into two types: <b>angular blocky</b> structure has edges and corners that remain sharp, whereas <b>subangular blocky</b> structure has edges and corners that are rounded. Sizes commonly range from 5 to 50 mm across. Blocky structures are typical in the subsoil (B and Bt horizons). They form by repeated expansion and contraction of clay materials.</p>
 <p><b>Prismatic</b></p> <p><b>Columnar</b></p>	<p><b>PRISMATIC</b></p> <p>In prismatic structure, peds are taller than they are wide. They often have five sides. Sizes are commonly 10–100 mm across. Prismatic structure is most common in the lower part of the subsoil (B and BC horizons). The prisms in some strongly developed soils have rounded tops because the tops have lost their corners by eluviation (downward movement of material). These prisms are called <b>columnar</b>.</p>
STRUCTURELESS	
 <p><b>Single Grain</b></p>	<p><b>SINGLE GRAIN</b></p> <p>In some very sandy soils, every grain acts independently and there is no binding agent to hold the grains together into peds. Permeability is rapid, but fertility and available water capacity are low.</p>
 <p><b>Massive</b></p>	<p><b>MASSIVE</b></p> <p>Compact, coherent soil is not separated into peds of any kind. Massive, claylike soils usually have very small pores, slow permeability, and poor aeration.</p>

**Note:** There are some terms that may be unfamiliar at this time. If more information on horizons is needed, see Lesson 6.

plates and prisms that break into blocks. Technical soil descriptions would include both situations.

### Grades of Soil Structure

The grade of soil structure refers to the strength and stability of structural peds. Structural grade is described using the terms **strong**, **moderate**, and **weak**.

Strong structures are stable structures. They provide favorable air-water relations and good soil tilth. Weak structures are unstable. Their surface soil readily slakes (breaks down) and seals (forms a crust) when irrigated or tilled. Weak structures slow down water movement into and within the soil and increase the erosion hazard. See Figure 5.2.

Figure 5.2 – Grades of Soil Structure

**Strong:** The units (peds) are distinct in undisturbed soil. They separate cleanly into whole units when the soil is disturbed. See Plate 6, p. 50-B.

**Moderate:** The units (peds) are well formed and evident in undisturbed soil. They part into a mixture of whole peds and broken units when the soil material is disturbed.

**Weak:** The units (peds) are barely observable in place. Most become broken when the soil material is undisturbed.

Two aspects of structural development work together to indicate the grade:

1. How well the entire soil mass is subdivided into distinct peds.
2. How well the grains in individual peds are held together to resist breakdown and give the peds stability.

### Determining Type and Grade of Soil Structure

The grade and type of soil structure can be determined by carefully observing the soil and by gently breaking it apart.

1. The first step is to study a large aggregate of soil to see if structural peds are evident. If you can detect the shapes of individual peds, then the grade is probably strong.
2. The next step is to fill your hand with a large aggregate of soil. Observe how easily the soil aggregate breaks out into your hand. The easier it breaks out, the stronger the structure. Observe also the shapes of the peds that lie in your hand.
3. Then, hold a large piece of the soil in both hands and gently apply pressure to break the soil apart. If the soil breaks easily along a natural plane of weakness, it has separate into distinct peds. If the soil fractures randomly, leaving an irregular, dull surface, a break has forced through a ped.
4. The ease with which the soil mass breaks into peds and the amount of unaggregated soil that remains indicates the structural grade. The shapes of the peds broken out of the soil indicate the structural type.

### Improving Soil Structure

Although soil structure becomes stronger and more distinct with time, it is not easy to improve and it usually takes several years if the structure is really weak. The most effective methods for improving soil structure in the surface layer are good residue management and use of minimum tillage, or no-till, with crop rotations that include pasture and hay crops. Deep-rooted legumes (such as alfalfa) are effective, as are barnyard manure and green manure crops (plowed under grasses or legumes).

### Summary

The original parent material is structureless, either massive or single grain. Weathering converts parent material

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into soil. Soil structure forms when individual grains of sand, silt, and clay are bound together physically and/or chemically. The arrangement of individual soil particles into different size units, or peds, is called soil structure.

A ped is a single unit of soil structure. A ped ranges in size from about 1 mm to 10 cm depending on the shape: granular, platy, blocky, or prismatic. The shape of the peds formed determines the type of structure. The grade of soil structure refers to the strength and stability of structural peds. Structural grades are strong, moderate, or weak.

Soil structure is important because it modifies some of the desirable and undesirable effects of texture on soil behavior. Structure is related to water infiltration, aeration, soil tilth, and the environment for plant root growth. The type and grade of soil structure can be determined

by observing the soil and gently breaking it apart. Soil structure can be improved by increasing organic matter content, using minimum tillage or no-till, and good residue management. Soil structure is broken down by over-tilling or tilling when the soil is wet.

### Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

Soil Survey Division Staff. *Soil Survey Manual, Handbook #18*, rev. Washington, DC: U.S. Government Printing Office, U.S. Department of Agriculture, Soil Conservation Service, 1993.

### Lesson 6: Soil Horizons

The first lesson states some reasons for studying soil. In subsequent lessons, factors and processes that affect the soil are discussed, along with three of the basic soil properties: color, texture, and structure. With this information, the horizons can be located and their properties can be determined. The properties from a particular soil can be interpreted in terms of factors and processes of soil formation. The student can also learn how to describe and interpret soil properties.

A soil horizon is a layer of soil parallel to the earth's surface. It has a unique set of physical, chemical, and biological properties. The properties of soil horizons, such as texture, color, and structure, are the results of the soil-forming processes, and they distinguish each horizon from other horizons above and below it.

### Pedon and Soil Profiles

When soil horizons are studied, the student needs to know how much of the soil must be observed or studied. The smallest volume that can be called "soil" is a **pedon** (peh-don). A pedon is three dimensional and large enough to permit study of all horizons. Its area ranges from 10 to 100 square feet (1–10 square meters), depending on the variability of the soil.

Also, if soil horizons are to be studied, a soil profile is needed. A soil profile is a vertical section (a cut or a hole in the ground) of a soil pedon beginning at the surface and continuing down through all of its horizons, including the parent material.

### Master Soil Horizons

Soil horizons are named using combinations of letters and numbers. Six general kinds of horizons may occur in soil profiles. They are named with the capital letters O, A, E, B, C, and R. These are called **master horizons**. In Figure 6.1, each master horizon is shown in the relative position in which it occurs in a soil profile. All six master horizons are shown, even though a soil usually has only three or four horizons.

Gradual changes from one master horizon to another give rise to transitional horizons. These are named with two letters, for example, AB, BA, and BC. Subordinate divisions of master horizons are named by adding lower case letters, for example, Ap, Bt, and Cr. Thick horizons may be subdivided using Arabic numerals, such as A1 and A2, or Bw1, Bw2, and Bw3. Transitional horizons, subordinate divisions of master horizons, and subdivisions of thick horizons are discussed later in this lesson.

A single soil profile may never have all the horizons that are possible. Most Missouri soils have A, B, C, and one or two transitional horizons. Other Missouri soils may have an A horizon resting directly on a C or R horizon, or an A-E-B-C horizon sequence, or even an O-E-B-C horizon sequence. Originally, the letters A, B, and C were used to indicate the consecutive order of the horizons. Later, for more clarity, O, E, and R were added, O meaning "organic," E meaning "eluviation," and R meaning "bedrock."

Because all six master horizons occur somewhere in Missouri or the United States, it is important to know what each one is and how it differs from the others. Each master horizon has a distinct set of properties.

#### O Horizon

The O stands for "organic." O horizons do not have to be 100 percent organic matter material. Forest soils usually have thin organic horizons at the surface. They consist of leaves and twigs in various stages of decay.

Wet soils in bogs or drained swamps often have O horizons of peat or muck. Very few soils in Missouri have O horizons of this kind. Most soils in Missouri have only thin O horizons, and these are usually forests. O horizons are destroyed by plowing and do not occur in cultivated areas.

#### A Horizon

The A horizon is the surface horizon of a mineral soil. Its unique characteristic is a dark color formed by the addition of humus. See Plates 2, 7, 10, 12, and 13, pp. 50-A to 50-D. The A horizon is also typified by a granular or fine

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blocky structure (aggregate shape) and friable consistence (easily crushed).

The thickness of the A horizon ranges from a few inches in most forested soils to more than 30 inches in some upland prairie soils and some alluvial soils on flood plains. Every cultivated agricultural soil has an A horizon.

A horizons are extremely important in maintaining soil fertility and providing a favorable environment for root growth. They should be protected from erosion and compaction.

### **E Horizon**

This horizon is generally grayish brown to white in color. It is not present in all Missouri soils, but when it is, it occurs

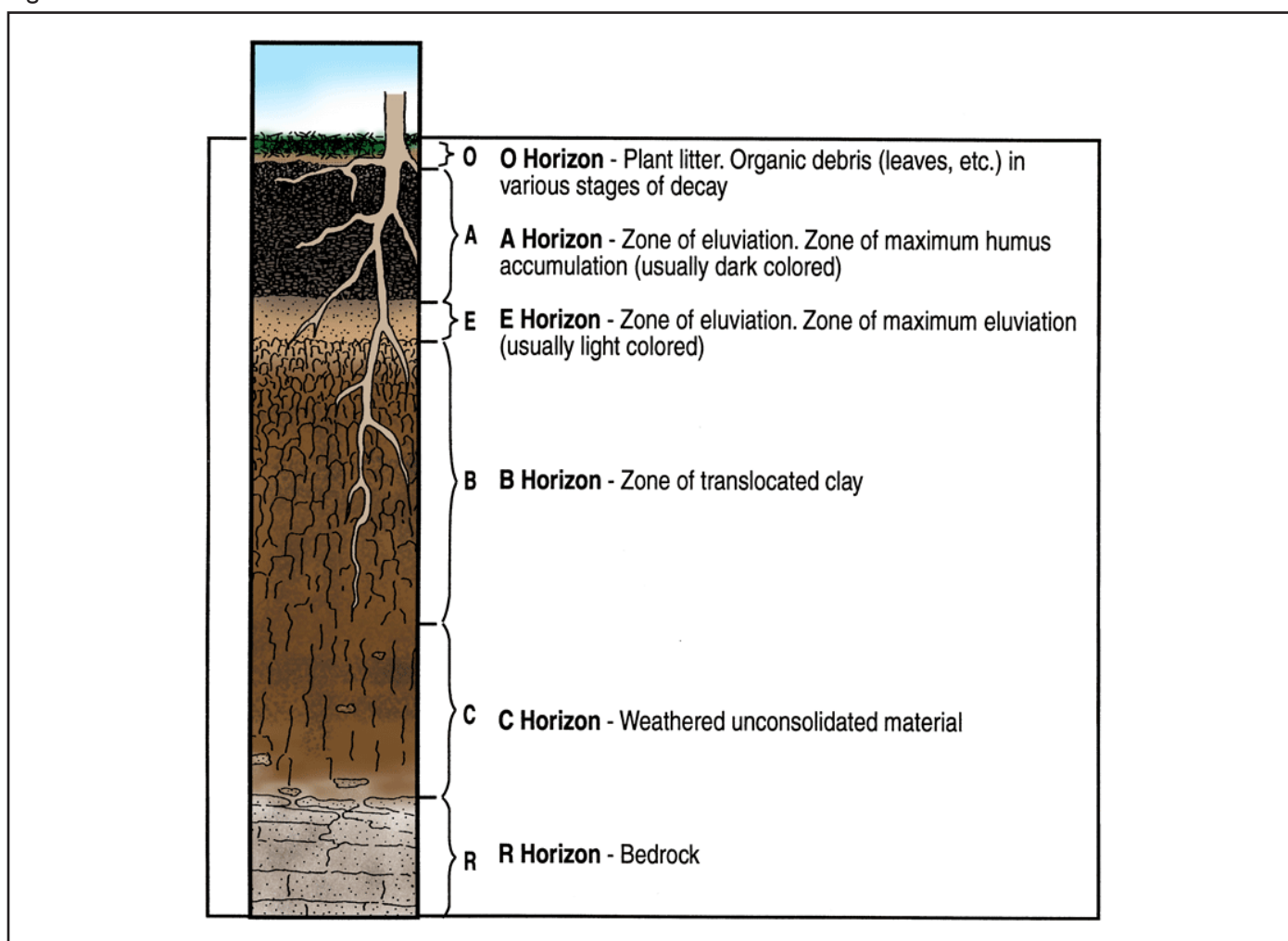
immediately beneath an O or an A horizon. See Plates 11, 12, and 13, pp. 50-C and 50-D. E horizons are light colored because nearly all the iron and organic matter have been removed. One can think of the E as meaning “eluviation” or “leaching” (This horizon was formerly referred to as the A2 horizon.)

E horizons occur in most forested soils that have not been cultivated, and in several of the prairie soils in Missouri. In most soils, the E horizon has noticeably less clay than the B horizon beneath it.

### **B Horizon**

The B horizon is the subsoil layer that generally changes the most because of soil-forming processes. Several kinds of changes are possible.

Figure 6.1 – Master Horizons





In some soils, the B horizon has bright yellowish-brown, reddish-brown, or red colors. See Plates 5 and 9, pp. 50-B and 50-C. In others, it has the most evident blocky or prismatic structure. See Plate 6, p. 50-B. (Lesson 5 has a detailed discussion on structure.) Many B horizons have more clay than other horizons, and clay films may be visible. Kinds of B horizons are discussed more fully in the section, “Subordinate Divisions of Master Horizons,” in this lesson.

### C Horizon

The C horizon is weathered, unconsolidated geologic material below the A or B horizon. Anything that one can dig with a spade, which has not been changed very much by the soil-forming processes, is considered C horizon.

### R Horizon

R stands for “bedrock.” It refers to hard bedrock that one cannot easily dig with a spade. Depending on the depth to bedrock, the R horizon may occur directly beneath any of the other master horizons. See Plate 1, p. 50-A.

## Horizon Boundaries

The boundary between any two horizons can vary both in distinctness and in form. Some boundaries are very sharp. Others merge gradually into the horizon below.

The nature of the boundary provides clues to soil development and to certain aspects of soil behavior. An abrupt boundary, for example, may indicate a sudden change to another kind of material, either geologic or formed by soil development. Such a change may limit root penetration, or it may signal a different rate of water movement through the soil. See Plate 20, p. 50-E. Gradual boundaries, on the other hand, may indicate a very young soil, or a deep, highly weathered, old soil. See Plates 2, 5, and 21, pp. 50-A, 50-B, and 50-F. Terms used to describe boundary distinctness are “abrupt,” “clear,” “gradual,” and “diffuse.” See Figure 6.2.

The form, or shape, of horizon boundaries also may be described. Evaluation of this characteristic, however, requires careful examination of a soil profile to be sure

that the true relationship between soil horizons has been discovered. Terms used to describe boundary form are “smooth,” “wavy,” “irregular,” and “broken.” See Figure 6.3.

Figure 6.2 – Classes of Horizon Boundary Distinctness

**Abrupt:**

Boundary is less than 1 inch (2.5 cm) wide.

**Clear:**

Boundary is 1–2.5 inches (2.5–6 cm) wide.

**Gradual:**

Boundary is 2.5–5 inches (6–12.5 cm) wide.

**Diffuse:**

Boundary is more than 5 inches (12.5 cm) wide.

Figure 6.3 – Classes of Horizon Boundary Form

**Smooth:**

Nearly a plane.

**Wavy:**

Shallow pockets are wider than they are deep.

**Irregular:**

Pockets are deeper than their width.

**Broken:**

Parts of the horizon are unconnected with other parts.

## Transitional Horizons

Master horizons rarely change abruptly from one to another. Instead, the changes occur gradually throughout a zone that may be 5 to 10 inches thick. These zones are called **transitional horizons**. There are three common ones in Missouri soils: AB, BA, and BC. See Figure 6.4.

### AB Horizon

This transitional horizon occurs between the A and B horizons. It is dominated by properties of the A, but some of the properties of the B are evident. Dark colors associated with organic matter are fading because organic matter is decreasing. The structure often changes from granular to subangular blocky. See Plate 22, p. 50-F.

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## BA Horizon

This horizon also occurs between the A and the B, but it has more characteristics of the B horizon. Generally, the structure will be the same type as the B, but less strongly expressed. The color may be a little darker than the B, or the clay content may be less than the maximum in the B. See Plate 23, p. 50-F.

## BC Horizon

This is a transition from the B to the C horizon. Properties of the B are dominant, but some influence of the C horizon is evident. In some pedons, the clay content will be less than the maximum in the B, but more than in the C. The C is structureless (massive), and the BC has structure, but the BC may have larger units and be more weakly expressed than the B.

## Subordinate Divisions of Master Horizons

Many horizons are the result of unique processes that leave a distinct mark on the horizon. These horizons are identified with a lower-case letter immediately following the master horizon symbol. More than 25 letters and combinations of letters are possible. Only the eight subordinate divisions of master horizons most common in Missouri are discussed here.

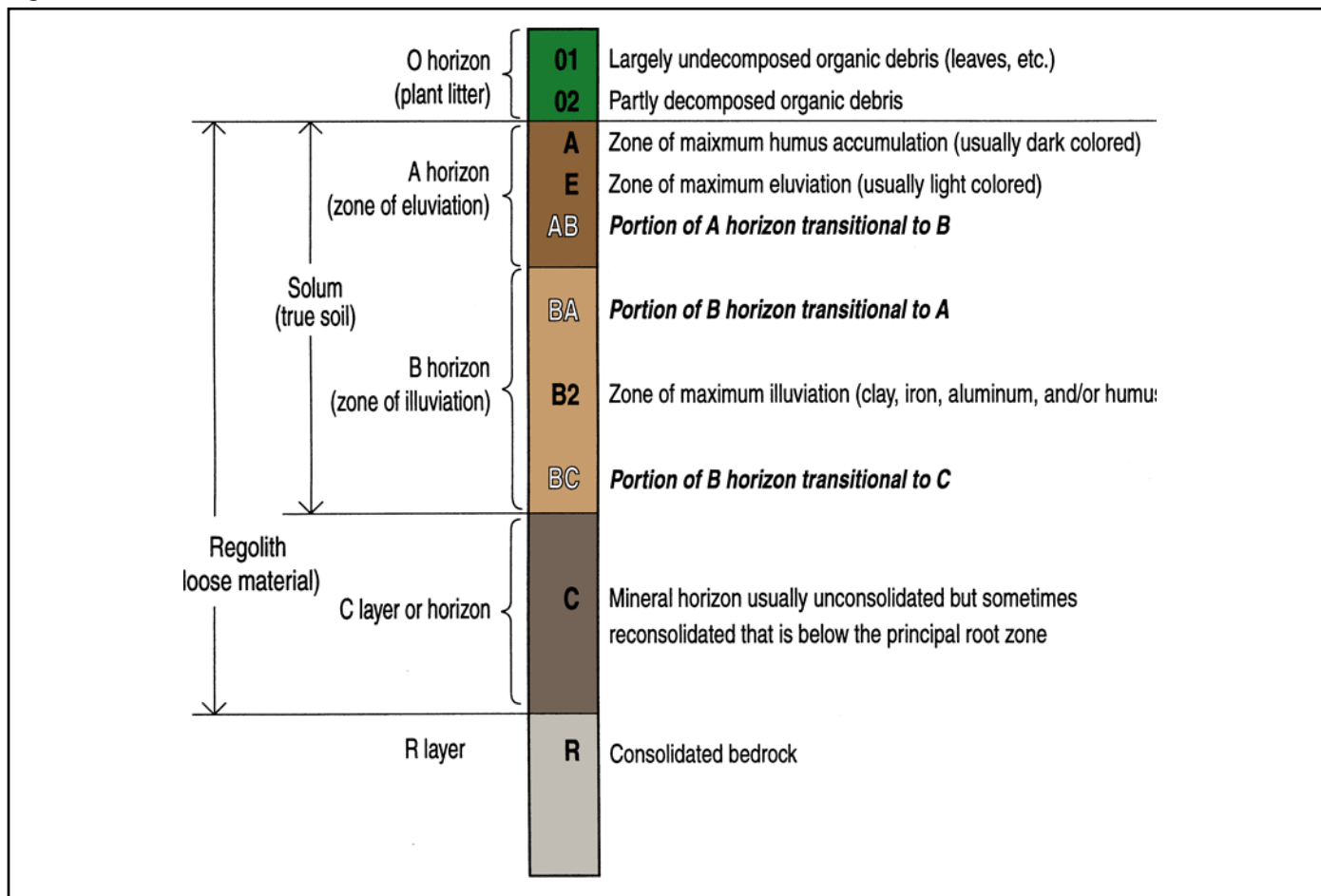
## Oi Horizon

The Oi horizon is a layer covering the A horizon with a layer of slightly decomposed twigs and leaves.

## Ap Horizon

The surface horizon of any soil that has been plowed or cultivated is called the “plow layer.” That is what the “p”

Figure 6.4 – Transitional Horizons



stands for. Cultivation thoroughly mixes the upper 8–12 inches (20–30 cm) of the soil and destroys any natural horizons that may have been present.

If the original A was very thick, plowing converts the upper part into an Ap, and the lower part remains simply as an A horizon. If the original A was very thin, then the Ap could rest on a B, C, or transitional horizon. Even where a soil has been severely eroded, such that all the original A is gone, plowing an exposed B or C horizon would automatically make the surface horizon an Ap. See Plates 4 and 24, pp. 50-A and 50-F.

### **Bt Horizon**

The “t” stands for “translocated clay.” Textural B horizons have distinctly more clay in them than the horizons above or below them. One may feel the difference by working a small amount of moist soil between the thumb and index finger. Soil that is high in clay content will ribbon or feel slick. See Figure 4.5 in Lesson 4.

Some of the clay comes from the soil horizons above the Bt horizon. Water moving down through the soil carries very fine clay particles with it. When the downward movement stops, the clay particles are deposited, building up the waxy coatings called clay films. Some of the clay also comes from the weathering of original minerals in the Bt horizon.

Bt horizons are quite common in Missouri soils. They usually have well-developed, blocky, or prismatic structure. See Plates 6 and 11, pp. 50-B and 50-C.

### **Bg Horizon**

The “g” stands for “gleyed” (glayed). That means the horizon is very wet for long periods of time. Iron in the soil is chemically reduced, and much of it has been leached out of the soil. As a result, gleyed horizons are usually dark gray. See Plate 13, p. 50-D. They may also be mottled.

Gleyed horizons usually indicate that the soil is poorly or very poorly drained. Gleying is not restricted to the B horizon. Other gleyed horizons include the Ag, Eg, BA<sub>g</sub>, BC<sub>g</sub>, and C<sub>g</sub>.

### **Bw Horizon**

Think of the “w” as meaning “weathered.” Bw horizons have been changed by weathering, but not enough to form a Bt or Bg. In Missouri soils, the Bw differs from the C by having weak or moderate blocky structure. The Bw may also have a brighter color, and it may be more leached than the C. Bw horizons are common in young soils of flood plains and low stream terraces. See Plate 4, p. 50-A.

### **Bx Horizon**

This refers to a special feature called a **fragipan** (frah-ah-pan). It typically is a massive, dense, but not cemented, soil horizon. This horizon is often mottled and has seams of gray silt scattered throughout. See Plates 25, 26, and 27, p. 50-G. The fragipan is so dense that neither plant roots nor water can readily penetrate, except in the gray silt seams. In Missouri, fragipans occur mostly in gently sloping upland soils and some high terrace soils in southern Missouri.

### **Bk Horizon**

This horizon has an accumulation of translocated calcium carbonate, or free lime. Carbonates leached from upper horizons have been redeposited in the Bk horizon. There are visible white streaks or nodules of free lime. A way to test for lime is to apply a drop of diluted hydrochloric acid (10% HCl) on the soil. Nodules of fine lime will bubble violently (effervesce).

Some soils on the Missouri River flood plain and in the uplands of northwest Missouri have free lime throughout their profiles. The “k” is used only to indicate a horizon enriched in visible deposits of carbonates by translocation. A Bk horizon may very well have an ordinary C horizon beneath it that contains only its original amount of calcium carbonate.

### **Cr Horizon**

The Cr horizon consists of weathered bedrock, or rock that is soft enough to slice with a knife or a spade. The original rock structure is often visible, but the rock is not hard enough to be designated as an R horizon.

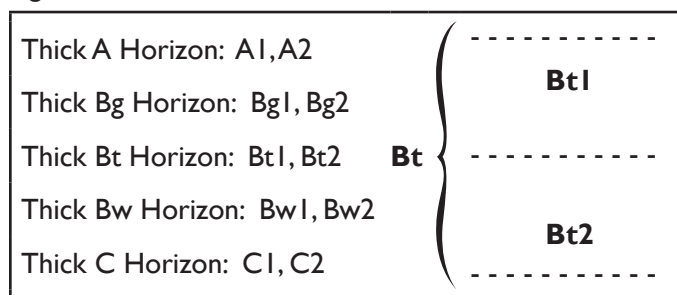
# Soil Science

## Subdivisions of Thick Horizons

Sometimes one or two of the master horizons or subordinate divisions in a soil are so thick that they need to be classified into special subdivisions. Subdivisions are vertical sequences within any single horizon. Small changes in texture, color, or structure are commonly used to make the subdivision.

Subdivisions are always indicated by a number immediately following the letter symbol(s). Figure 6.5 offers a few examples of some thick soil horizons that are subdivided.

Figure 6.5 – Subdivisions of Thick Horizons



## Lithologic Discontinuities

Parent material is the geologic material from which soils form. It may be material from a flood deposit (alluvium), material weathered from rock in place (residuum), windblown material (loess), material moved by gravity (colluvium), or material moved by glaciers (glacial till). When all the horizons of a soil have formed in a single kind of parent material, the ordinary A, B, and C designations for those horizons are used.

Some soils, however, have formed in more than one kind of parent material. A flooding river, for example, may deposit fresh silt on top of older sands and gravels. In northern Missouri soils, loess may be deposited on glacial till. In southern Missouri soils, it is common to have a very thin layer of loess over residuum or colluvium, or colluvium may be deposited on residuum.

If soil horizons are developed in more than one parent material, a number is placed in front of the horizon letter symbol to indicate its position from the top down. This is

referred to in soil science as a **lithologic discontinuity**. A lithologic discontinuity expresses a significant change in texture and/or mineralogy that indicates a difference in parent material from which the horizons formed. The geologic material at the surface is always assumed to be first, and the number 1 is never used. The second geologic material is indicated by a 2, the third by a 3, and so on. Thus, a soil formed in silt over gravel could have the following set of horizons: A-AB-B-2BC-2C. See Plates 9, 17, and 28, pp. 50-C, 50-E, and 50-G.

## Common Horizon Sequences

Several official Missouri profiles that are presently used by the United States Department of Agriculture's Natural Resources Conservation Service are listed in Figure 6.6. The names of the horizons in the typical profile are given, along with the landform. Nearly all geographic areas of Missouri are represented on this list.

Figure 6.7 gives an example of an Official Soil Description (OSD) of the Menfro series. It is a soil common to the hills adjacent to the Missouri and Mississippi Rivers.

## Summary

The smallest volume that can be called a soil is a pedon. A pedon is three-dimensional and large enough to permit study of all horizons.

A soil profile is a vertical section of a soil pedon beginning at the surface and continuing down through all of the horizons, including the parent material. Six kinds of horizons may occur in soil profiles. They are called master horizons and are named with capital letters: O, A, E, B, C, and R.

The boundary between any two horizons can vary both in distinctness and in form. Some boundaries are very sharp (abrupt), while others are gradual. Most changes in horizons are gradual. Generally, if the change occurs over more than 5 inches, there is a zone called a transitional horizon. A transitional horizon usually has properties of both the horizon above and the one below. Transitional horizons are named by using the two capital letters of the two horizons they separate.

Some horizons have special features, which are identified by a lower-case letter immediately following the master horizon letter symbol. The eight most common in Missouri are i (slightly decomposed organic material), p (plow layer), t (translocated clay), g (gleyed), w (weathered), x (fragipan), k (translocated calcium), and r (soft bedrock).

Some horizons are very thick but may have small changes in texture, color, or structure, which require further divi-

sion. Thick horizons are identified by adding a numeral after the letter symbol(s).

Lithologic discontinuities are soils formed in more than one parent material. They are indicated by a numeral placed in front of the letter symbol(s).

Some common horizon sequences are listed. An Official Soil Description is given.

Figure 6.6 – Common Horizon Sequences in Missouri

<p><b>Arbela:</b> Ap, E, Btg, BCg (flood plain)</p> <p><b>Arisburg:</b> Ap, A, Bt, Btg1, Btg2, Btg3, Btg4, Cg (upland)</p> <p><b>Armstrong:</b> Ap, E, BE, Bt1, 2Bt2, 2Bt3, 2Bt4, 2BC (upland)</p> <p><b>Barco:</b> A1, A2, Bt1, Bt2, Bt3, Bt4, Cg (upland)</p> <p><b>Bardley:</b> A, E, 2Bt1, 2Bt2, 2Bt3, R (upland)</p> <p><b>Bolivar:</b> Ap, E, BE, Bt1, Bt2, Bt3, Cr, R (upland, see Plate 1, p. 50-A)</p> <p><b>Caneyville:</b> Oi, A, E, Bt1, Bt2, R (upland)</p> <p><b>Cedargap:</b> A1, A2, A3, C1, C2 (flood plain)</p> <p><b>Chariton:</b> Ap, E, BE, Btg1, Btg2, Btg3, 2Cg (stream terrace)</p> <p><b>Clarksville:</b> Oi, A, E, BE, Bt1, Bt2, 2Bt3, 2Bt4, 2C (upland)</p> <p><b>Creldon:</b> A1, A2, Bt1, Bt2, Bt3, 2Btx1, 2Btx2, 3Bt1, 3Bt2 (upland)</p> <p><b>Dockery:</b> Ap, C1, C2, C3, C4 (flood plain)</p>	<p><b>Gasconade:</b> A, Bw, R (upland)</p> <p><b>Gepp:</b> A, E, BE, 2Bt1, 2Bt2 (upland, see Plate 28, p. 50-G)</p> <p><b>Grundy:</b> Ap, A, BA, Btg1, Btg2, Btg3, Btg4, Cg (upland, see Plate 7, p. 50-B)</p> <p><b>Hamburg:</b> A, AC, C1, C2 (upland)</p> <p><b>Lebanon:</b> Ap, BE, Bt1, Bt2, Bt3, 2Ex, 2Bx, 2Bt1, 2Bt2, 2Bt3 (upland)</p> <p><b>Leonard:</b> Ap, Btg1, Btg2, 2Btg3, 2Btg4, 2Btg5 (upland)</p> <p><b>Menfro:</b> Ap, E, BE, Bt1, Bt2, Bt3, C (upland, see Plate 24, p. 50-F)</p> <p><b>Niangua:</b> A, E, 2Bt1, 2Bt2, 2Bt3, 2R (upland)</p> <p><b>Nodaway:</b> Ap, C (flood plain)</p> <p><b>Racket:</b> A1, A2, A3, A4, 2C (flood plain)</p> <p><b>Sibley:</b> Ap, A1, A2, Bt1, Bt2, Bt3, C1, C2 (upland)</p> <p><b>Vesser:</b> Ap, E1, E2, Btg1, Btg2, BCg (flood plain)</p>
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## Soil Science

Figure 6.7 – Sample of an Official Soil Description (OSD)

### MENFRO SERIES

The Menfro series consists of very deep, well-drained, moderately permeable soils formed in thick loess deposits on upland ridgetops, backslopes, and benches adjacent to the Missouri and Mississippi Rivers and their major tributaries. Slopes range from 2 to 60%. Mean annual temperature is 56° F, and mean annual precipitation is 36 inches.

**TAXONOMIC CLASS:** Fine-silty, mixed, mesic Typic Hapludalfs.

**TYPICAL PEDON:** Menfro silt loam-pasture. (Colors are for moist soil unless otherwise stated.)

- Ap: 0–6 inches; dark brown (10YR 3/3) silt loam; dark brown (10YR 4/3) rubbed; pale brown (10YR 6/3) dry; moderate, very fine granular structure; very friable; many fine roots; neutral; abrupt smooth boundary. (6–9 inches thick)
- E: 6–12 inches; dark brown (10YR 4/3) silt loam; weak, thin, platy structure parting to weak very fine subangular blocky; friable; common fine roots; moderately acid; clear smooth boundary. (0–8 inches thick)
- BE: 12–15 inches; dark yellowish brown (10YR 4/4) silt loam; weak fine subangular blocky structure; friable; common fine roots; moderately acid; clear smooth boundary. (0–8 inches thick)
- Bt1: 15–30 inches; dark brown (7.5YR 4/4) silty clay loam; moderate fine and medium subangular blocky structure; firm; few fine roots; many faint clay films on faces of peds; slightly acid; clear smooth boundary.
- Bt2: 30–40 inches; dark brown (7.5YR 4/4) silty clay loam; strong medium angular blocky structure; firm; few fine roots; many distinct clay films on faces of peds; common fine pores and old root channels with clay linings; slightly acid; gradual smooth boundary.
- Bt3: 40–68 inches; dark yellowish brown (10YR 4/4) silty clay loam; weak fine subangular blocky structure; friable; few faint clay films on faces of peds and vertical surfaces; slightly acid; diffuse wavy boundary. (Combined thickness of the Bt horizon is 24–75 inches.)
- C: 68–86 inches; dark brown (10YR 4/3) silt loam; few fine faint brown (10YR 5/3) mottles; massive; friable; slightly acid.

**TYPE LOCATION:** Boone County, Missouri. About 40 feet west of center Rocheport Road, 450 feet south of the south end of Rocheport overpass over interstate 70; about 132 feet east and 1,320 feet north of the southwest corner of sec. 8, T. 48 N., R. 14 W.

### Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

Soil Survey Division Staff. *Soil Survey Manual, Handbook #18*, rev. Washington, DC: U.S. Government Printing

Office, U.S. Department of Agriculture, Soil Conservation Service, 1993.

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### Lesson 7: Soil Chemical Properties

Soil chemistry is important to study because of its significant effects on crop yields. Obtaining high productivity while at the same time protecting the soil is what good soil stewardship is all about. The relationships among solids, liquids, and air largely determine the productive capacity of the soil.

The chemistry of the surface layer is subject to rapid change caused by fertilizer additions, plant depletion, and erosion. Soil chemistry involves the relationship between the minerals, the water, and other elements in the soil. In soil chemistry, the clay minerals are important. Most clay minerals are composed of silicon and oxygen, called **silicates**. Some silicates that include aluminum are called **aluminosilicates**. Some common names for silicate clay minerals in Missouri are kaolinite, montmorillonite, illite, and vermiculite (the last two are not as abundant).

One of the important factors in soil fertility is the quantity and proper balance of nutrient elements. To learn what amounts of the different plant nutrients should be present in a soil (i.e., how much fertilizer is needed), the **cation exchange capacity (CEC)** of the soil must be determined. The CEC is the soil's capacity to hold and exchange essential cations. Oxygen, silicon, and aluminum make up about 85 percent of the earth's crust, and to a large extent, determine the CEC.

### Cation Exchange Capacity (CEC)

All elements—for example, calcium (Ca), magnesium (Mg), and oxygen (O)—are made up of **atoms**. Atoms make up the smallest portion of an element that can take part in a chemical reaction. An atom or group of atoms that has become electrically charged is called an **ion(s)**. For example, the Ca ion has two positive (+) charges, written  $\text{Ca}^{++}$ . An O ion has two negative (–) charges, written  $\text{O}^{--}$ .

Many elements, including those in fertilizers and agricultural lime, have either positive or negative ions. Like charges repel and unlike charges attract (compare to magnets). Most ions have from one to four positive or negative charges. In chemical systems, there is always

an equal balance of positive and negative charges. For example, a water molecule has two hydrogen ions with one positive charge each which attract one oxygen ion with two negative charges ( $\text{H}_2\text{O} = \text{H}^+ \text{H}^+ \text{O}^{--}$ ).

The surfaces of clay minerals possess negative electrical properties that attract and hold positively charged ions of elements such as calcium ( $\text{Ca}^{++}$ ), magnesium ( $\text{Mg}^{++}$ ), potassium ( $\text{K}^+$ ), sodium ( $\text{Na}^+$ ), aluminum ( $\text{Al}^{+++}$ ), and hydrogen ( $\text{H}^+$ ). See Figure 7.1. (It should be noted that Na is not calculated on soil tests in Missouri, even though small amounts exist in the soil.) Other elements are held in a similar manner, but they usually occur in smaller quantities in most soils.

Such elements that form positively charged ions are called **cations**, for example,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{K}^+$ ,  $\text{Na}^+$ ,  $\text{Al}^{+++}$ , and  $\text{H}^+$ . Elements that have negative charges are called **anions**, for example, oxygen ( $\text{O}^{--}$ ) and chlorine ( $\text{Cl}^-$ ).  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{K}^+$ , and  $\text{Na}^+$  are often called **bases** because they tend to make the soil alkaline. Hydrogen ( $\text{H}^+$ ) and aluminum ( $\text{Al}^{+++}$ ) are acid cations. They tend to make the soil acidic. The phenomenon of cations being attracted and held by the soil particle surfaces is called **adsorption**. Terms such as “cations,” “acids,” and “bases” are used in all soil test results.

The very small soil particles are not ions but have several negative charges per particle. **Micelle** (my-cell) is a term used for a negatively charged solid particle composed of clay or organic matter. The term **colloid** often is used to describe clay particles (such as colloidal clay). Micelles contain many negative charges, and the soil water surrounding the micelles contains many positive charges. See Figure 7.1.

### Cation Exchange

Micelles exchange acid  $\text{H}^+$  ions for  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , and  $\text{K}^+$  bases because the chemical attraction of the bases is much greater than the attraction of hydrogen  $\text{H}^+$  ions. These bases are some of the most important plant nutrients. Plant roots exchange  $\text{H}^+$  acid ions for the  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ , and  $\text{K}^+$  base ions. The process generally is referred to as **cation exchange**. Collectively, the sites of attraction for cations on the surfaces of soil particles and organic

## Soil Science

matter (micelles) make up the cation exchange capacity (CEC) of the soil. Most of the sites are located on the surfaces of clay particles.

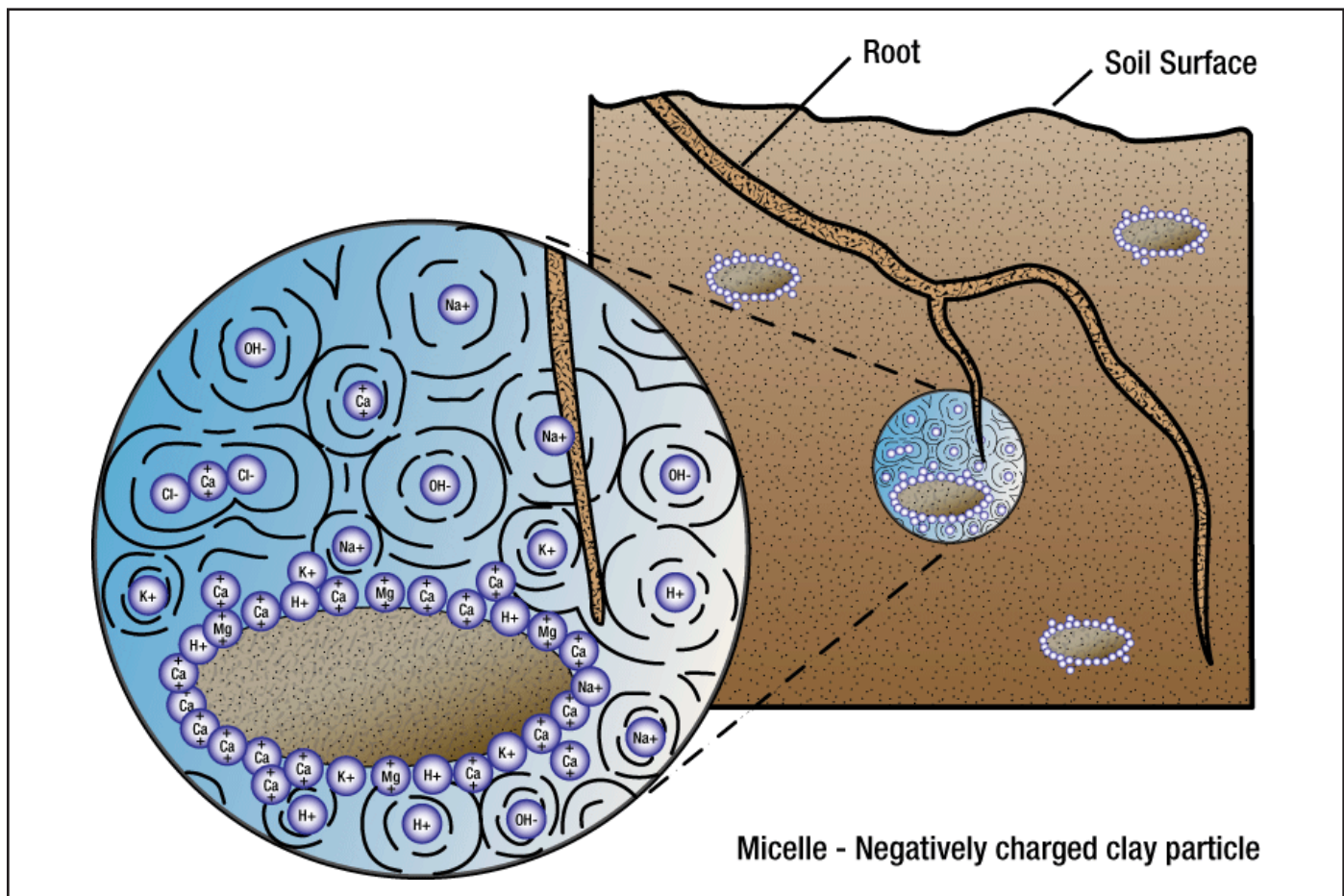
Sites of attraction are always occupied by cations. The cations present in the films of water surrounding the soil particles and in the pores between the particles may exchange places with acid cations adsorbed on the soil particles. Thus, these cations are called **exchangeable cations**. The amount of base cations in relation to the total CEC is referred to as the **percent of base saturation**. Many soil minerals weather to release bases that move either to fill up the exchange capacity or go into soil solution. Either can be used by plants or by microbes. Any excess amounts are leached down through the soil to groundwater and into rivers. Various equilibriums among the plant nutrient elements are established in the soil by cation exchange. This equilibrium affects the ease with which plant roots may obtain the nutrient elements.

High organic matter content contributes greatly to the CEC. Organic matter is used to indicate the amount of N available for crops each year. To learn what amounts of the different exchangeable plant nutrients should be present in a soil, the CEC of the soil must be calculated.

### Calculating CEC

How many grams there are of each cation per 100 grams of soil can be determined from the atomic weight of each element and the number of positive charges on each ion. The atomic weight of K=39, Mg=24, and Ca=40. The equivalent weight is calculated by dividing the atomic weight by the number of charges for a particular element. For example, the K ion has only one charge, so 39 (atomic weight) is divided by 1. The weight of Mg or Ca is divided by 2 because each of their ions has two charges. Therefore, the equivalent weight of  $K = 39 \div 1 = 39$ ,  $Mg = 24 \div 2 = 12$ , and  $Ca = 40 \div 2 = 20$ . The equivalent weight for an element

Figure 7.1 – Micelle Construction



## Soil Chemical Properties

is equal to the reactive power (attraction) of any other element's equivalent weight. See Table 7.1.

Table 7.1 – Equivalent Weights for Selected Elements

Element	Atomic Weight	No. of Charges	Equivalent Weight
Potassium (K)	39	+1	39
Magnesium (Mg)	24	+2	12
Calcium (Ca)	40	+2	20

Calculations used in determining the cation exchange capacity (CEC) are based on the upper 7 inches of the surface layer (which weighs about 2,000,000 pounds per acre). Each unit of CEC is expressed as milliequivalent (meq) per 100 grams of soil. Although an equivalent of one element is exactly equal in reactive power to an equivalent of any other element, the actual weight of an equivalent will vary among the elements. For each milliequivalent of CEC, the soil will hold any one of the following amounts of the different exchangeable cations as shown in Table 7.2.

Table 7.2 – Milliequivalent Weights of Potassium, Magnesium, and Calcium

Potassium (K)	0.039 g of K / 100 g of soil or 0.039 lbs of K / 100 lbs of soil or 390 lbs of K / 1,000,000 lbs of soil or 780 lbs of K / 2,000,000 lbs of soil or 780 lbs of K / acre
Magnesium (Mg)	0.012 g of Mg / 100 g of soil or 0.012 lbs of Mg / 100 lbs of soil or 120 lbs of Mg / 1,000,000 lbs of soil or 240 lbs of Mg / 2,000,000 lbs of soil or 240 lbs of Mg / acre
Calcium (Ca)	0.020 g of Ca / 100 g of soil or 0.020 lbs of Ca / 100 lbs of soil or 200 lbs of Ca / 1,000,000 lbs of soil or 400 lbs of Ca / 2,000,000 lbs of soil or 400 lbs of Ca / acre

The soil contains various amounts of each of the exchangeable cations. In order to determine the cation exchange capacity of the surface soil, one must obtain the results of a soil test. (A soil test shows what a particular soil sample contains.) The CEC then can be calculated by adding the number of milliequivalents per 100 g of soil occupied by each element. The example in Table 7.4 illustrates this procedure, using information from Table 7.2 and the information from the sample report of a soil test from Table 7.3.

Table 7.3 – Sample Report

Sample Report of a Soil Test						
OM %	P <sub>2</sub> O <sub>5</sub> lb/A	K lb/A	Mg lb/A	Ca lb/A	NA meq	pHs
2.5	180	390	360	2,400	4.0	5.2
<b>Note:</b> OM = organic matter NA = neutralizable acidity						

It should be noted that only K, Mg, Ca, and neutralizable acids (for example, H and Al) are used to calculate the CEC. The remaining items on the soil test are included here only because they are usually found in an actual soil test report.

Most soil tests will show the individual amounts, in milliequivalents, of Ca, Mg, and K (bases) and H and Al (acids). The total of these is the sum of the cations shown on the soil test. This is the CEC.

The sum of the bases is then divided by the sum of the cations. This figure indicates the percent of the base saturation. For example, the soil test shows the sum of bases = 8 and neutralizable acidity = 4. Therefore, the total cations = 12,  $8 \div 12$  equals **66.6 percent base saturation**.

Soils are adequately supplied with exchangeable plant nutrients when each unit of the exchange complex contains the proper amounts of K, Mg, and Ca. If the soil has a low exchange capacity, the total amounts of the different nutrients required for good plant nutrition will be lower than if the exchange capacity is high. See Table 7.4.



# Soil Science

Table 7.4 – Calculating the CEC

<u>390 lbs/acre of potassium</u>		
390 ÷ 780	=	<b>0.5 meq K / 100 g of soil</b>
<u>360 lbs/acre of magnesium</u>		
360 ÷ 240	=	<b>1.5 meq Mg / 100 g of soil</b>
<u>2,400 lbs/acre of calcium</u>		
2,400 ÷ 400	=	<b>6.0 meq Ca / 100 g of soil</b>
		<b>4.0 meq Na / 100 g of soil</b>
Total CEC	=	<b>12.0 meq / 100 g of soil</b>

## Determining Amount of Fertilizer Needed

Results of field experiments suggest that for each milliequivalent of exchange capacity the soil should contain .02 to .03 meq (approximately 20 lbs) of K per acre, 0.1 meq (24 lbs) of Mg per acre, and 0.75 meq (300 lbs) of Ca per acre. To determine the amount of nutrients needed per acre of a soil with a CEC of 12, simply multiply each of the amounts needed for 1 meq by 12. The following example in Table 7.5 illustrates this procedure.

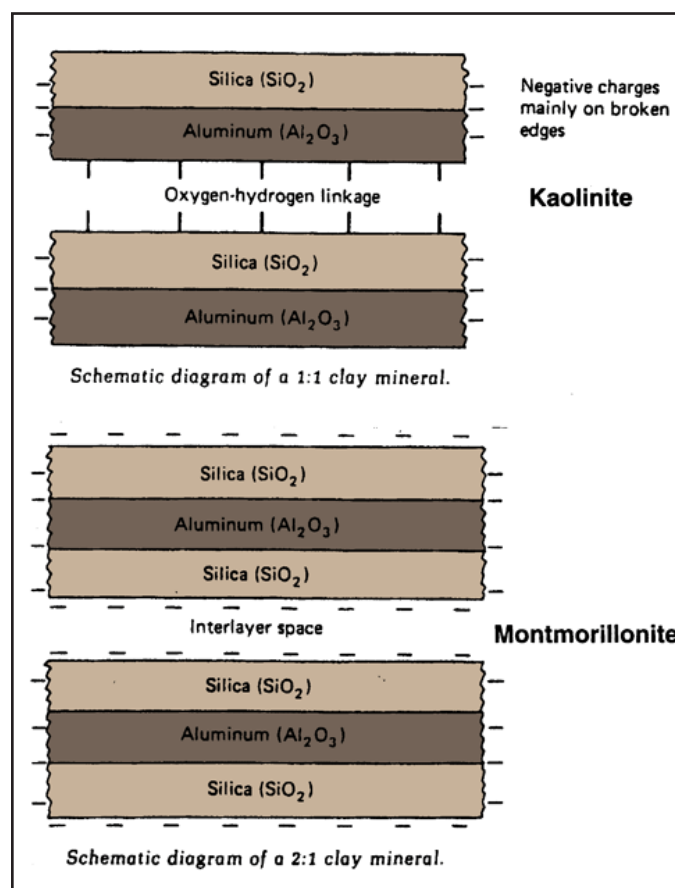
Table 7.5 – Optimum Nutrient Amounts

Optimal Amount of Nutrient Per Acre for CEC of 12				
K	=	20 x 12	=	240 lbs per acre
Mg	=	24 x 12	=	288 lbs per acre
Ca	=	300 x 12	=	3,600 lbs per acre

Next, compare the results of the soil test (how much K, Mg, and Ca there is) with how much nutrient is needed. For example, the soil test report in Table 7.3 shows that the soil has 390 lbs/A of K. Table 7.5 indicates that the soil should have 240 lbs/A of K. Therefore, no additional K is needed. The soil test report (Table 7.3) indicates that there are 360 lbs/A of Mg, and Table 7.5 indicates that 288 lbs/A are needed. Again, no additional Mg is needed. Lastly, the soil test report indicates that the soil has 2,400 lbs/A of Ca, but Table 7.5 indicates that 3,600 lbs/A are needed. Therefore, additional Ca (1,200 lbs/A) should be added to the soil.

The soil exchange capacity is governed mostly by the amount and kind of clay and the organic matter content in the soil. Therefore, the level of the exchange capacity is related largely to the characteristics of soil texture. Montmorillonite clay has a larger CEC than kaolinite. See Figure 7.2. It should be noted that although phosphorous is not a part of the CEC, field tests indicate that soils which contain more than 120 lbs of phosphorus per acre produced adequate crops.

Figure 7.2 – Schematic Diagram of Kaolinite and Montmorillonite



## Soil Properties Affecting the CEC

Soils with low clay content, such as sand and sandy loam, have a low CEC, while soils with high clay content, such as silty clay and clay, have a high CEC. Loam and silt loam have a medium CEC. With average organic matter content, loam and silt loam average between 12 and 18 milliequivalents per 100 grams of soil. The effect of textural differences on CEC can easily be seen if soil samples are



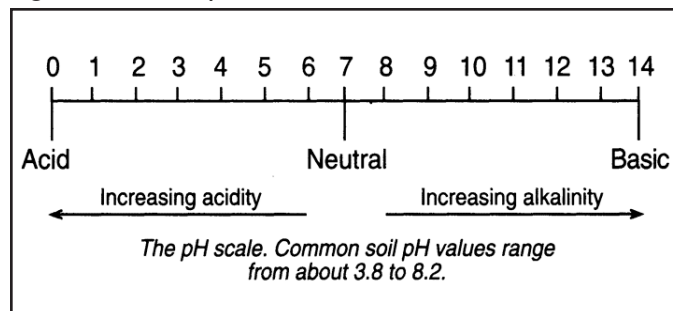
obtained from uneroded and severely eroded areas of the same field. The sample from the severely eroded area will have much more clay and a much higher CEC. This does not mean that soils should be allowed to erode to get a higher CEC. Eroded soils have higher clay content, but they also have less organic matter, poorer tilth, and lower available water capacity.

Organic matter also has exchange capacity. Soil that contains 4 percent organic matter may have as much as 8 meq per 100 grams of soil. Therefore, the most ideal soil condition is a silt loam with high organic matter content. Also, loam and silt loam have a high available water capacity.

### pH

The pH is a scale that measures acidity to alkalinity (0–14). See Figure 7.3. The pH range of Missouri soils is about 4.5–8.4. A few soils may be lower or higher. Neutral pH (or pH 7) occurs when the concentration of  $H^+$  ions and  $OH^-$  ions in pure water at 75° F is equal. Neutral pH is neither acid nor alkaline. In 75° water, there are  $1.0 \times 10^{-7}$  g of  $H^+$  ions per liter and an equal number of  $OH^-$  ions weighing  $17.0 \times 10^{-7}$  g per liter of water.

Figure 7.3 – The pH Scale



Numbers like 0.0000001N or  $1.0 \times 10^{-7}$  are hard to use. The pH scale simplifies this by changing the  $-7$  exponent to give pH 7. When the concentration of  $H^+$  ions increases, the pH is lower (acid), and when the concentration of  $OH^-$  ions increases, the pH is higher (alkaline). It should be noted that the pH increases 10 times between consecutive units. For example, pH 5 is 10 times more acidic than pH 6; pH 6 is 10 times less acidic than pH 5.

### Determining pH

Two methods generally are used to determine soil pH. One is water pH ( $pH_w$ ) and the other is salt pH ( $pH_s$ ). Salt pH is the more precise method. Water pH is largely a measure of the  $H^+$  ions in the soil solution, while salt pH is a measure of the  $H^+$  ions in the soil solution and the  $H^+$  ions that were attached to soil particles. By adding calcium chloride ( $CaCl_2$ ) to the test solution, the  $H^+$  ions attached to the soil particles are released so they can be measured. The  $pH_s$  is a reflection of the **neutralizable acidity (NA)**. The  $Ca^{++}$  ion in the  $CaCl_2$  displaces the  $H^+$  ions on the soil particle. Salt pH generally is about one-half unit lower than water pH.

### Importance of pH

The pH value of the soil gives a quick estimate of the balance between the plant nutrient elements in the soil (K, Mg, and Ca) and the other non-nutrient elements, such as H and Al. See Figure 7.4. Strongly acidic soils usually are those that have a relatively low amount of the CEC occupied by K, Mg, and Ca. The pH also indicates if agricultural lime is needed to grow a particular crop. For example, legumes require more neutral soils ( $pH_w$  6.8–7.3) than do such crops such as corn, small grain, and grass ( $pH_w$  6.0–6.8). Some crops (like blueberries) actually require a soil that is quite acid for the best growing conditions. Many trees grow better on soils that are well below a  $pH_w$  of 7.

The soil pH alone gives little indication of the amounts of lime needed to correct the nutrient level of a given soil. The lime requirement (Ca) is a function of the CEC. So are the needs for Mg and K. The neutralizable acidity (NA) value is a direct measure of the quantity of acidity that can be neutralized by lime.

The effect of soil  $pH_w$  on pesticides should first be checked by looking for information on the pesticide label, and also by checking with the latest test results from chemical dealers and university experimental data. It is suspected that some herbicides may become overreactive when the soil  $pH_w$  is high, causing crops to burn, or there may be dangerous effects with a low soil pH which may cause herbicide carryover into the next crop. High application

## Soil Science

rates of a coarsely ground agricultural lime may also cause a delayed effect, resulting in an undesirably high  $pH_w$  several years after the application.

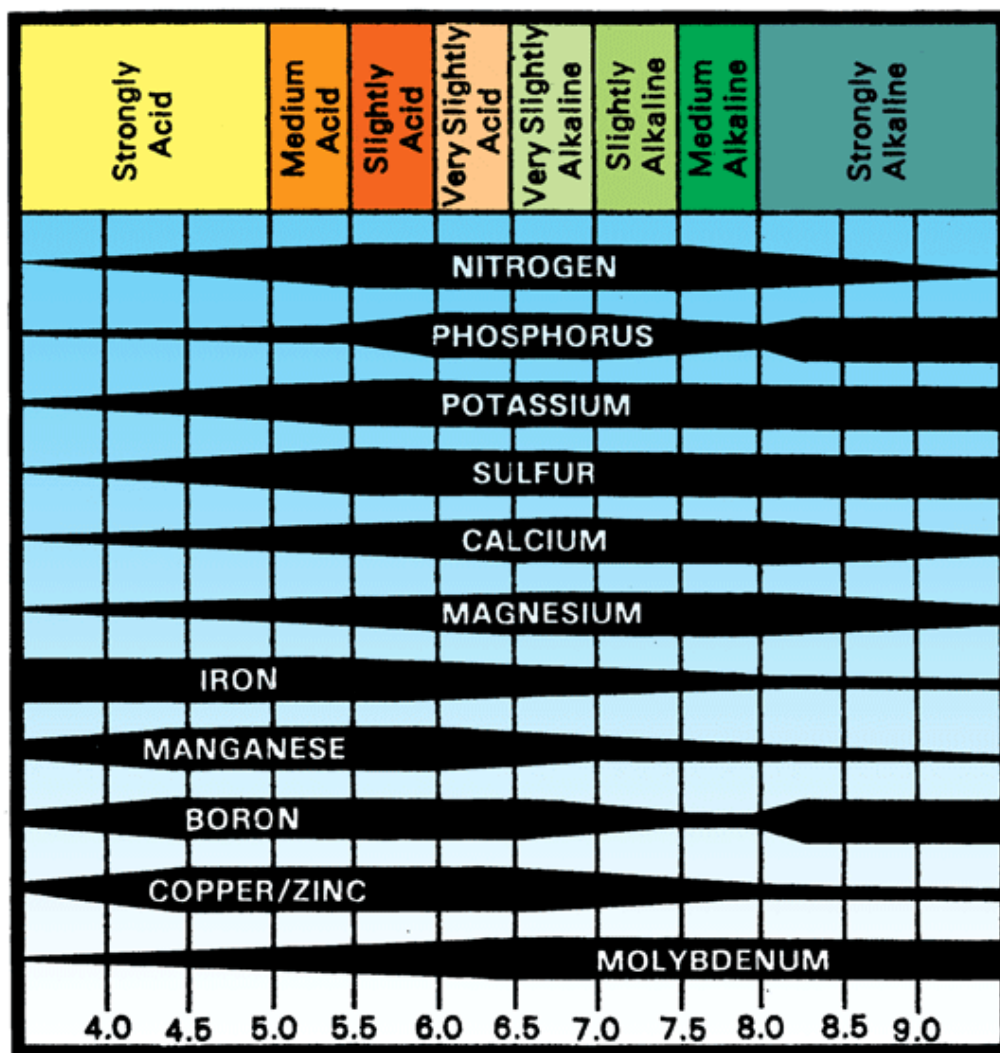
### Correcting Soil pH

Acidity is caused by the leaching (removing) of bases by water or the absorption of base nutrients by growing

plants. Growing plants require large amounts of base nutrients. The depletion of Ca can be the greatest cause of increased acidity. By applying lime (calcium carbonate, or  $CaCO_3$ ) the soil pHs can generally be raised to any desirable level.

Lime does two things for the soil. First, the  $H^+$  on the surface of clay particles (micelles) is replaced by  $Ca^{++}$ .

Figure 7.4 – How Soil pH Governs Nutrient Release



**Soil pH Governs Nutrient Release**  
Acidity or alkalinity (pH) controls relative nutrient availability.

Second, the  $H^+$  acts with the  $CO_3$  ion to form carbonic acid ( $H_2CO_3$ ), which further breaks down to form carbon dioxide gas ( $CO_2$ ) and water ( $H_2O$ ). Other materials such as gypsum, which contain Ca, will add  $Ca^{++}$  to the soil, but will not raise the pHs by removing the  $H^+$  in the soil solution.

Crops require different levels of pH for optimal growth. The levels which need to be maintained can only be determined by a soil test. Liming helps to release other non-base plant nutrients and make these nutrients more available to plants. After the nutrients have been used by plants, they have to be replenished by fertilization if a high productive level is to be maintained.

### Summary

Soil chemistry and the cation exchange capacity (CEC) are important to study because of their effects on crop yields. Soil chemistry involves the relationship between the minerals, the water, and other soil elements. In soil chemistry, the clay minerals are especially important. CEC is the capacity of the soil to hold and exchange essential nutrients with plants.

The surfaces of clay minerals possess negative electrical properties that attract and hold positively charged ions, called cations. Elements that have negative charges are called anions. Micelles are negatively charged solid particles composed of clay or organic matter. The soil water surrounding the micelles contains mostly positive charges. Micelles exchange  $H^+$  ions (acid cations) for  $Ca^{++}$ ,  $Mg^{++}$ , and  $K^+$  (base cations) because the chemical attraction of the bases is much greater than the attraction of the  $H^+$  acid ions.

The CEC can be calculated using the results of a laboratory soil analysis so that accurate fertilizer recommendations can be made for a particular crop. A method for calculating CEC and the appropriate amount of fertilizer is given in

this lesson. The most ideal soil for a high CEC is a silt loam with high organic matter content.

The pH is a scale which measures acidity to alkalinity (0–14). In Missouri, the soil pH range is about 4.5–8.4. There are two kinds of soil tests for pH, water (pH<sub>w</sub>) and salt (pH<sub>s</sub>). Water pH gives the pH of the acid ions (such as  $H^+$  and  $Al^{++}$ ) in the soil solution. Salt pH is more precise and gives the total pH of the soil including the acid ions in the soil solution and those attached to the micelles (colloidal particles). Salt pH is generally about one-half unit lower than water pH. Soil pH gives an estimate of the balance between plant nutrient elements (bases) and non-nutrient elements (acids).

The pHs indicates if agricultural lime is needed for a particular crop, but the exact quantity that is required is a function of the CEC. Each crop has its own level of pH for good production.

Acidity is caused by the leaching of bases by water or the absorption of base nutrients by growing plants. The depletion of calcium can be the greatest cause for increased acidity. The pH can be raised by applying agricultural lime. After nutrients have been used by plants, they need to be replenished by fertilization to maintain a level of high production.

### Credits

Brown, J.R., and R.R. Rodriguez. *Soil Testing: A Guide for Conducting Soil Tests in Missouri* (Guide #EC 923). Missouri Cooperative Extension Service, 1983.

Scrivner, C.L., James C. Baker, and Harold E. Grogger. *Evaluating Missouri Soils*. Columbia, MO: University Extension, 1972.

Thompson, L.M., and F.R. Troeh. *Soils and Soil Fertility*, 3rd ed. New York: McGraw-Hill, 1973.



## Lesson 8: Soil Fertility

What is a fertile soil? A fertile soil produces high-yielding, healthy crops. A fertile soil has a balance and quantity of nutrients, but nutrients alone are not enough to make a soil fertile. There are soils that are rich in calcium (Ca), nitrogen (N), or potassium (K) that will not produce high yields of crops. In addition to nutrients, the soil texture, structure, rooting depth, organic matter content, available water capacity, aeration (porosity), and length of growing season must be favorable for maximum growth. Fertile soil also depends on physical support, such as good seed, timely planting and harvesting, erosion control practices, and good plant residue management.

### Plant Nutrients

About 17 elements are necessary for plant growth, including 9 essential macronutrients. Three—carbon (C), hydrogen (H), and oxygen (O)—are supplied by water and air; 14 are found in the soil. Plant nutrients can be divided into six macronutrients that are needed in large

amounts, and eight micronutrients that are needed in small or trace amounts. See Table 8.1.

### Macronutrients

Six macronutrients are available in the soil. Calcium (Ca), magnesium (Mg), and potassium (K) are available mainly in mineral solids. Phosphorus (P) and sulfur (S) are available in both mineral solids and organic matter. Nitrogen (N) is available mostly in organic matter.

Soil air is necessary for plant roots to grow and to absorb nutrients. Plants may suffer deficiencies of some nutrients just because the oxygen (O) supply is limited. O is also necessary for the production of nitrate (NO<sub>3</sub>) and the activity of bacteria.

For each macronutrient:

- ◇ The origin and natural form in the soil are given, along with ways it can be supplemented.
- ◇ Each nutrient's effect on plants is discussed.
- ◇ Signs of plant deficiencies are described.

Table 8.1 – Seventeen Essential Plant Nutrients

NUTRIENTS			SOURCE
<b>Macro</b>	Ca	Calcium	Mineral solids
	Mg	Magnesium	
	K	Potassium	
	P	Phosphorus	Mineral solids, organic matter
	S	Sulphur	
	N	Nitrogen	Organic matter (primarily)
	C	Carbon	Water and air
	H	Hydrogen	
	O	Oxygen	
<b>Micro</b>	B	Boron	Naturally in soil; can be added with fertilizers
	Cl	Chlorine	
	Co	Cobalt	
	Fe	Iron	
	Mn	Manganese	
	Mo	Molybdenum	
	Zn	Zinc	
	Cu	Copper	



## Soil Science

**Calcium (Ca)** – Calcium usually makes up more than 80 percent of the total bases present in the soil. Exchangeable Ca is important for changing the pH of the soil because Ca generally aids in the availability of other elements. However, a very high or low pH<sub>w</sub> may reduce the availability of some plant nutrients. A pH<sub>w</sub> of 6.0 to 6.8 is considered the most desirable for most grain crops and grasses. Legumes, such as alfalfa, need a higher pH<sub>w</sub> level (around 7.0). Ca can be supplied to the soil through agricultural limestone that is high in calcium carbonate (CaCO<sub>3</sub>). Ca is essential for building cell walls in plants, new roots, and leaves.

Ca deficiencies do not show in definite colorations in plants as some other nutrient deficiencies do. Deficiencies result mostly in low production, even in soils that are adequately supplied with the other major nutrients.

**Magnesium (Mg)** – Magnesium makes up about 15 percent of the bases in the soil. Mg can be supplied to the soil through dolomitic limestone that is high in magnesium carbonate (MgCO<sub>3</sub>). An Mg fertilizer is magnesium sulfate (MgSO<sub>4</sub>), also known as epsom salts.

Mg is vital in the photosynthesis process. Most of the Mg in plants is in chlorophyll or in seed. Mg deficiencies do not show in definite colorations in plants, but result mostly in low production, even in soils that are adequately supplied with the other major nutrients.

### Other Macronutrients

The other macronutrients are potassium (K), phosphorus (P), sulfur (S), and nitrogen (N); these are supplied in commercial fertilizers. Farmers (and even a few city people!) have used 12-12-12 fertilizer. Much of the fertilizer used for farm applications is now in the form of granular or liquid bulk mixes. Many fertilizer mixes are labeled P<sub>2</sub>O<sub>5</sub> or K<sub>2</sub>O to indicate the P or K. Neither of these compounds (P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O) are actually contained in these fertilizers! The form of P mainly used by plants is dihydrogen phosphorus (H<sub>2</sub>PO<sub>4</sub>) and the form of K mainly used by plants is just the K<sup>+</sup> ion. See Figure 8.1.

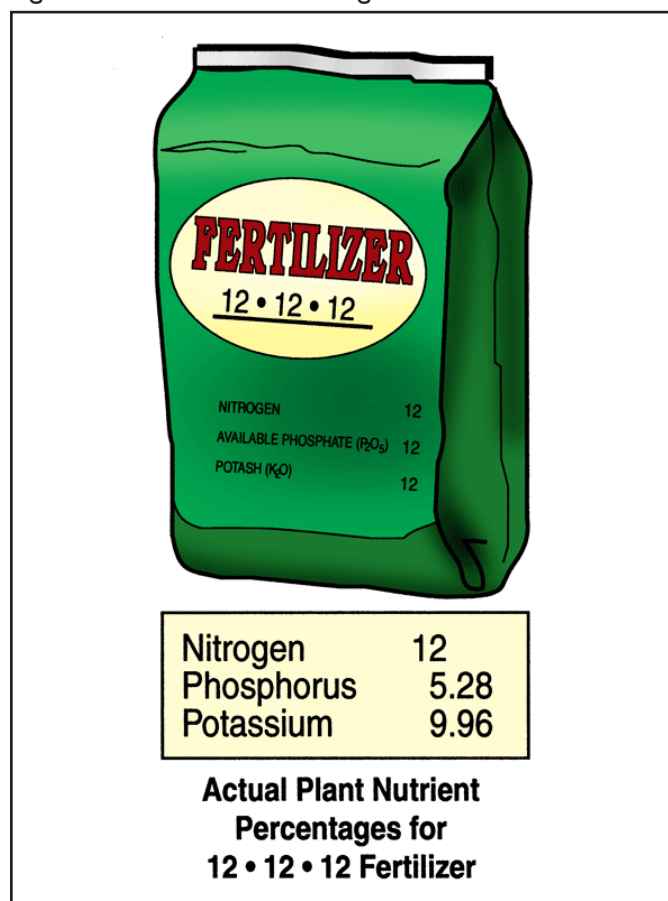
To compare the prices of commercial fertilizer, the actual price of the N, the P, and the K must be determined. Most

commercially mixed fertilizers give the actual percentage of N. P<sub>2</sub>O<sub>5</sub> actually contains 44 percent P. K<sub>2</sub>O actually contains 83 percent K. To determine the actual P and K in a 12-12-12 fertilizer, multiply the appropriate number in the fertilizer (12-12-12 = N-P-K) by the percent, for example,  $12 \times .44 = 5.28$  lbs of P, and  $12 \times .83 = 9.96$  lbs of K.

**Potassium (K)** – Potassium is the third element in all complete fertilizers. For example, in 3-12-24 fertilizer, the stated make-up is 3 lbs of N, 12 lbs of P<sub>2</sub>O<sub>5</sub>, and 24 lbs of K<sub>2</sub>O. (To find the actual amounts of P and K, follow the example above.)

The upper 7-inch layer of topsoil contains, on the average, about 30,000 lbs of K, but the exchangeable ion K makes up only 200-500 lbs per acre, or one percent of the total. Plants use K in this K<sup>+</sup> ion form. A good crop of alfalfa may use more than 25 percent of the available K in the soil in one year. Because only a small percentage of the K

Figure 8.1 – Contents of a Bag of Fertilizer



in the soil is available to plants and because plants absorb large amounts of K, the K level can be depleted rather quickly, especially when growing high forage-producing crops. Additions of K fertilizer on a regular basis are very important. The most commonly used K fertilizer is potassium chloride (KCl), also known as muriate of potash. Many commercial fertilizers, however, still use an old term for potash, expressed as  $K_2O$ . There is actually no  $K_2O$  compound in the fertilizer.

K helps in the uptake of other nutrients, it assists in many enzyme systems affecting metabolism and photosynthesis, and it is important in the formation of carbohydrates. K helps to regulate the opening and closing of stomata in the leaves (openings or slits in the outside of leaves that allow for breathing and the transportation of water) and the uptake of water in root cells. K is important for strong brace roots in corn and helps to prevent the plant from falling over (lodging in small grain). If the soil is too wet and aeration is inadequate, K cannot be absorbed by plant roots. Plant deficiencies can be detected by comparing deficient and healthy plants. The edges of older leaves and areas between the veins first turn yellow, then brown. Small brown spots develop while the veins are still green.

**Phosphorus (P)** – All P comes originally from rock. P in the soil forms complex anions with O. The solubility of P is low, making it less available to plants. This often causes P deficiencies in plants. The availability of P to plants is very complex and is related to the pH level, soil moisture, the amount of N in the soil, and other chemical properties. One positive factor about the low solubility of P is that unlike N, P is not readily leached from the soil.

Phosphorus in soil comes in both organic and inorganic forms. The organic form accounts for about one-half of the P in the soil. It is held very tightly in the soil and usually is not available to plants. Microorganisms break down organic forms of P into inorganic forms that plants can use ( $H_2PO_4$  and  $HPO_4$ ). This process develops best in warm, well-aerated soils where bacteria are most active. The amount of available P in the soil depends to a large extent on the soil pH, the types of P fertilizers added, and how they are applied. Application needs should be determined by soil test recommendations. P can be

added to the soil by applying finely ground P rock, super phosphate, or mixed fertilizers containing P.

Phosphorus is a component of every living cell. In plants it is concentrated in seeds and in the growing parts. P is needed for energy and root development and aids in the maturing of crops. Low temperatures stop the availability of P. P is second only to N in fertilizer usage.

Phosphorus deficiencies in plants result in stunting and late maturity. The lack of P results in slow conversion of sugar to starches and cellulose. The excess sugar causes the formation of anthocyanins, which result in purple spots and streaks in the leaf tissues.

**Sulfur (S)** – Plants adsorb S as a sulfate ( $SO_4^{--}$ ) ion or from the air as sulfur dioxide ( $SO_2^{--}$ ). It is also available through organic matter. Sulfur is a vital part of all plant proteins and some hormones. Plants use about as much S as P. Sulfur can be applied in the form of ferrous sulfate or aluminum sulfate (alum). Sulfur can also be added to reduce high pH levels. The amount of sulfur needed can be calculated in the same way as the lime (Ca) requirement is calculated.

Sulfur deficiencies slow down protein synthesis and the formation of amino acids. S deficiencies in plants resemble N deficiencies (e.g., leaves turn yellow during dry periods).

**Nitrogen (N)** – Nitrogen is a major component of the atmosphere. About 78 percent of the atmosphere is made up of N gas ( $N_2$ ). N is also found in soil. Organic matter releases N in the soil through the activity of microbes. N is one of the most critical elements for plant growth. Plants use two forms of N: ammonium ( $NH_4^+$ ) and nitrate ( $NO_3^-$ ).  $NH_4$  is held mostly on the soil colloid and  $NO_3$  is in the soil water and leaches out easily. There is also some  $NH_4$  in the soil water that leaches out.

Organic matter may contain up to 2,000–3,000 lbs of N per acre, but only a very small percent becomes available each year. Each percent of organic matter in the soil will supply only about 20 lbs of N per acre each year. This is not usually sufficient for most crops, so N is added to the soil in fertilizer.

## Soil Science

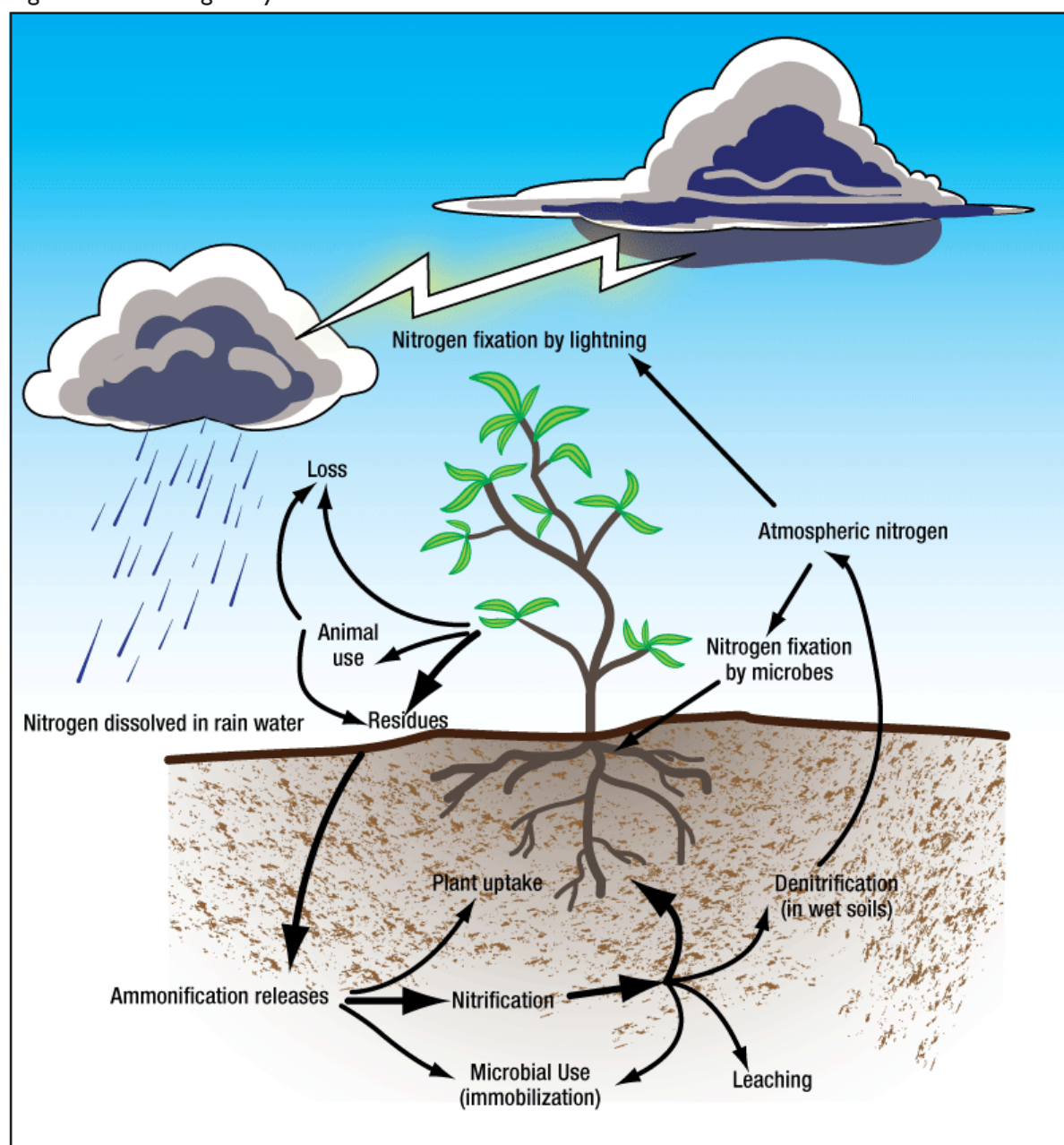
Many of the compounds in plants, such as amino acids and enzymes, contain N. Each molecule of chlorophyll contains four atoms of N. Chlorophyll is needed for the production of carbohydrates by photosynthesis. Plants also need N to form cells, and especially for root development.

Nitrogen not only is a very important plant nutrient, but it is equally important in the breakdown of the complex raw organic materials to humus by microbes. A fixed ratio of carbon and nitrogen (C:N ratio of 32:1) is necessary

for microbes to decompose residues. If microbes run out of N, they stop working. This can be noticed when crop residue (like corn stalks) do not decompose within a year in the soil. N cycles through various forms as it moves from the soil to microbes and back to the soil. N can enter or leave the cycle in different ways and places. Figure 8.2 shows the nitrogen cycle.

Nitrogen is to plants as gas is to a car. Just as a car will not run with an empty gas tank, soil will not produce

Figure 8.2 – Nitrogen Cycle



without N. Most of the N applied to soils is in fertilizers, such as ammonium nitrate, anhydrous ammonia, urea, and ammonium sulfate.

Abundant N results in a dark green, lush growth. The pale green color of N-deficient plants results from a shortage of chlorophyll. The N deficiency is caused mainly by inadequate soil moisture, even though adequate amounts of N may have been supplied. N deficiencies are most noticeable during long dry periods. For example, the center of corn leaves may turn yellow and die during extended dry periods. Therefore, N should be applied deeply enough in the soil so that roots can get adequate supplies during dry periods.

### **Micronutrients**

The eight micronutrients are:

- |                  |                     |
|------------------|---------------------|
| 1. Boron (B)     | 5. Iron (Fe)        |
| 2. Chlorine (Cl) | 6. Manganese (Mn)   |
| 3. Cobalt (Co)   | 7. Molybdenum* (Mo) |
| 4. Copper (Cu)   | 8. Zinc (Zn)        |

\*(muh-lib-deh-num)

These elements are sometimes referred to as trace elements or minor elements. However, a much more appropriate term is **micronutrient**. Some plants absorb large amounts of Na and Cl just because they are abundant in the soil, but only a small amount is necessary to the plants.

Shortages of micronutrients were not noticed much until the use of very high-analysis fertilizers became common. Adequate levels of micronutrients could be maintained in the soil in the past when crop yields were low. But with the heavy applications of fertilizers that are now generally applied, micronutrients are quickly depleted. The effect of small amounts of micronutrients is remarkable. A deficiency may have a devastating effect on plant growth, even though the plant requires only a minute amount.

Some micronutrients are a part of the enzyme molecules or act as an aid in the function of the enzyme. Others function in the processes of plant metabolism. Some micronutrients, such as Cu and Fe, aid in the formation of

chlorophyll. The amount of micronutrients needed usually is only a few pounds per acre; therefore, they generally can be included in other complete fertilizer mixes. It is very important that micronutrients are mixed thoroughly because only a small amount is needed and it must be applied evenly over the field. Overdoses can be toxic to plants, perhaps killing them or making them unfit for human consumption. It should be noted that plants also absorb varying amounts of several nonessential elements just because they are available, but the plants apparently show no adverse side-effects.

### **Organic Matter**

An abundance of organic matter makes the soil black. Most people associate this with a fertile soil. If organic matter does nothing else, it makes a person who owns a garden spot or farm just feel good to know the soil is, or appears to be, fertile! However, there are other important factors in favor of a soil that has a high organic matter content. Organic matter improves soil structure. Good soil structure enhances aeration and healthy root development. Organic matter supplies N. In fact, it supplies nearly all the N to plants unless N fertilizer is added to the soil. Organic matter also contains P and may account for about one-half of the P in the soil. Organic matter adds to the total CEC of the soil, of which it may make up 25–50 percent, depending on the amount of montmorillonite, kaolinite, or other minerals in the soil.

### **Summary**

A fertile soil produces high-yielding, healthy crops. Although a fertile soil has nutrient balance and quantity, nutrients alone are not sufficient to make a soil fertile. Fertile soil depends on soil texture, structure, rooting depth, organic matter content, available water capacity, aeration, length of growing season, and physical support.

There are nine essential macronutrients: three are supplied by water and air (carbon, hydrogen, and oxygen); six are supplied by soil mineral solids or organic matter (calcium, magnesium, potassium, phosphorus, sulfur, and nitrogen). Calcium (Ca) makes up more than 80 percent of the bases, so it is very important in changing soil pH

## Soil Science

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and making other nutrients available to plants. Calcium deficiencies usually result in low production, even if soils have adequate supplies of other major nutrients.

Magnesium makes up about 15 percent of the bases in the soil. It is vital in the photosynthesis process (chlorophyll contains Mg). Magnesium deficiencies usually result in low production, even though soils have adequate supplies of the other major nutrients.

Potassium is the third element in all complete fertilizers. Regular additions of potassium fertilizer are very important because only a small amount of the potassium in the soil is available to plants, and it is depleted rather quickly. Potassium is absorbed in large amounts by plants. It helps in the uptake of other nutrients and assists in many enzyme systems that affect metabolism and photosynthesis. Plant deficiencies are evident when leaf edges yellow and then brown, or small brown spots develop while veins are still green.

Phosphorus is a component of every living cell. It helps in root development and aids in the maturing of crops. Phosphorus deficiencies in plants result in stunting and late maturity. An absence of phosphorus causes purple spots and streaks.

Sulfur is a vital part of all plant proteins and some hormones. Sulfur deficiencies turn leaves yellow during dry periods.

The nitrogen in the soil that is available to plants is usually insufficient for most crops, so nitrogen is generally added to the soil in fertilizer. Nitrogen is one of the most critical elements for plant growth. It has an effect on many compounds in plants, such as amino acids and enzymes. Deficiencies are evident in a pale green plant color, which is a result of a shortage of chlorophyll.

The eight essential micronutrients are boron, chlorine, cobalt, copper, iron, manganese, molybdenum, and zinc. Only a small amount of these elements is necessary for good plant growth, but deficiencies can have a devastating effect. Organic matter is important because it supplies most of the nitrogen that is naturally present in the soil, and may account for about half of the phosphorus. It also aids in good soil aeration, healthy root development, the formation of soil structure, and the soil's total CEC.

### Credits

Brown, J.R., and R.R. Rodriguez. *Soil Testing: A Guide for Conducting Soil Tests in Missouri* (Guide #EC 923). Missouri Cooperative Extension Service, 1983.

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

Thompson, L.M., and F.R. Troeh. *Soils and Soil Fertility*, 3rd ed. New York: McGraw-Hill, 1973.





### Plate 1

Moderately deep, moderately well drained soil formed into sandstone residuum. Light brown A horizon and a gray prominent E horizon. Bedrock starts at about 24 inches. (Bolivar silt loam)



### Plate 3

Clay flow shows the downward movement of clay into the subsoil. Clay coatings on peds and sand grains give them a waxy appearance.



### Plate 2

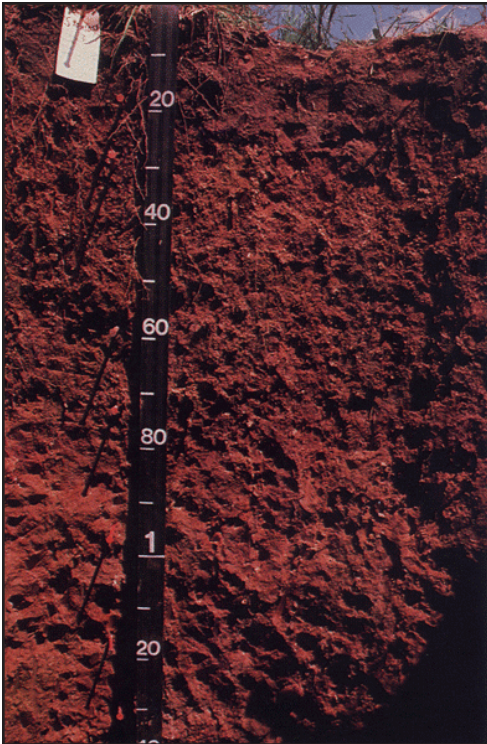
Well drained soil formed in loess. Thick, very dark brown A horizon, high organic matter. (Marshall silt loam)



### Plate 4

Well drained young soil. Colors and textures of the profile vary very little with depth. A horizon has low organic matter. (Ida silt loam)





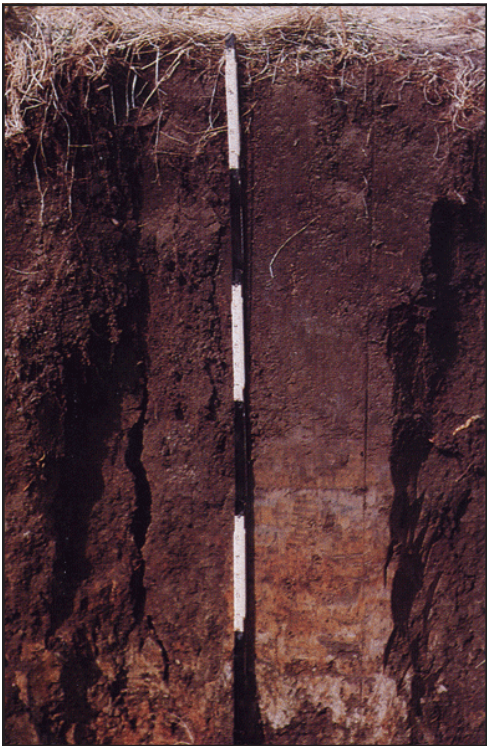
### Plate 5

Well drained old soil. Color is uniform throughout the profile. Red color indicates high oxidation of iron. (Cotton silt loam)



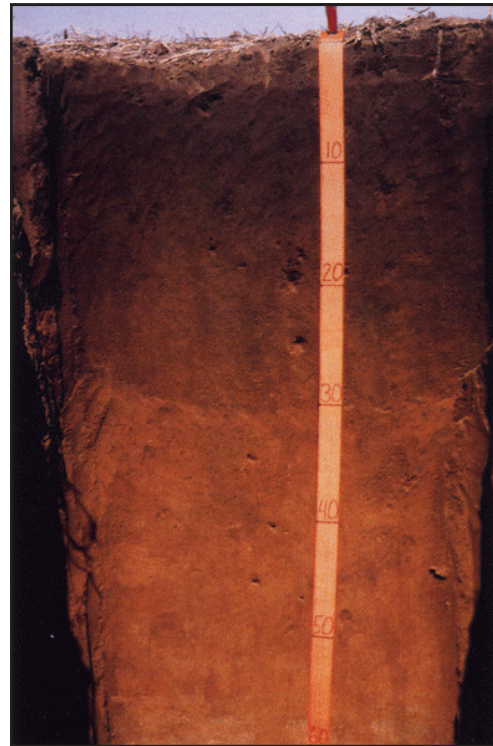
### Plate 6

Btg horizon shows well developed prismatic structure.



### Plate 7

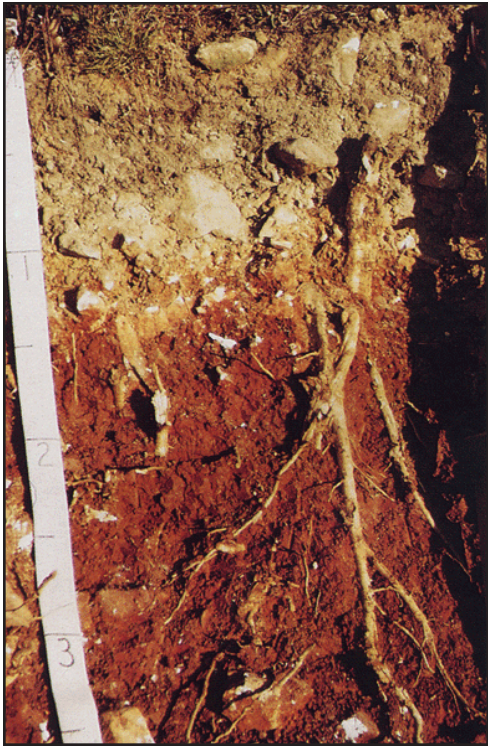
Somewhat poorly drained soil formed in loess. Entire subsoil is dark gray with brown mottles indicating a perched seasonal high water table. (Grundy silt loam)



### Plate 8

Well drained soil formed in loess. Thick, very dark brown A horizon. High organic matter. (Monona silt loam)





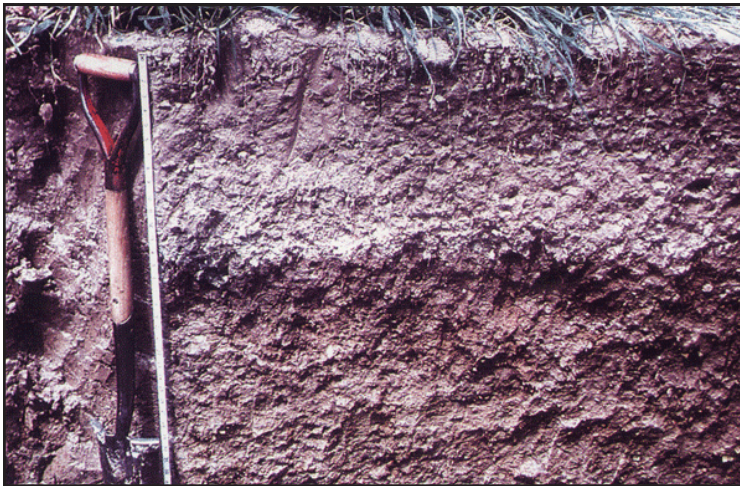
**Plate 9**

Well drained soil formed in colluvium and the underlying residuum. (Doniphan gravelly silt loam)



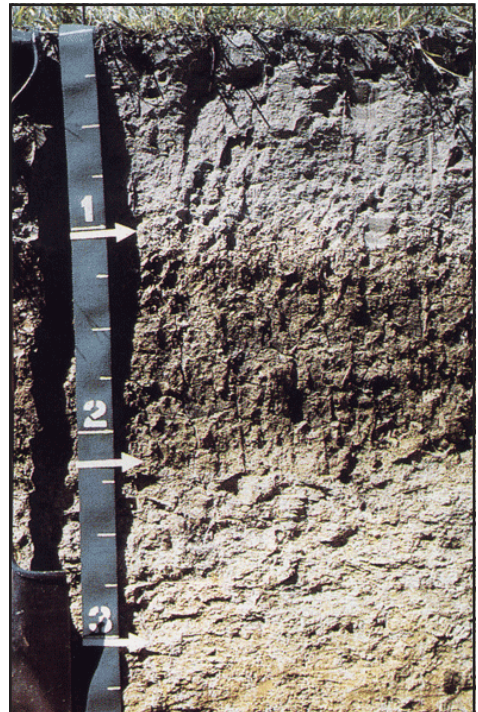
**Plate 10**

Thick black A horizon. High organic matter.



**Plate 11**

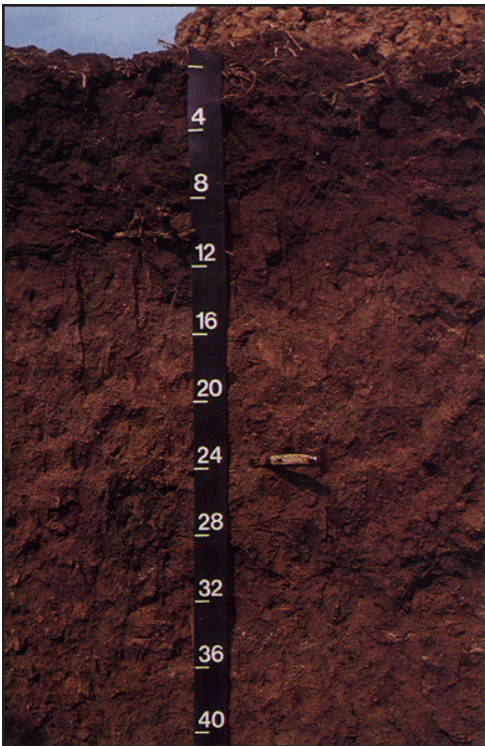
Poorly drained soil formed loess. Dark brown A horizon. Thick gray, silty E horizon over a gray, clayey Btg horizon. An abrupt texture change between the E and Btg horizon. (Putnam silt loam)



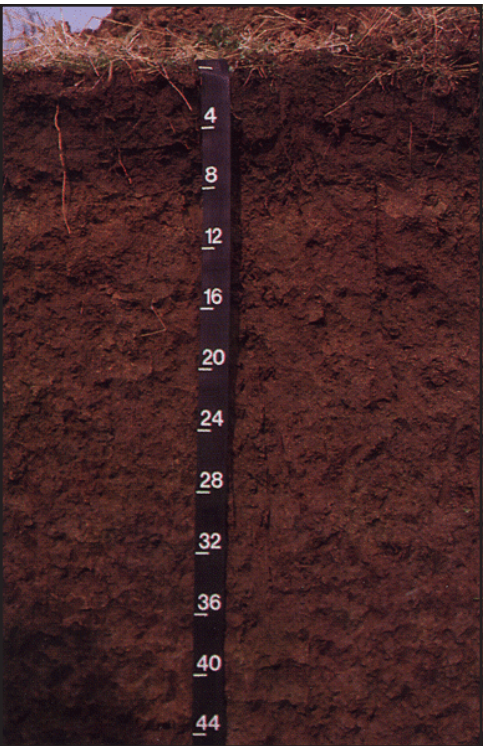
**Plate 12**

Poorly drained soil formed in loess and residuum. Gray A horizon. Light gray E horizon over a dark gray, clayey Btg horizon. An abrupt texture change between the E and Btg horizon at 14 inches. Fragipan at 27 inches. (Gerald silt loam)

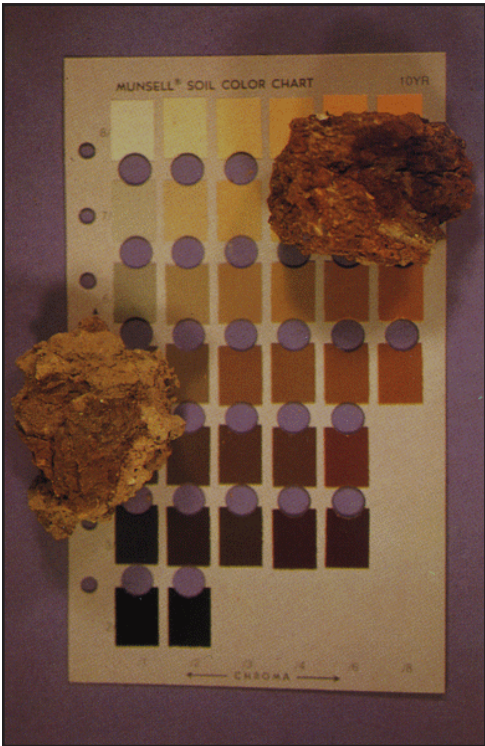




**Plate 13**  
 Poorly drained soil formed in alluvium. Dark brown A horizon over a thick gray E horizon at 14 to 24 inches. (Vesser silt loam)



**Plate 14**  
 Somewhat poorly drained soil formed in loess. Dark brown A horizon over a Btg horizon. (Weller silt loam)

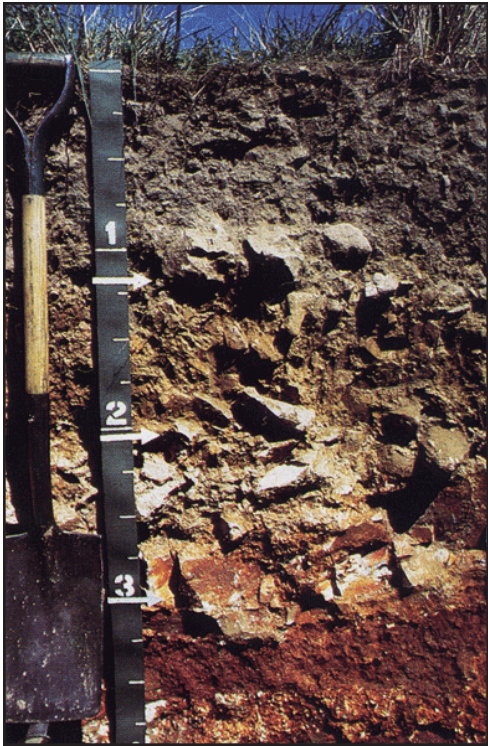


**Plate 15**  
 10YR Munsel color chart.



**Plate 16**  
 Soil with an extremely cobbly surface layer.





**Plate 17**

Extremely cobbly fragipan layer at 24 to 36 inches. (Keeno gravelly silt loam)



**Plate 18**

A young soil formed in silty and gravelly alluvium. Thick black A horizon. Extremely gravelly C horizon. (Dameron silt loam)



**Plate 19**

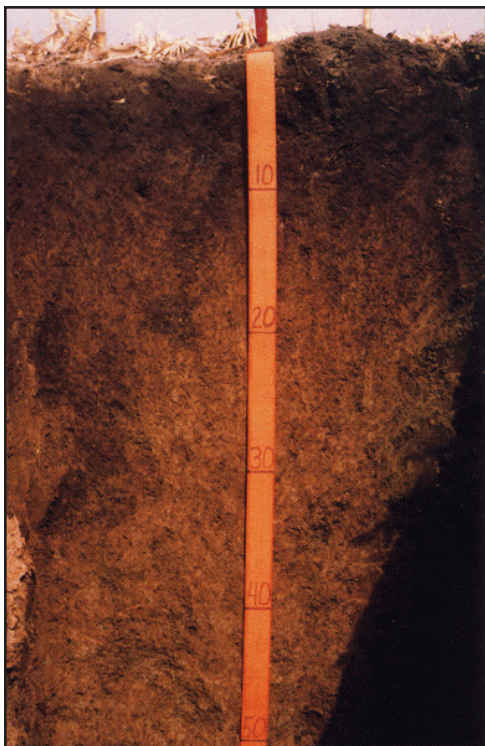
Soil has a high percentage of montmorillonite clay that causes high shrink-swell during dry and wet periods.



**Plate 20**

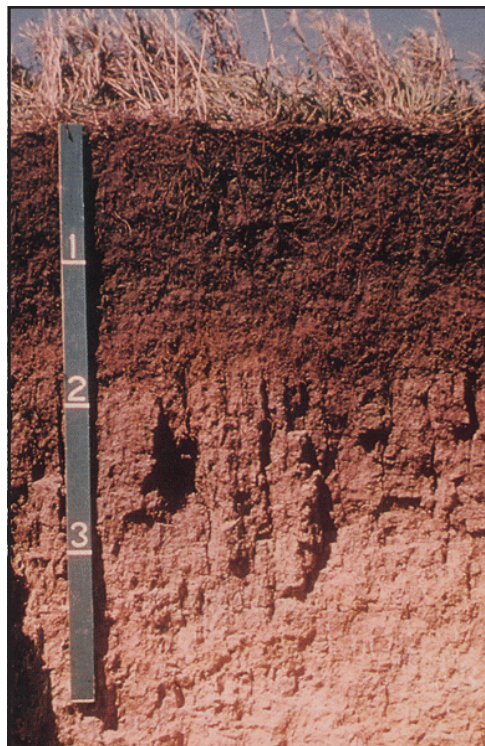
An abrupt horizon boundary between the Ap and Al horizons caused by yearly plowing at the same depth.





**Plate 21**

Moderately well drained soil. Profile shows gradual horizon boundaries. (Sharpsburg silt loam)



**Plate 22**

Well drained soil with a dark brown BA transitional horizon at 15 to 23 inches, a Bt horizon at 23 to 34 inches with strong prismatic structure.



**Plate 23**

Well drained soil with a very dark grayish brown AB transitional horizon at 12 to 18 inches and a Bw horizon at 12 to 30 inches.



**Plate 24**

Well drained soil with a thin Ap horizon over a Bt horizon. (Menfro silt loam)





### Plate 25

Somewhat poorly drained soil with a dense thick fragipan at the 24 to 48 inch depth. (Hobson silt loam)



### Plate 26

Moderately well drained soil. Brown Bt horizon at 9 to 30 inches and a gray mottled fragipan at 19 to 30 inches. (Credon silt loam)



### Plate 27

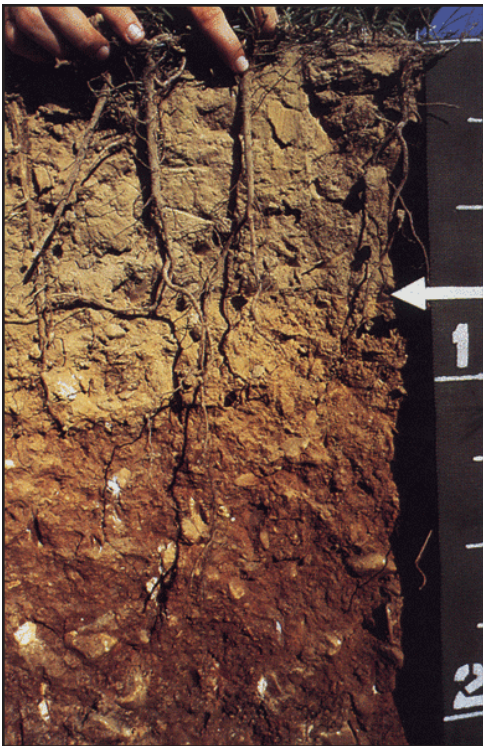
Soil with a distinct fragipan starting at 24 inches.



### Plate 28

Well drained soil formed in colluvium and the underlying residuum. (Gepp gravelly silt loam)





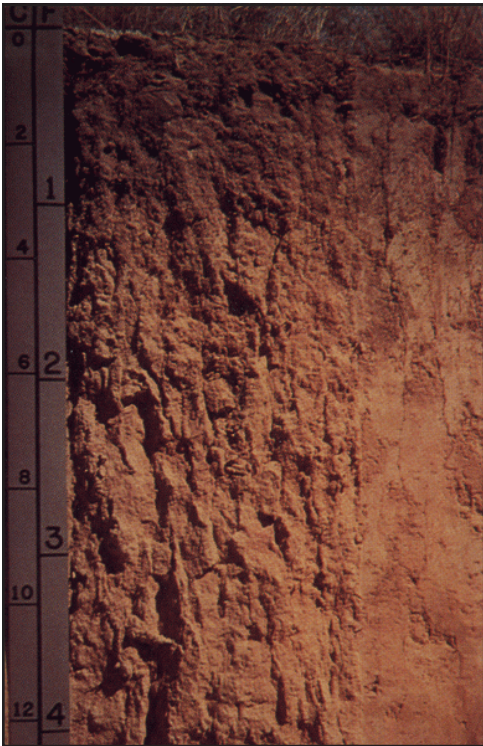
### Plate 29

Brown A horizon, light brown B horizon with a dense layer at about 15 inches preventing root penetration.



### Plate 30

Well drained soil that formed in naturally gray parent material of loess. Gray colors are not caused by wetness. (Contrary silt loam)



### Plate 31

Somewhat excessively drained soil formed in coarse loess. Grayish brown A horizon 0 to 8 inches, pale brown AC transitional horizon 8 to 16 inches over a C horizon.



### Plate 32

Small ponded areas. Surface drainage is needed. (Putnam silt loam)

*Slides and photos courtesy of John Baker, Bill Broderson, Herb Huddleston, Paul Minor, Wiley Nettleton, C.L. Scrivner, and Fred Young.*

# Soil Sampling and Interpreting Soil Test Results

## Lesson 9: Soil Sampling and Interpreting Soil Test Results

Soil samples are taken from crop fields or gardens to determine the percentage of the organic matter, the pH, and the amount of available nutrients in the soil. The balance of plant nutrients needs to be adequate for the kind of crop desired. Each crop requires a particular balance of nutrients for optimal yields. For example, corn requires large amounts of additional nitrogen while soybeans require none, because soybeans have nitrogen-producing nodules on their roots. Recommendations based on soil test data are needed so adequate plant nutrients can be applied to produce healthy, high-yielding plants at a minimal cost.

### Factors that Influence Sampling

A soil sample should be representative of the field, or an area within a field, but it should never represent more than 20 acres. A field should be divided if it includes different soil types, if different kinds of crops were grown in some parts of the field, or if the natural surface texture varies within the field. Also, eroded and wet areas should be sampled separately.

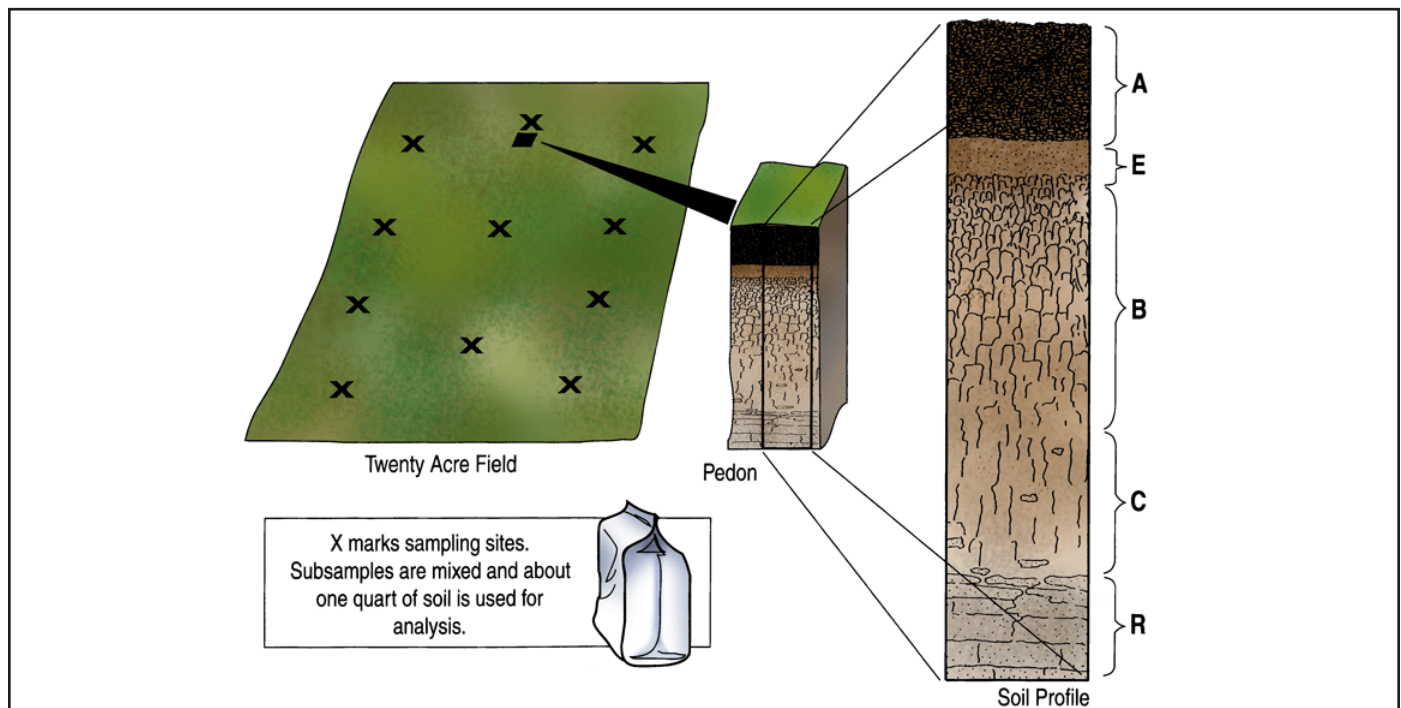
### When to Sample

Samples can be taken at any time of the year. Samples can generally be obtained when the soil is dry enough to till. If the soil is slightly wet, it can be dried slowly and crumbled up by stirring or mashing with a mallet. Samples should not be taken when the soil is muddy. Generally, fields should be retested every 3 to 4 years to determine if any changes have occurred in the fertility level.

### Sampling Procedure

A soil auger, probe, or spade can be used to take soil samples. Each subsample should include the top 7 inches of soil. Soil samples should be taken from different areas of the field and mixed thoroughly. Then, an adequate amount (about one quart) of sample material should be placed in a small box or bag. Special sample bags can be obtained from many fertilizer dealers or from the local university extension center. The sample should be identified by field number and field map. The container should be left open in a clean, dust-free area to air-dry. The sample should be taken to the local university extension center for analysis. Figure 9.1 shows the relationship among a 20-acre field, a

Figure 9.1 – Field, Pedon, Profile, Soil Sample





## Soil Science

pedon (with a surface area of 1–10 sq meters), a profile, and typical soil sampling points.

### ***Soil Sampling Procedure for a Cultivated Field***

In a 20-acre cultivated field, 10–20 subsamples are needed. The soil in a freshly cultivated field may need to be pressed down slightly (with the foot) to obtain a natural depth.

### ***Soil Sampling Procedure for a No-Till Field***

Most no-till fertilizers are applied to the surface, so only the top 3 inches of soil may be affected. Therefore, when taking soil samples from a no-till field, two samples are needed: one sample from the top 3 inches, and another sample from the next 4 inches. In a 20-acre field, 10–20 subsamples are needed from the top 3 inches, and another 10–20 subsamples from the next 4 inches are needed.

### ***Sampling Procedure for a Garden***

Four to 10 subsamples (from the top 7 inches of soil) should be taken from a garden or yard, even though the garden area is very small.

## **Pitfalls of Soil Sampling**

It is important that a soil sample be representative of the field or area within a field. Samples should not be taken just inside the field boundary, near a limestone gravel road, or from a severely eroded area. The test results from samples such as these are worthless. In the first example above, the area may have had a low pH if sampled correctly, but this sample would probably show a high pH because of the lime dust from the road. In the second example, taken from a severely eroded area, the sample probably would show a high cation exchange capacity, and would be low in available calcium. The test results would indicate a large lime requirement, which really would not be necessary for the entire field.

Taking samples that are not representative of the area can be costly in two ways. First, it may indicate much more fertilizer than is actually needed. Second, it may indicate less fertilizer than is actually needed, which would greatly

reduce the crop yield desired. Either example above could prevent the landowner from obtaining a reasonable profit. Therefore, avoid sampling areas near a field boundary, a limestone gravel road, dead furrows, end rows, eroded spots, wet spots, and old barn lots. Above all, do not dry samples in an oven or microwave, as this may distort the test results.

## **Available Soil Testing Services**

Some fertilizer companies will pay for soil tests if their fertilizer is purchased. Some companies do their own testing. However, others send soil samples to a laboratory. Recommendations should be made by an independent laboratory or the local university extension center.

## **Crop History**

The crop history (list of crops grown in the previous 3 or 4 years) helps to explain varying levels of nutrients found in the soil. For example, a sample showing a low nutrient level may indicate that the soil was naturally low in plant nutrients, when, in reality, an intensive cropping system without fertilizer applications had depleted the soil of available nutrients. In other words, the recent crop history usually helps to explain unusual test results and present nutrient levels. It also helps in making recommendations for future crops.


## **Soil Test Data**

Data obtained from a complete soil test report (see Figures 9.2 and 9.3) shows the percentage of organic matter content, the pH, the CEC, and the available calcium, magnesium, phosphorus, and potassium. It will also give the neutralizable acidity (NA). Available nitrogen is not tested because it is quickly exhausted from the soil by erosion, leaching, denitrification (loss of nitrogen gas to the air), and growing crops. Therefore, nitrogen generally must be replenished as needed for each growing crop. Allowances can be made for nitrogen supplied by the organic matter and legume crops, but these amounts depend largely on how much residue is decomposed by microbes. In other words, the C:N ratio comes into effect here (see Lesson 8). To determine the actual nutrients for a particular soil, see Lesson 7.



# Soil Sampling and Interpreting Soil Test Results

Figure 9.2 – Soil Test Report for a Corn Field

 <b>University Extension</b> <small>UNIVERSITY OF MISSOURI COLUMBIA</small>	<h2 style="margin: 0;">Soil Test Report</h2>	<b>Soil Testing Laboratory</b> 23 Mumford Hall, MU Columbia, MO 65211 Phone: (314) 882-0623	or <b>Soil Testing Laboratory</b> P.O. Box 160 Portageville, MO 63873 Phone: (314) 379-5431
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<b>FIELD INFORMATION</b>				Serial no. <b>L 6519</b> Lab no. <b>05538</b>
Field ID <b>2 / 1</b>	Sample no. <b>1</b>	Area <b>15</b>	County <b>010</b> Region <b>3</b>	
Acre <b>28</b>	Last Lined <b>&gt;5</b>	Irrigated <b>NO</b>	Submitted <b>03/28/94</b>	Processed <b>03/31/94</b>
Last crop <b>103 CORN (GRAIN)</b>				

This report is for:

Soil sample submitted by:  
**MFA EXCHANGE**  
**BOX 67**  
  
**CENTRALIA, MO 65240**  
**FIRM=077 OUTLET=144**

SOIL TEST INFORMATION		RATING					
		Very low	Low	Medium	High	Very High	Excess
pH <sub>s</sub> (salt pH)	<b>6.5</b>	*****					
Phosphorus (P)	<b>57 lbs/a</b>	*****					
Potassium (K)	<b>231 lbs/a</b>	*****					
Calcium (Ca)	<b>3135 lbs/a</b>	*****					
Magnesium (Mg)	<b>136 lbs/a</b>	*****					
Sulfur (SO <sub>4</sub> -S)	<b>3.8 ppm</b>	*****					
Zinc (Zn)	<b>1.3 ppm</b>	*****					
Manganese (Mn)	<b>ppm</b>						
Iron (Fe)	<b>ppm</b>						
Copper (Cu)	<b>ppm</b>						
Organic matter	<b>3.2 %</b>	Neutralizable acidity		<b>0.5 meq/100g</b>	Cation Exch. Capacity		<b>9.2 meq/100g</b>
pH in water		Electrical Conductivity		<b>mmho/cm</b>	Sodium (Na)		<b>lbs/a</b>
Nitrate (NO <sub>3</sub> -N) Topsoil	<b>ppm</b>	Subsoil	<b>ppm</b>	Sampling Depth	Top	Inches	Subsoil inches

NUTRIENT REQUIREMENTS							LIMESTONE SUGGESTIONS	
Cropping options	Yield goal	Pounds per acre					Effective neutralizing material (ENM)	
		N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Zn	S		
<b>115 SOYBEANS</b>	<b>40 BU/A</b>	<b>0</b>	<b>20</b>	<b>70</b>	<b>0</b>	<b>0</b>		
<b>115 SOYBEANS</b>	<b>40 BU/A</b>	<b>0</b>	<b>20</b>	<b>70</b>	<b>0</b>	<b>0</b>		
<b>119 WHEAT</b>	<b>60 BU/A</b>	<b>65</b>	<b>20</b>	<b>30</b>	<b>0</b>	<b>0</b>	Effective magnesium (EMg)	<b>**</b>

Some herbicide labels list restrictions based on soil pH in water. Your sample has an estimated pH in water of 7.0. Use this value as a guide to the label. If you wish to have soil pH in water analyzed, contact your dealer or local Extension specialist listed below.

The cation exchange capacity of this soil would suggest very low potential for sulfur response. Monitor the crop by plant analyses for potential need for sulfur.

Limestone is not currently recommended. For a future limestone application, suggest using dolomitic limestone if readily available, but yield response to magnesium is not likely.

Nitrogen requirements may be reduced by 30 pounds per acre for the first crop following soybeans.


## Summary

Soil samples are needed to determine the organic matter content, the pH, and the amount of available nutrients in the soil. Soil samples should be *representative* of the field or plot. If the area includes different soil types, different crops, different soil textures, or eroded and wet areas, the field should be divided and those areas should be sampled separately. Samples should be taken within uniform areas.

Samples should be taken every 3 to 4 years and at a time when the soil is dry enough to cultivate. An auger, probe, or spade can be used to take soil subsamples from the top 7 inches (except for no-till fields in which the top 3 inches and the next 4 inches are sampled separately). Ten to 20 subsamples should be taken from large fields (up to 20 acres); 4 to 10 subsamples should be taken from gardens or lawns. Subsamples should be thoroughly

## Soil Science

Figure 9.3 – Soil Test Report for an Existing Lawn

 <p><b>University Extension</b> UNIVERSITY OF MISSOURI SYSTEM LINCOLN UNIVERSITY</p> <p>RECOMMENDATIONS FOR SAMPLE ID: - Bermudagrass or Zoysia Lawn - Avg. Maintenance of Existing Lawn</p> <p>Last limed unknown</p>	<p><b>SOIL TEST REPORT</b></p> <p>— MU Laboratories —</p> <p>23 Mumford Hall      P.O. Box 160 Columbia, MO 65211      or      Portageville, MO 63873 (314) 882-0623      (314) 379-5431</p>		<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 25%;">Serial no. <b>Q1799H</b></td> <td style="width: 15%;">Area <b>15H</b></td> <td style="width: 15%;">County <b>010</b></td> <td style="width: 45%;">Region</td> </tr> <tr> <td colspan="2">Submitted <b>05/31/94</b></td> <td colspan="2">Processed <b>06/02/94</b></td> </tr> </table>				Serial no. <b>Q1799H</b>	Area <b>15H</b>	County <b>010</b>	Region	Submitted <b>05/31/94</b>		Processed <b>06/02/94</b>	
	Serial no. <b>Q1799H</b>	Area <b>15H</b>	County <b>010</b>	Region										
Submitted <b>05/31/94</b>		Processed <b>06/02/94</b>												
<p>This report is for:</p>														

SOIL TEST INFORMATION		RATING					
		Very low	Low	Medium	High	Very high	Excess
pHs	6.4	*****					
Phosphorus (P)	49 lbs/a	*****					
Potassium (K)	368 lbs/a	*****					
Calcium (Ca)	5007 lbs/a	*****					
Magnesium (Mg)	427 lbs/a	*****					
Organic Matter: 5.2 %		Neutr. acidity: 1.0 me				CEC: 15.8 me	

**FERTILIZER & LIMESTONE SUGGESTIONS**

Nitrogen (N): 2.0    Phosphate (P2O5): 0.5    Potash (K2O): 0.0    Lime: 25.0

Fertilizer rates are given in pounds of actual nutrient per 1000 square feet to be applied. See additional comments below.

The soil should be tested every two to three years to determine the effects of your fertilization practices and to develop a new set of fertilizer and limestone guidelines.

Apply suggested agricultural or horticultural limestone rate one time. Do not apply additional limestone unless soil tests indicate further need.

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\*\*\* Apply two pounds of nitrogen (N) per 1000 square feet in late April or or early May. See Guide 6706, "Establishment and Care of Zoysia Lawn."

mixed together, air-dried, and taken to an independent laboratory. Samples should not be taken close to roads, disturbed areas, eroded spots, dead furrows, end rows, wet spots, and old barn lots. Large eroded areas should be sampled separately.

The crop history helps to explain present nutrient levels and unusual test results. It also aids in making recommendations for future crops.

### Credits

Brown, J.R., and R.R. Rodriguez. *Soil Testing: A Guide for Conducting Soil Tests in Missouri* (Guide #EC 923). Missouri Cooperative Extension Service, 1983.

Buchholz, Daryl D., James R. Brown, and Roger G. Hansen. *Using Your Soil Test Results* (Guide #9111). Columbia, MO: University Extension, 1992.

## Water Movement and Retention

### Lesson 10: Effects of Soil on Water Movement and Retention

#### Importance of Water to Plant Growth

Water is a basic natural resource. All plants and animals need it to survive, although the amount needed varies widely. Actively growing plants are composed of up to 90 percent water.

Plants need water to take up soil nutrients. Roots take up soil water and the leaves release water through transpiration. See Figure 10.1. **Transpiration** is the process whereby plant moisture is released in water vapor through the plant pores. Water is necessary for plant transpiration to occur. Wind, temperature, soil fertility, and humidity all can affect the rate of plant transpiration. If transpiration water exceeds the quantity of water entering through the roots, the plant will wilt and may eventually die.

The soil loses water through evaporation and plant use. **Evaporation** in the soil occurs where pores are so interconnected that air circulates to the soil surface. Evaporation usually only affects the surface 2 or 3 inches,

but when large cracks are present, it can extend to 2 or 3 feet in depth. Plants use 300–500 lbs of water for every pound of dry weight. For example, an acre of corn requires about .5 million gallons of water for healthy growth. As vital as water is to healthy plant growth, too much water in the soil can be harmful to crops commonly grown for food production. Conversely, the lack of water interferes with the normal growth processes as well as the food-making power of the plant.

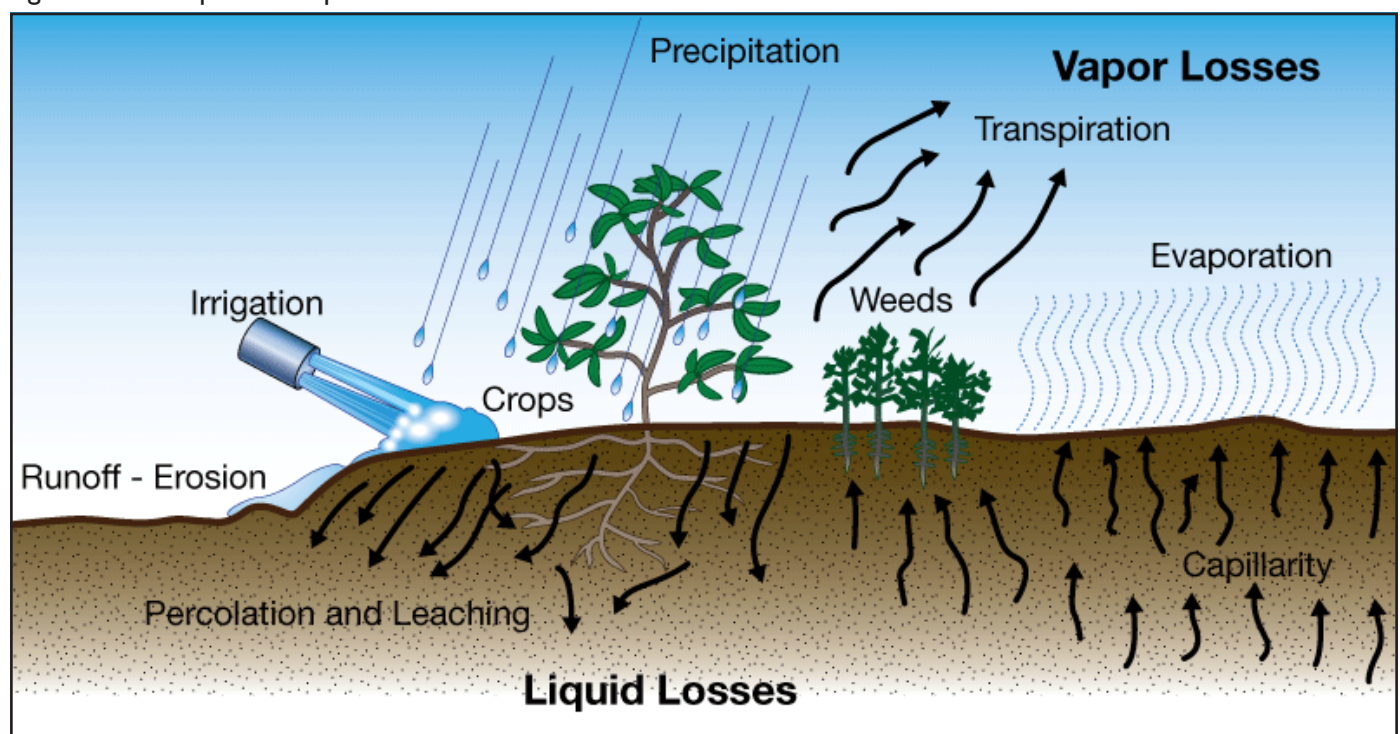
#### Types of Soil Water

Only part of the water contained in the soil is available to plants. There are three major kinds of soil water: gravitational water, capillary water, and hygroscopic water. See Figure 10.2. Only the available water is useful to plants.

**Gravitational water** fills large pores when the soil is saturated. It drains away quickly as soon as the water table drops or it stops raining. Plants cannot use gravitational water.

**Capillary water** is held in smaller soil pores or capillaries against a force of gravity similar to water drops on a glass

Figure 10.1 – Liquid and Vapor Losses



## Soil Science

or cohesion (attraction between water molecules). Most of this water is available to plants.

**Hygroscopic water** is held so tightly in tiny soil pores by adhesion (a strong attraction between soil particles and water molecules) that roots cannot remove it. When a soil is so dry that only this water remains in the soil, plants will wilt and die. Clayey soils contain large amounts of unavailable water that plants cannot use.

### Available Water Capacity (AWC)

Adequate water in the soil is vital to plant growth. Plants need water for the physiological actions that take place, for example, photosynthesis and respiration. Water also contains plant nutrients that are readily usable by plants. Water comes mostly from precipitation, but the soil needs good infiltration and storage of the water for use between rains. Water often is the most limiting factor in crop yields.

It is possible to make field measurements of water content, rates of water movement, and internal drainage, but they require a great deal of time, skill, and expensive equipment. However, by observing some of the primary properties of soil horizons, such as color, texture, and structure, estimates of the available water capacity (AWC),

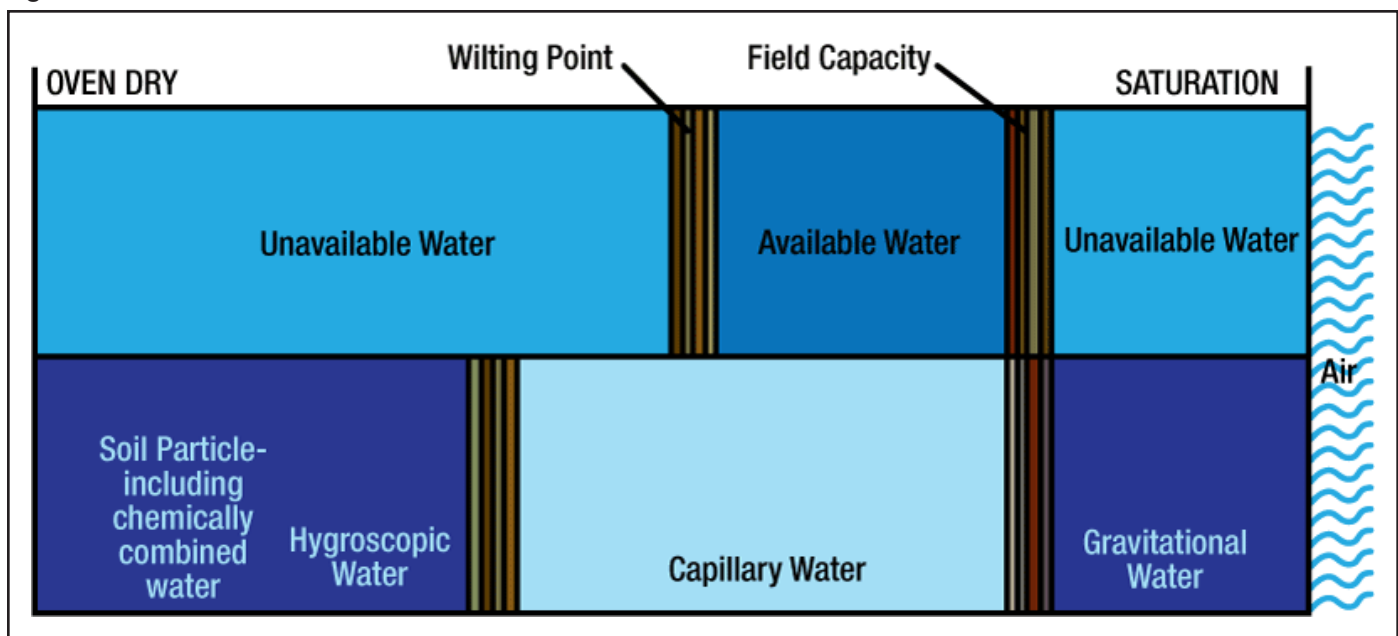
permeability, internal drainage, and several other properties can be made. These estimates are useful for learning how the soil may respond to use and management.

The **available water capacity** or **AWC**, is the potential of a soil to hold water in a form available to plants, and commonly is defined as the amount of water held between **field capacity** (the point at which the downward movement of water caused by gravity and underlying dry soil has ceased) and the **wilting point** (the point at which all available water is depleted). See Figure 10.2. Since the soil provides the only reservoir of water from which plants can draw, the size (or volume) of the reservoir is one of the most important properties of the soil. Soils that have a high AWC have a greater potential to be productive than soils that have a low AWC.

Water is held on soil particles by surface tension. The force holding water is closely related to the total surface area of the soil particles. Because the volume of small particles has more total surface area than the same volume of large particles, small particles exert a greater holding force than large particles.

Plant roots must overcome the force of surface tension in order to take up water from the soil. This tension can actually be measured and provides valuable information

Figure 10.2 – Kinds of Soil Water





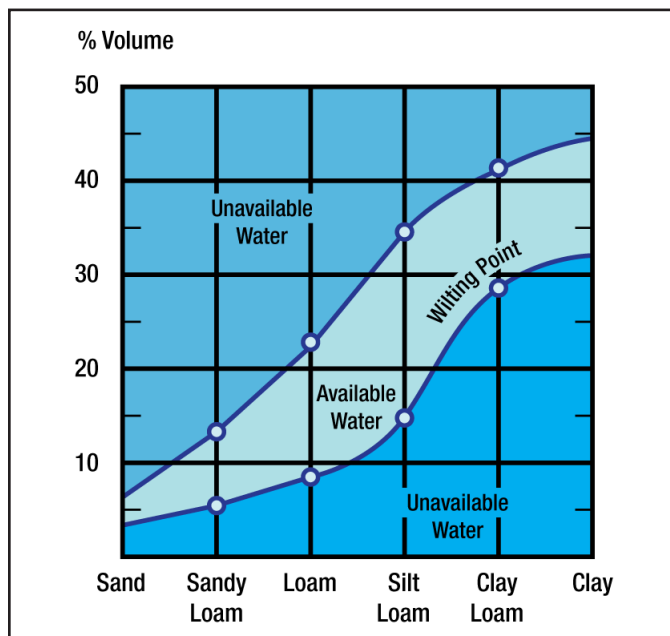
# Water Movement and Retention

for obtaining the wilting point. Irrigation water should be applied before the wilting point is reached, because wilting may cause enough damage to substantially reduce crop yields.

## Field Capacity

The moisture content of the soil, when downward movement of water caused by gravity and the underlying dry soil has ceased, is called **field capacity**. Expressed in another way, field capacity is the maximum amount of water left in the soil after losses to the forces of gravity have ceased and no surface evaporation has occurred. About one-half or more of the water held in the soil at field capacity is held so tightly that it is unavailable to plants. The amount of water at field capacity is reduced either by plants or evaporation and is restored only by another rain, rising water table, irrigation, or flooding. The texture of the different layers is important because more water will move downward if there is a greater attraction for the water in the lower layer. Clayey layers can delay downward movement of water when the soil is saturated, but they also can exert strong tension and can pull water out of silty and loamy layers that are above. This is especially true during dry periods when plants and evaporation have nearly depleted the water from the surface layer. See Figure 10.3.

Figure 10.3 – Available Water



## Wilting Point

The **wilting point** occurs when all available water for a particular kind of plant is removed. It is critical in irrigation not to let plants reach the wilting point before irrigation water is applied to the soil. The wilting point will vary with plants and sometimes with atmospheric conditions. Some plants are more tolerant to drought than others. That is why grain sorghum produces better than corn in some areas.

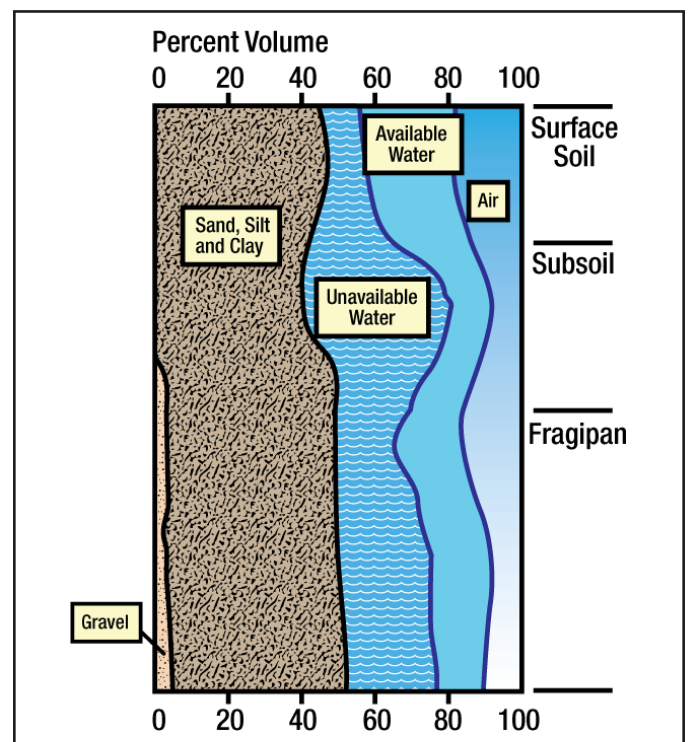
## Soil Properties that Affect AWC

Available water capacity depends primarily on texture, effective rooting depth, and rock fragment content. To a lesser extent, AWC depends on structure and organic matter. See Table 10.1 and Figure 10.4.

Table 10.1 – Soil Properties that Affect AWC

AWC depends on...	
Texture	Structure
Effective rooting depth	Organic matter
Rock fragment content	

Figure 10.4 – Volumes of Air, Water, and Solids for Gerald Silt Loams





## Soil Science

The **texture** has the greatest effect on the AWC because of the differences in sizes of soil particles. Clay has a tremendous surface area per volume of soil as compared to sand, with silt somewhere in the middle (see Lesson 4). The surface areas have been determined for the different texture classes. As water is held on the surfaces of soil particles, the AWC can be estimated by determining the texture, percentage of rock fragments of each horizon, and the effective rooting depth.

The **effective rooting depth** is simply the distance from the surface to the top of any soil horizon that prevents significant root penetration. Dense layers or horizons, such as fragipans, and extremely gravelly or cobbly layers limit root development. Extended periods of free water (high water table) at high levels in the soil also inhibit root growth. Bedrock completely blocks root penetration, unless it has large cracks filled with soil material. See Plate I, p. 50-A.

Fragipans are very dense layers with high bulk density (mass of dry soil per unit bulk volume) and very low permeability. Fragipans are hard and brittle, but not cemented. They are so dense and have such poor structure that roots generally cannot penetrate. See Plates 25, 26, 27, and 29, pp. 50-G and 50-H.

Many plants extend roots to depths well beyond 3 feet, provided there is no physical barrier to root growth. Soils that allow deep rooting are potentially very productive because plants that grow in them can use the greatest possible volume of soil in search of water and nutrients.

Soils that have restricted rooting depths are more susceptible to drought because of the lower available water capacity. Crop production will require either more moisture through irrigation or the use of drought tolerant plant species. See Table 10.2.

Table 10.2 – Classes of Effective Rooting Depth

Very deep:	>60 inches (>150 cm)
Deep:	40–60 inches (100–150 cm)
Moderately deep:	20–40 inches (50–100 cm)
Shallow:	10–20 inches (25–50 cm)
Very shallow:	<10 inches (<25 cm)

**Rock fragments** cannot store water, so horizons that contain rock fragments contain less available water. Soil **structure** and **organic matter** affect the AWC because they influence the size of aggregates. This is most noticeable in the amount of pore spaces between particles. Pore spaces are needed to hold water and for aeration.

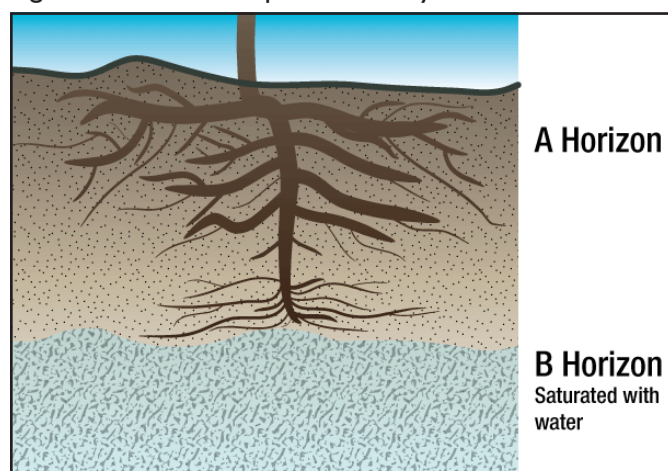
### **Field Observations for Determining Effective Rooting Depth**

Soil color, texture, structure, and density each provide clues for judging the effective rooting depth. Soils that have brown or red colors throughout usually allow deep rooting. These colors indicate good drainage and good aeration, both of which favor deep root penetration.

Gray colors and iron and manganese concretions usually indicate soil wetness. Most roots will not grow in soil that is saturated for long periods of time. See Figure 10.5. But if the water table is not present during the growing season, or if it can be removed with artificial drainage, then gray colors do not necessarily indicate a limitation to root development.

Soil texture limits root growth only where the texture changes abruptly from one horizon to another. Silt loam over clay, or loam over gravelly sand, are common examples of abrupt textures that inhibit root penetration. Textures that are nearly uniform throughout, even in clayey or gravelly soils, are not likely to prevent root

Figure 10.5 – Roots Spread Sideways



## Water Movement and Retention

growth. However, other factors may be responsible for limiting root growth in these soils.

Structure and density work together to influence rooting depth. Moderate and strong structures always favor root development. Weak structures and massive soil horizons may or may not limit rooting, depending on the density. In fragipans, for example, massive, dense soil restricts rooting.

### Determining AWC

The available water capacity has been determined for each class of soil texture. It is expressed in inches of water per inch of soil depth. The AWC can be calculated for any single horizon (within the effective depth of rooting) by multiplying the inches of water per inch of soil (for that texture) by the total thickness of the horizon. For

example, if a 6-inch horizon is sandy loam, use Figure 10.6 to find the AWC rate for sandy loam (.12). Next, multiply the given rate by the thickness of the horizon (.12 x 6 inches). This gives the AWC (.72) for this horizon.

To determine the AWC class for the whole soil, repeat the calculation above for each horizon within the effective depth of rooting. The total for the whole soil is the sum of the AWC for each horizon. If some horizons contain rock fragments, determine the percentage of rock fragments. Subtract the percentage of rock fragments from 100 to give the percentage of the fine earth (soil particles) for that horizon. Then multiply the AWC rate by the thickness of the horizon by the percentage of fine earth (AWC rate x thickness x percent fine earth). This will give the AWC. Total the AWCs for all horizons. To find the AWC class, refer to the chart in Figure 10.6.

Figure 10.6 – Determining Available Water Capacity (AWC)

### Field Procedure for Estimating AWC

1. Identify the horizons present in the soil profile.
2. Measure the thickness of each horizon.
3. Determine the effective depth of rooting.
4. For each horizon:
  - a. Determine the texture and the rock fragment (2 mm–25 cm) content.
  - b. Find the percent fine earth by subtracting:  
100% – percentage rock fragment content = percent fine earth.
  - c. Use the AWC rate that corresponds to the texture of each horizon.
  - d. Multiply the AWC rate by thickness of horizon by percent fine earth to determine the AWC.
5. Total the AWC for all horizons within the effective rooting depth.
6. Determine the correct AWC class.

Soil Texture	AWC Rate in Inches of Water/Inch of Soil	AWC Class (rates to 60 inches)
Sand, loamy sand	.06	Very low: <3 inches
Sandy loam	.12	Low: 3–6 inches
Loam, silt loam	.22	Moderate: 6–9 inches
Silty clay loam, clay loam	.17	High: 9–12 inches
Silty clay, sandy clay	.12	Very high: >12 inches
Sandy clay loam	.15	
Clay	.09	

# Soil Science

## Permeability

**Permeability** refers to water movement through the soil, specifically the rate at which a saturated soil (pores full of water) transmits water. This rate is called the saturated hydraulic conductivity of soil physics. Because water moves through the pores of the soil (the spaces between the grains of sand, silt, and clay), the rate of water movement depends on the amount of total pore space (porosity), the size of the pores, and the connections between the pores.

### Properties Affecting Permeability

Pore characteristics cannot be measured directly, although porosity and permeability are closely related to soil texture and structure. Thus, permeability can be estimated in the field by carefully observing the texture, structure, pore size, and density of the soil. Soil color is also important in determining permeability because it relates to organic matter and mineralogy.

For many soils, **texture** is the soil characteristic that exerts the greatest control on permeability. If texture exerts the greatest control, permeability can be related to the texture class and can be modified up or down on the basis of structure, pore size, organic matter, and type of clay. Permeability classes are used to characterize a soil horizon or a soil profile. If applied to a soil horizon, the permeability class describes the potential of that horizon to transmit water. When it is applied to a soil profile, the water-transmitting potential of the least permeable layer is implied.

Soil layers also have other properties that affect permeability. **Tillage pans** (dense layers that are caused by continuous tillage at the same depth) have poor structure and smaller pore space than the Ap horizon above it. See Plate 20, p. 50-E. Water cannot flow through the pan as fast as through the layer above it. That is why, during heavy rainfall or irrigation, all the pores in the upper layer fill with water and any additional water that falls will run off. This tends to increase soil erosion. Subsoil layers with slow permeability could be fragipans (dense horizons) or layers high in clay. Water moves very slowly through these layers because of the small pore space and thus tends to

build up and perch on top of the layers. This often causes the water to move horizontally and explains the genesis of E horizons (eluviation-leaching) in some soils.

Because permeability depends on the amount and size of soil pores, and on how interconnected they are, any soil property that increases any of these factors increases permeability. Sandy and gravelly soils have large, well-connected pores and rapid permeability. Clayey soils have tiny pore spaces and slow permeability, unless well-developed structure creates some larger pores. Silt loam and clay loam tend to have moderate permeability, especially if the structure is moderate or strong.

In Missouri, there is an exception to the general rule that horizons with clay texture have slow permeability. Some clays in southern Missouri mainly consist of the kaolinite clay mineral, which absorbs much less water in its inner structure than the montmorillonite clay mineral. Kaolinite generally does not swell when wet and is moderately permeable. In fact, many ponds constructed in red clays will not hold water. See Table 10.3.

Table 10.3 – Permeability Class

Permeability Class	Water Flow in Saturated Soil (inches/hour)
Very rapid	>20.0
Rapid	6.0 – 20.0
Moderately rapid	2.0 – 6.0
Moderate	0.6 – 2.0
Moderately slow	0.2 – 0.6
Slow	0.06 – 0.2
Very slow	0.01 – 0.06
Extremely slow	<0.01

### Surface Soil Permeability

The rate of water and air movement through the surface layer of sloping soils directly affects runoff, erosion, and water applied through irrigation. Soils with rapid or moderate infiltration rates are best suited for irrigation and are subject to less erosion than soils with slow infiltration. If water cannot enter into the soil when it rains or during irrigation, it runs off, causing erosion.

## Water Movement and Retention

Besides causing erosion, runoff wastes water that could be stored in the soil for plant use. Excessive runoff also can increase the hazard of flooding in downstream areas.

One way to maintain good permeability is to incorporate enough crop residues to maintain or increase the amount of organic matter in the surface layer. Minimum tillage or no-till systems help to improve the structure and organic matter content, and enhance the infiltration rate of the surface layer. Minimum tillage leaves more plant residue, and allows for an increase in root growth, organic matter content, and better aeration. Soils that have adequate pore space and permeability also are the best soils for on-site waste disposal and building sites.

Excessive tillage causes compaction and reduces pore space. Without adequate pore space, the soil is not a good place for roots to grow. Driving over wet soils also causes compaction, reduces the total pore space, and destroys the large pores needed for good permeability.

### Subsoil Permeability

Water movement through B and C horizons affects soil drainage, leaching of salts and fertilizers, and performance of septic tank absorption fields. Rapidly permeable soils are readily leached. Soluble salts, especially nitrogen fertilizers, are easily lost from the soil without benefitting the crops. Leaching also may contaminate the groundwater if easily soluble components are present. Rapidly

permeable soils do not make good waste disposal sites. Effluent (waste water) from the septic tank absorption field is likely to leave the soil too quickly to receive adequate biological treatment. Sanitary landfills placed on these soils increase the hazard of leaching dangerous chemicals and other pollutants into the groundwater.

In slowly permeable soils, water moves so slowly toward the drainage lines and the lines must be so closely spaced in the soil that drainage is not feasible. Slowly permeable soils are also unsuitable for conventional septic tank absorption fields because the soil near the distribution lines is likely to become saturated and cause the septic system to fail.

Because the texture, structure, and porosity may change from horizon to horizon in the subsoil, the permeability of each horizon should be evaluated individually. The overall permeability of the subsoil is that of the least permeable horizon within the subsoil. The Cr and R horizons are not considered. In any case, the permeability of the entire profile can never be greater than the horizon with the slowest permeability.

### Guide for Determining the Permeability of Each Horizon

This is a guide for determining the permeability of each horizon by texture and structure and special features (such as fragipans and type of clay). See Table 10.4.

Table 10.4 – Guide for Determining Soil Permeability

Texture	Structure	Permeability (inches of water/hour)
Sand, loamy sand	Single grain	Rapid and very rapid (>6.0 inches/hour)
Sandy loam	Granular	Moderately rapid (2.0–6.0 inches/hour)
Loam, silt loam	Granular	Moderate (0.6–2.0 inches/hour)
Sandy clay loam*	Blocky	Moderately slow (0.2–0.6 inches/hour)
Clay loam, silty clay loam*	Blocky	Moderately slow (0.2–0.6 inches/hour)
Sandy clay*	Blocky	Moderately slow (0.2–0.6 inches/hour)
Silty clay, clay*	Blocky	Very slow and slow (<0.2 inches/hour)
All fragipans will be very slow in permeability	Platy	Very slow (<0.06 inches/hour)

\*NOTE: If the horizon is kaolinite/sandy clay loam; clay loam, silty clay loam; sandy clay; or silty clay, clay use the moderately slow permeability to the right.

For subsoil permeability, use permeability of most limiting layer (between the base of the surface layer to a depth of 60 inches excluding the CR and R horizons).

# Soil Science

## Internal Soil Drainage

When all the pores of a soil are full of water, the soil is **saturated**. The top of a zone of saturated soil is called a **water table**. A **seasonal high water table** (internal free water) is the highest level of a saturated zone in the soil during the wettest season, and is used in reference to undrained soils. It is based on evidence of **reduction**, such as grayish colors or mottles. Generally, the zone of saturation has to last longer than one month for the reduction of iron to occur to produce mottling. The height of the water table and the length of time that the soil remains saturated determine the internal drainage of a soil. Soil drainage is important because it affects the environment of plant root growth. See Figure 10.5. Ideally, about half of the pores in the soil should contain water. The other half should contain air.

### Wet Soil Conditions

When the soil is saturated, plant roots quickly become oxygen-starved; prolonged saturation kills many plants. That is why the choice of crop plants is severely limited in poorly-drained or very poorly-drained soils.

Wet soils are also cold soils. Early spring growth is slower because it takes longer for wet soils to warm up. Wet soils cannot be plowed, tilled, or cultivated as early in the year, so planting dates may have to be delayed. Nitrogen fertilizers are not used as efficiently in wet soils, because the wetness causes the loss of some of the nitrogen to the atmosphere. Root rot and other plant diseases are also more serious in soils that are not well drained.

Wet soils are poorly suited for homesites, too. Conventional septic tank absorption fields installed in these soils will not function properly because waste water does not receive adequate treatment. No one wants water in the basement, so special precautions must be taken when houses are constructed on poorly-drained soils.

### Soil Properties and Other Factors in Drainage Classification

Many times when soils are studied in the field, the soil surface is dry and the water table is below the bottom of

the pit. Rarely is the water table observed as it fluctuates throughout the year. That makes it necessary to determine the drainage class from the permanent properties observed in the soil profile. Color, permeability, horizons (especially restrictive layers), and landscape position all enter into the evaluation of soil drainage.

**Color** – The most important clues come from color and mottling. Brown, yellowish-brown, and red colors are characteristic of well-oxidized soils. These soils are rarely saturated, and when they are, it is only for very short periods of time. Dark gray or olive-gray colors reflect intense reduction, which can only be caused by long periods of saturation. Poorly-drained and very poorly-drained soils have these colors.

Mottles indicate that a soil undergoes repeated cycles of saturation and oxidation. They often represent the effects of temporary water tables that may be perched above slowly permeable layers. Mottles also are present in moderately well-drained and somewhat poorly-drained soils.

**Permeability** – Permeability is another clue to internal soil drainage. It is not the same as drainage, though. Some rapidly permeable sandy soils may be poorly drained if they lie in a depression that has a permanently high water table. Some slowly permeable soils may have good drainage if they are on rounded upland hills.

Slow permeability, though, does suggest that excess water cannot escape quickly by moving through the soil. This situation often leads to buildup of temporary high water tables.

**Horizons (restrictive layers)** – Subsoil permeability is especially important when combined with evidence of restrictive layers like fragipans or clay layers. Because these layers are so slowly permeable, water does tend to build up above them, creating **perched water tables**.

Perched water tables are temporary, and their presence is usually indicated by mottling just above and in the upper part of the restrictive layer. The closer these restrictive layers are to the surface, the more frequent and prolonged is the existence of the perched water table. On the other hand, restrictive layers deep in the soil may have little effect on internal drainage.



**Landscape position** – Landscape position also provides valuable information on soil drainage. Soils on **convex** (rounded, arching out) uplands tend to lose water both by runoff and by flow within the soil. They generally are well drained.

Soils lower on the slope, or on **concave** (saucer-shaped) footslope positions, tend to receive extra water both as runoff and as seepage from higher soils. Water tables in these landscapes are likely to be periodically close to the surface. If the soils in these positions also contain slowly permeable horizons, they are sure to be somewhat poorly drained or even poorly drained.

Soils in low-lying areas, on broad, level landscapes, or in depressions, may have permanent water tables just a few inches beneath the surface. They may be poorly drained or very poorly drained. Again, slow permeability compounds the problem, although poor drainage conditions can exist by themselves.

### ***Classes of Internal Drainage***

The seven classes of internal drainage are defined in Figure 10.7. Soil color and depth to mottles are the primary keys to correct classification. Remember, however, that a few soils may have color patterns or coating on aggregates that are not related to internal drainage. The other factors—landscape, permeability, and restrictive layers—are all used as supporting evidence when determining drainage class.

### **Seasonal High Water Table**

A **seasonal high water table** refers to a zone of saturation at the highest average depth during the wettest season. It is at least 6-inches thick, persists in the soil for more than a few weeks, and is within 6 feet of the soil surface. Soils that have a seasonal high water table are classified according to the depth to the water table, the kind of water table, and the time of year when the water table is highest.

A seasonal high water table is an important criterion in a number of engineering and biological uses of soils. Its depth and duration influence the limitation of soils for

such uses as septic tank absorption fields, and the ease of excavation for roadfill and topsoil, building sites, and roads and streets. A high water table during the growing season is detrimental to most crops. There are two kinds of seasonal high water tables: apparent and perched.

### ***Apparent Water Table***

An **apparent water table** is the level at which water stands in a freshly dug unlined borehole after adequate time for adjustments in the surrounding soil.

### ***Perched Water Table***

A **perched water table** is one that exists in the soil above an unsaturated zone. To prove that a water table is perched, the water levels in boreholes must fall when the borehole is extended.

The depth and duration of a water table can actually be measured with boreholes caused with perforated pipe. Measurements are recorded periodically. However, soil scientists can make close approximations of the depth of a seasonal high water table at any time by observing the depth to gray mottles. Gray mottles that have a chroma of two or less are evidence of a seasonal high water table in most soils. The presence of concretions and uncoated sand grains is also a good indicator of water tables in some soils. A few soils have relict mottles, which do not represent wetness, but are a reflection of the original color of the parent material. See Table 10.5.

### **Summary**

Plants need water to survive, although the amount of water needed varies widely. There are three kinds of soil water: gravitational water, which fills large pores and drains quickly; available water, which is held in small pores that plants can use; and unavailable water, which is held so tightly in tiny soil pores that plant roots cannot remove it.

Available water capacity (AWC) is the capacity of the soil to hold water in a form available to plants, and is determined largely by soil texture. Clayey soils hold large amounts of water in tiny pore spaces, but only a small

## Soil Science

Figure 10.7 – Classes of Internal Drainage

**1. Excessively drained (E).** Water is removed very rapidly. Internal free water (water table) is very rare or very deep. These soils are characterized by bright colors and coarse textures throughout the profile. These soils have sand to sandy loam textures and are often extremely gravelly or cobbly. The permeability is rapid or very rapid. They have the brownish colors of well-oxidized soils, and they are not mottled. They typically have a low or very low AWC and generally are not suitable for crops unless irrigated.

**2. Somewhat excessively drained (SE).** Water is removed from the soil rapidly. Internal free water (water table) commonly is very rare or very deep. These soils commonly are loamy sand, sandy loam, or extremely gravelly or cobbly. The permeability is rapid or moderately rapid. They have brownish colors of well-oxidized soils, and they are not mottled. They typically have a low AWC and are suited only to crops that are moderately tolerant to drought.

**3. Well drained (W).** Water is removed from the soil readily but not rapidly. Internal free water (water table) commonly is deep or very deep. Wetness does not inhibit the growth of roots for significant periods during most growing seasons. The soils are free of mottles to a depth of 40 inches. These soils may have any texture, though the most common are silt loam, silty clay loam, loam, clay loam, and sandy loam. Soil colors are various shades of yellowish brown and reddish brown throughout, all indicating well-aerated soil. Well-drained soils generally have moderate subsoil permeability. Occasionally, however, the lower part of the soil may be saturated for a day or two at a time. Thus, the soil below a depth of 40 inches may have a few gray mottles. These soils are not wet close enough to the surface to restrict equipment use.

**4. Moderately well drained (MW).** Water is removed from the soil somewhat slowly during some periods of the year. Internal free water commonly is moderately deep. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that some crops are affected. These soils may have any texture. Subsoil permeability is usually moderate or slow. There may be a deep, restrictive layer that temporarily perches water. The soil commonly is mottled at depths of 24–42 inches (60–105 cm) below the surface. The mottles may be gray in a brownish matrix, or they may be yellowish brown in a grayish-brown matrix. It only takes a few gray or grayish-brown mottles to indicate enough wetness to drop a soil into a moderately well-drained class. These soils are wet close enough to the surface to restrict equipment use during wet periods of the year, mainly early spring.

**5. Somewhat poorly drained (SP).** Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. Internal free water commonly is shallow to moderately deep. The soils are wet for extended periods during the growing season and crop growth is markedly restricted. These soils may have any texture and any permeability. They usually occur on nearly level or low-lying positions and have a seasonal high water table. Some have fragipans or clayey subsoils. Somewhat poorly-drained soils are rarely saturated all the way to the surface for long periods of time. The profile is mottled below the surface layer. The water table is high enough to cause some mottling of the soil somewhere between 12 and 24 inches (30–60 cm). Some soils have a gray E horizon and at increasing depths, the mottling becomes more noticeable. In some somewhat poorly-drained soils, black or very dark grayish-brown colors extend throughout the soil. These either have a gray matrix with yellowish-brown or reddish-brown mottles below 12 inches, or they have a few grayish mottles throughout, starting right below the Ap. Iron and manganese concretions are typical throughout the profile. Equipment usage is markedly restricted unless artificial drainage is provided.

**6. Poorly drained (P).** Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or it remains wet for long periods. Internal free water is shallow or very shallow. Free water commonly is at or near the surface long enough that crops cannot be grown unless the soils are drained. They either occupy low-lying or depressional areas that have permanently high water tables, or they have restrictive layers close to the surface, or both. Any texture or permeability can occur, but fine textures and slow permeabilities are most common. Poorly-drained soils are mottled in the lower part of the A horizon and have gray matrix colors and reddish mottles or black concretions in the Ap or A horizon. In a few soils, the black colors (caused by high organic matter content) may completely mask the mottles in the surface horizons. Equipment usage is very restricted unless artificial drainage is provided. Gleyed horizons are common, and are designated by gray colors caused by water saturation. The soil below the A horizon is gray or dark gray and becomes noticeably lighter upon drying. Landscapes are low-lying or in depressions in nearly every case. Water-tolerant plants do best on these soils.

**7. Very poorly drained (VP).** Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. Internal free water is very shallow. Unless drained, most crops cannot be grown. These soils commonly are gray or black throughout the profile, and may have reddish colors only in root channels. Gleyed horizons are common, and are designated by gray colors caused by water saturation. These soils may or may not be mottled. The soil below the A horizon is gray or dark gray and becomes noticeably lighter upon drying. Landscapes are low-lying or in depressions in nearly every case. Equipment usage is severely restricted except where artificial drainage is provided. Water-tolerant plants do best on these soils.

## Water Movement and Retention

Table 10.5 – Guide for Internal Drainage and Depth to Water Table

Drainage Class	Subsoil Color	Mottles	Depth to Water Table
Excessive (E)*/Somewhat excessive (SE)*	Brown, red	No gray colors or mottles within 72 inches	>6 feet
Well (W)	Brown, red	Gray mottles below a depth of 42 inches	3.5–6 feet
Moderately well (MW)	Brown, red	Gray mottles at depths of 24–42 inches	2–3.5 feet
Somewhat poorly (SP)	Grayish brown, gray	Gray mottles below the A horizon at depths of 12–24 inches	1–2 feet
Poorly (P)	Gray, black	Gray mottles in and below the A horizon or at a depth of less than 12 inches	0–1 foot
Very poorly (VP)	Gray, black	Gleyed colors or gray mottles to the surface, depressional areas, and evidence of long periods of ponding above the surface	0–1 foot

\*These soils commonly are loamy sand, sandy loam, or extremely gravelly or cobbly.

amount of this water is available to plants. Silty or loamy soils hold smaller amounts of water than clayey soils, but more is available for plant use.

Effective rooting depth of plants is restricted by bedrock, very dense horizons, extremely gravelly or cobbly layers, or extended periods of high water tables. Soils with restricted rooting depths are more susceptible to drought because of the lower AWC.

Rock fragments cannot store water, so horizons that contain rock fragments contain less available water. Other properties that affect AWC are structure and organic matter. The AWC can be estimated by determining the soil texture, percentage of rock fragments, and effective rooting depth for each horizon.

Permeability refers to water movement through the soil, specifically the rate at which a saturated soil transmits water. This rate depends on the soil texture, structure, and color as they relate to the amount of total pore space, size of the pores, and connections between the pores. The permeability of the subsoil is determined by the least permeable horizon within the subsoil. Factors that affect the internal drainage of soil are the height of the water table and the length of time that the soil remains saturated.

A seasonal high water table is the highest average depth of a saturated zone during the wettest season. It is based on evidence of reduction, such as gleyed colors or gray mottles. There are two kinds of seasonal high water tables: apparent and perched.

### Credits

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## Lesson 11: Site Characteristics

An evaluation of soils includes more than the horizons that make up their profiles. Soils are also part of the landscape. The landscape is what people see if they gradually turn in a circle and view everything there is between themselves and the horizon (the line where the earth and sky meet). The position of the soil in the landscape tells something about the age of the soil and the kind of geologic materials from which the soil formed. The characteristics of the landscape in which the soil evaluation is made are called **site characteristics**.

Site characteristics affect runoff, erodibility (potential for erosion), and internal drainage. They also affect management decisions about choice of crops, conservation tillage systems, mechanical practices, drainage, and irrigation. Site evaluation, then, is just as important in judging soils as the description of the properties of each horizon. Five major site characteristics are used in a site evaluation:

- |             |                            |
|-------------|----------------------------|
| 1. Landform | 4. Parent materials        |
| 2. Slope    | 5. Stoniness and rockiness |
| 3. Aspect   |                            |

## Landform

Landforms are distinct parts of the landscape that have characteristic shapes and are produced by natural geologic processes. To evaluate landforms, one needs to look in every direction around a site to assess the general lay of the land. Both slope steepness and slope shape (convex, linear, or concave) should be considered. The parent material may also be a guide, although the correlation between landform and parent material is not perfect.

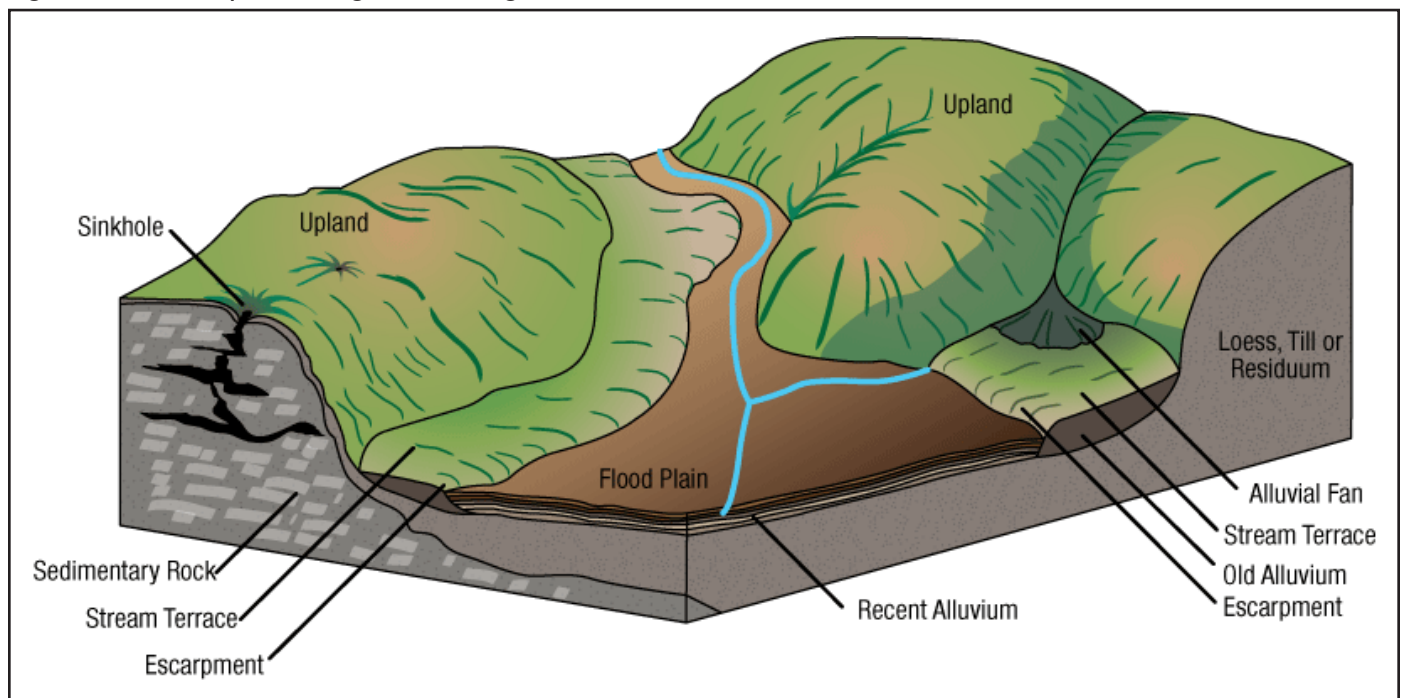
Although there are many specific landforms, only six general landforms that commonly occur in Missouri are discussed here. See Figure 11.1. They are:

- |                 |                   |
|-----------------|-------------------|
| ◇ Uplands       | ◇ Flood plains    |
| ◇ Foot slopes   | ◇ Stream terraces |
| ◇ Alluvial fans | ◇ Sinkholes       |

## Uplands

Uplands are the highest parts of the land surface. Most uplands are gently rolling to hilly, although some are nearly level plains. Uplands include narrow rounded ridges and

Figure 11.1 – Composite Diagram Showing Landforms



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broad divides. Uplands commonly have parent material of loess, glacial till, colluvium, and residuum. Uplands also include high bench terraces with parent material of loess, colluvium, or residuum.

### **Foot Slopes**

Foot slopes are at the base of upland hillslopes. They mark the change from upland to stream terrace or flood plain. They might be thought of as a transitional area between the uplands and the stream terrace or flood plain. There generally is a foot slope position on the landform, but many times it is very narrow and only a few feet wide. Foot slopes usually are concave. They collect more water than they shed by runoff. The parent materials of foot slope soils often accumulate by gravity (colluvium) from the upland slopes. Some foot slopes, however, may have parent materials that consist of loess, alluvium, or residuum.

### **Alluvial Fans**

Fans also occur at the junction of sloping uplands and nearly level flood plains. They form where a rapidly flowing stream emerges from a narrow flood plain into a stream terrace or larger flood plain. See Figure 11.1. The fan is narrow and sloping at the upstream point of origin and broadens and flattens as the stream spreads sediment onto the larger flood plain. The surface of the fan is gently rounded. The parent material is alluvium. Many times it contains coarse sand, gravel, and even fragments as large as cobbles.

### **Flood Plains**

Most flood plains are nearly level surfaces adjacent to stream channels. Every time a stream overtops its banks, the excess water flows out onto the flood plain. Flood water may not cover the entire flood plain in each flood, but all parts of the flood plain will be covered with water at least once every 100 years.

Although most flood plains are nearly level, some have slopes up to 5–6 percent. Scouring (cutting or eroding by fast moving water) by water in overflow channels may give the flood plain a rolling, hummocky appearance,

especially adjacent to large rivers. The parent material on a flood plain is recent alluvium and commonly consists of sand, silt, and clay size particles. Any sediments deposited within the last 100 years are considered recent.

### **Stream Terraces**

Stream terraces are abandoned flood plains. When a river cuts down through its existing flood plain, it establishes a new flood plain at a lower level. The old flood plain is abandoned and becomes a stream terrace that is no longer subject to flooding. In some places, the line separating stream terraces from flood plains is very difficult to determine because the change in elevation is so slight. However, a stream terrace should be above known flooding levels.

At the junction of a stream terrace and a flood plain is a rise, called an **escarpment**. In some places the escarpment is very obvious, but in other places it may be a very gradual rise that requires close observation to detect. Some rivers may have two or three separate terrace levels, each separated by an escarpment. See Figure 11.1. Such compound landforms resemble a giant set of stairs.

Lateral movement of a river channel may remove all of the flood plain on one side. The river channel then is at the base of a stream terrace or upland that never floods. Some streams flow next to a rock bluff. In such cases, the flood plain on one side of the river will be distinctly lower than the landform on the other side.

Because stream terraces are abandoned flood plains, their parent material is old alluvium, commonly overlain by a thin mantle of loess. Soils on stream terraces are older with more-developed horizons than soils on flood plains.

### **Sinkholes**

Sinkholes are bowl-shaped areas caused by the weathering of the limestone bedrock that underlies the area. The bedrock cracks and water dissolves the limestone around the cracks. The cracks enlarge over long periods of time until water literally flows through these underground openings, causing the soil material above to fall in and fill the openings, leaving depressions on the surface. Sinkholes

are common in some areas of Missouri, especially in the uplands of south Missouri and the upland areas adjacent to the Missouri and Mississippi Rivers.

The parent materials of sinkholes are colluvium or loess. Some sinkholes fill up with water after heavy rains. This is considered ponding (standing water for significant periods of time) rather than flooding. Typically, this will not result in as wet a soil as in ponding of flood plain soils. Most sinkholes that pond water usually drain quickly enough that the saturation of the soil does not cause reduction of iron and gray colors. In fact, many soils in sinkholes have well-drained profiles. See Figure 11.1.

### Slope

Slope is important because it affects use and management of the soil. It is directly related to the soil erosion hazard, and it influences a farmer's choice of crops and conservation practices.

#### Slope Gradient

Slope, or slope gradient, refers to the steepness of the land surface. Slope is measured in percent calculated as

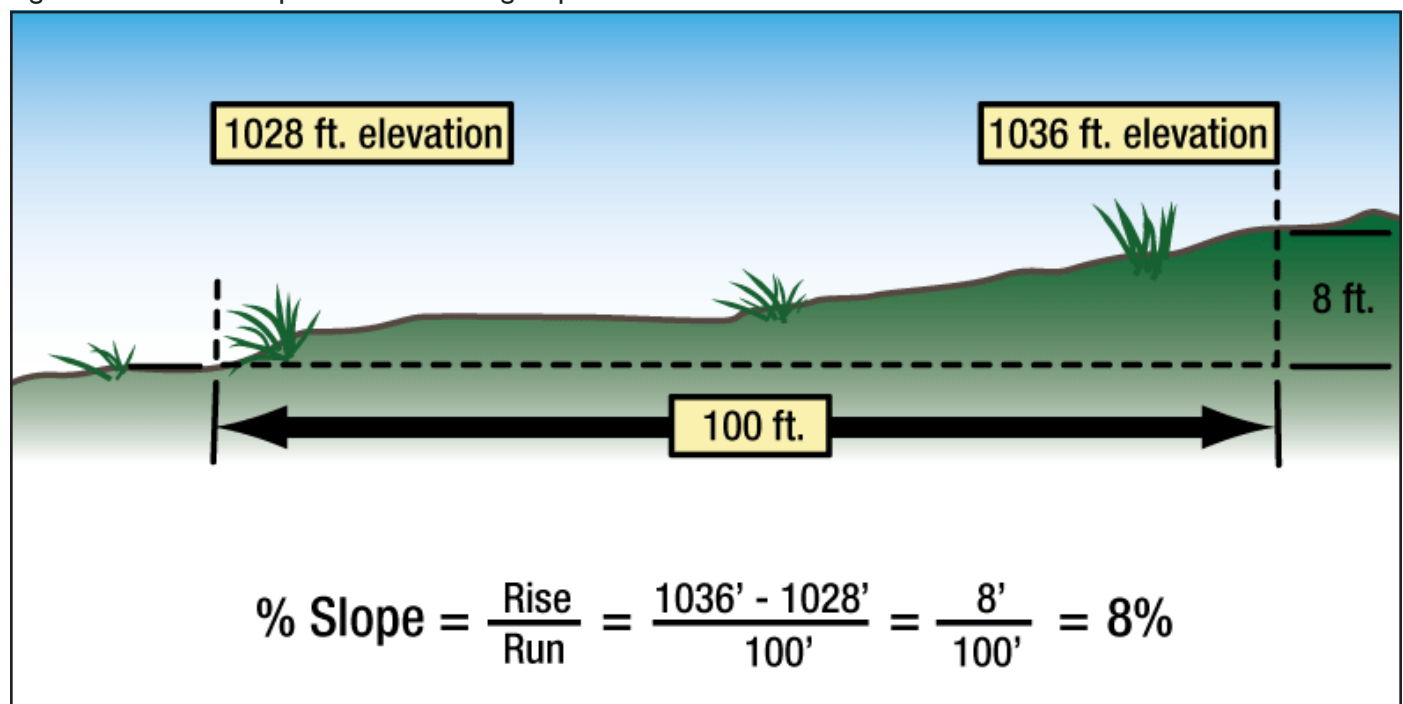
the amount of vertical change in elevation over some fixed horizontal distance. Slope is always measured in the same direction as water runs over the surface. Slope is described as the "rise over the run." If two points are 100 feet apart (the run), and one point is 10 feet higher than the other (the rise), then the slope is 10 over 100, or 10 percent. See Figure 11.2.

Irrigation becomes difficult on steeper slopes, and so does the operation of farm machinery. In general, as the slope steepness increases, agricultural suitability decreases.

#### Slope Length

Slope has other characteristics besides steepness. One is slope length, which is the point of overland flow to the point of deposition. Long, uniform slopes are easier for equipment operation than short, broken slopes, but long slopes also allow runoff water to gather more volume as it flows over the surface. Long slopes are, therefore, more subject to erosion than short slopes. Diversion terraces or level terraces are an effective erosion control practice because they break up the long slopes into several short segments, thus decreasing the volume of the water, which reduces erosion.

Figure 11.2 – An Example for Determining Slope



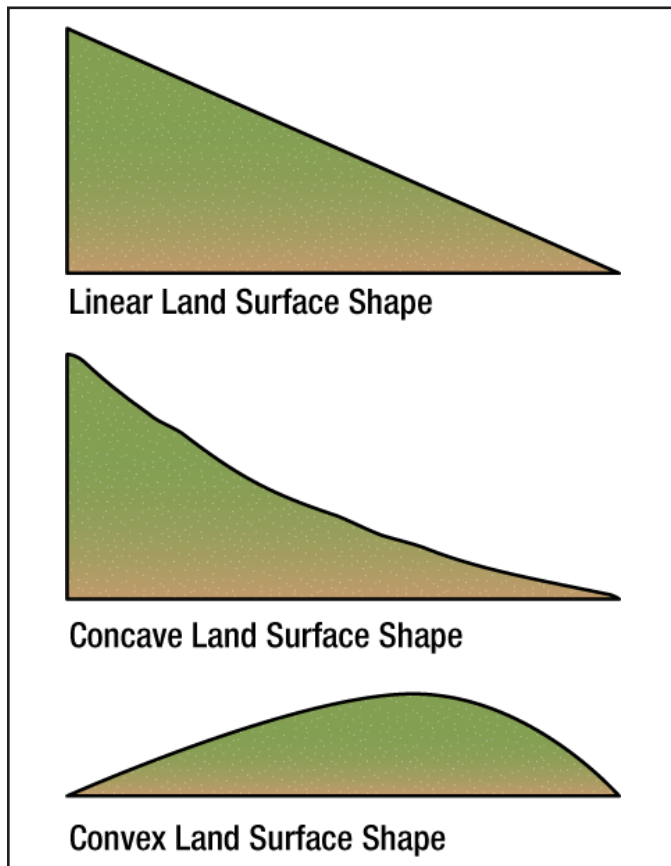
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## Slope Shape

Another slope characteristic is slope shape. Slopes may be linear, concave, or convex.

- ◇ **Linear** means flat, or without curvature. Imagine a clipboard sitting on a table. The surface of the clipboard is flat, and as it sits on the table it is level. Now tilt it by lifting one end. The surface is still flat, but it now slopes at some gradient (percentage of rise or fall).
- ◇ **Concave** means saucer-shaped or bowl-shaped. The slope gradient progressively decreases over a concave slope.
- ◇ **Convex** slopes are like mounds, and are just the opposite of concave slopes. Rounded, convex slopes get progressively steeper. Many ridges have convex tops, linear sides, and concave foot slopes. See Figure 11.3.

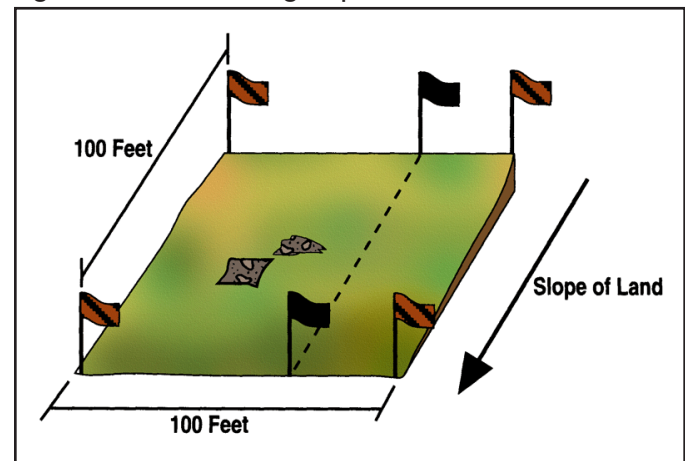
Figure 11.3 – Land Surface Shapes



## Measuring Slope

Slope gradient can be measured with a number of surveying instruments. Soil scientists usually use an Abney level or a clinometer to measure slope. With practice, they can often estimate the slope gradient within 1 or 2 percent without instruments. Since these instruments may not be available and experience at estimating slopes may be limited, a different method can be used for judging slope. See Figure 11.4.

Figure 11.4 – Measuring Slope



At each soil evaluation contest site, two stakes are in the ground for evaluating the slope. The elevation of each stake and the horizontal distance between the stakes generally are given. To figure the slope:

- ◇ Calculate the difference in elevations.
- ◇ Divide the rise by the run.
- ◇ Figure the percent of the slope.

The stakes will not always be 100 feet apart, so the answer in percent needs to be calculated accordingly. For example, if the stakes are 100 feet apart and the rise is 10 feet, the slope is 10 percent. If the distance between the stakes is 50 feet in the example above, and the rise is 5 feet, the percentage of the slope will still be 10 percent, or the same percentage as a 100-foot run with a 10-foot rise ( $5 \div 50 = .10 = 10\%$ ). The final step is to determine the proper slope class\* according to the chart in Table 11.1. (\*Note: Percentages may vary with different types of landscapes.)



Table 11.1 – Slope Gradient

Classes of Slope Gradient	
Nearly level	0–2%
Gently sloping	2–5%
Moderately sloping	5–9%
Strongly sloping	9–14%
Moderately steep	14–20%
Steep to very steep	>20%

## Aspect

Another site characteristic is the aspect of the slope. Aspect is the compass direction that the slope faces. The soil on a slope is influenced by temperature and exposure to the sun, dependent on the compass direction. Aspect will have little influence on nearly level to moderately sloping soils because the difference in temperature and exposure of the sun is slight.

Southerly aspects are more nearly perpendicular to the sun's rays and are exposed to the sun for longer periods of time each day than northerly aspects. Soils on southerly aspects tend to be warmer and drier than soils on northerly aspects. There generally is less vegetation on southerly aspects, therefore, the soil is often shallower and more susceptible to erosion than northerly exposures. For all these reasons, soils on southerly aspects tend to have considerably lower productivity potentials than soils on northerly aspects.

In Missouri, the growing season on steeper northerly aspects is a little shorter, and it takes longer for the soil to warm up in the spring. In forested areas, especially those of south Missouri, the species of trees as well as the understory plants (small plants) on southerly aspects are different from those on the northerly aspects.

Easterly and westerly aspects are intermediate in their response to sunlight and moisture supply. In general, an easterly aspect will be more like a northerly aspect, and a westerly aspect will be a little more like a southerly aspect.

## Parent Materials

Parent material is the geologic material from which soils have formed. Some soils formed in place by the weathering of bedrock. These are called **residual soils**, and the parent material is called **residuum**.

Other soils form in loose materials transported by water, wind, ice, or the force of gravity. These materials are called **sediments**, and there are several kinds. Sediments carried by a river and deposited on a flood plain or in a fan are called **alluvium**. Silty sediments carried by wind are called **loess**. In some areas in the Bootheel of Missouri and along its river, there are wind-blown sands that are called **eolian sand**. Sediments transported by glacial ice are called **glacial till**. Sediments transported by gravity are called **colluvium**.

Parent materials are determined by comparing upper horizons with C and R horizons. The problem is that once A, E, and B horizons are fully developed, the character of their original parent materials may no longer be clear. Usually, it can be assumed that the C horizon is still pretty much like the original parent material of the A, E, and B horizons. This is often the case in very deep soils that have nearly uniform textures.

In some soils, properties of the upper horizons are very different from those of the C and R horizons beneath them. These differences, combined with abrupt changes from B to C, or B to R, suggest two different kinds of parent materials. For these soils, it is not correct to say that the C or R horizons are like the original parent materials of the A, E, and B.

Many Missouri soils have a complex geologic history, but attempts should be made to determine all the parent materials that have influenced the entire soil profile. Sometimes all the horizons in a soil profile appear to have a single parent material. For example, alluvium may have distinct layers with different textures, but all layers formed the same way, and represent a single kind of parent material. The layers are a result of different episodes of flooding.

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Sometimes there are two or more parent materials. Examples may include loess resting directly on glacial till, residuum, or colluvium, and colluvium resting on top of residuum. Abrupt changes in color, texture, and rock fragment content provide the major clues to these situations. See Plates 11, 24, and 25, pp. 50-C, 50-F, and 50-G.

There is a close relationship between the kind of parent material and the landform of a soil. Uplands usually have loess, glacial till, residuum, or colluvium as parent materials. Soils on flood plains develop from recent alluvium. Many stream terraces have a thin mantle of loess on top of old alluvium. Sometimes, however, it is difficult to distinguish between two similar kinds of parent material unless the geology of an area is familiar. Six kinds of parent materials are common in Missouri: residuum, alluvium (both recent and old), loess, eolian sand, glacial till, and colluvium.

### **Residuum**

**Residuum** is the unconsolidated, weathered, or partly weathered mineral materials that accumulate as consolidated rock disintegrated in place. Different kinds of rocks give rise to different kinds of residuum and influence the size of the soil particles. For example, granite and coarse sandstones typically weather to loamy and sandy soils. Siltstones and fine-grain sandstones weather to silt loam and silty clay loam. Shales, limestones, and dolomites weather to silty clay or clay.

In the strictest sense, residual materials have not been moved from the place of weathering. If there were no exceptions, there would be very few truly residual soils in Missouri. Small movements due to windthrow (the action of wind uprooting trees), animal mixing (burrowing and digging), slope creep (slow downward movement), and localized slumping (small areas of soil that slide down a steep hill) occur almost everywhere, particularly in the upper foot or so of soil. Such movements do not exclude a material from being classified as residuum, especially if it can be determined that the entire profile formed from material weathered from the rock that underlies it. Generally, as depth increases in a residual material, there is a gradual increase in the amount and size of rock fragments, and they are less and less weathered. Some soils may have relatively unweathered rock fragments

throughout, especially in southern Missouri where there is an abundance of chert (flint) in the limestone bedrock. Some of these fragments are rounded and others are sharp and angular. This gives a clue that the parent materials are different and that the rounded chert gravel may be of colluvial or alluvial origin.

Residuum is common on uplands and on some foot slopes. It may also be buried beneath a thin deposit of alluvium on stream terraces or fans. It may also be buried beneath a thin mantle of loess.

### **Alluvium**

**Alluvium** refers to sediments, such as sand, silt, and clay, deposited on land by flooding.

**Recent alluvium** refers specifically to materials on the flood plains of modern rivers. All streams and rivers carry a load of suspended sediments, particularly during periods of heavy runoff. Each time a river floods, fresh sediments are added to the recent alluvium of the flood plain.

The consistency of alluvium is dependent on the speed of the water and the size of the particles deposited. When a river overflows, water moving over the flood plain flows much more slowly than water in the main channel. Suspended sediments then have a chance to settle out on the flood plain. The coarser sediments settle out nearest the river. Fine sediments are carried farther away and settle out in slow-moving, backwater areas.

Repeated episodes of flooding result in gradual accumulation of thick deposits of sediment on the flood plain. These deposits may have fairly uniform textures, or they may be distinctly stratified into layers of widely different textures. If any of the layers contain rock fragments, they usually are rounded. This is caused by the abrasive movements of fragments on the bottom of the stream channel over long distances.

Soils formed in recent alluvium are young soils, and may have simple A-C profiles. If the period between deposition of fresh sediments is longer, the soil may have an A-B-C profile.

An **alluvial fan** is formed as a modern stream emerges from steep terrain. The parent material, recent alluvium, is often stratified and commonly contains sand and gravel layers.

**Old alluvium** is associated with a stream terrace or an abandoned alluvial fan. The alluvium was originally laid down on a flood plain, but when the flood plain was abandoned by the stream, no further deposits of fresh sediments were made. Old alluvium may be more difficult to distinguish than recent alluvium, but overall the same properties of uniform texture, stratified layers, and rounded rock fragments are the best clues.

### Loess

Wind-blown material is called **loess**. Loess consists of fine, dominantly silt-size particles, deposited by the wind. Where numerous sand grains are encountered in a profile, it commonly is the contact between loess and another parent material. The silts were formed by glacial grinding action, and were then carried in the melted glacial water of rivers and deposited on flood plains or in lake basins. Later the wind picked them up, transported them, and redeposited them on top of existing uplands or stream terraces. Soils formed in loess can be quite productive, but they are particularly susceptible to erosion. See Plates 2, 4, and 12, pp. 50-A and 50-C.

Loess originally covered nearly all of Missouri but has been removed from steeper sloping areas by geologic (natural) erosion. Loess is a common parent material on uplands in north and east Missouri. It is thickest near the Missouri and Mississippi Rivers and thins to the north and east. The texture of the loess also changes from coarse silt near the river, to fine silt and clay with increasing distance from the river. Many soils in southern Missouri are thought to have a very thin mantle of loess on top of residual or colluvial parent materials, particularly on stable summit divides.

### Eolian Sand

**Eolian** is a term applied to materials deposited by wind action, and includes clays, silts, and sands. Clays and silts that are deposited by wind are most commonly referred

to as loess. Sand deposits, such as dunes, are commonly referred to as **eolian sand**. Most of the eolian sand deposits of importance are in the Mississippi Delta areas.

### Glacial Till

**Glacial till** is a parent material that consists of a mixture of clay, silt, sand, and gravel; it may have a few stones and boulders. Glacial till was transported during periods of glaciation. Much of the glacial till was moved long distances, but some is of local origin. It commonly is brown with some gray streaks, and contains many small soft masses of calcium carbonate. Most of the glacial till is a clay loam texture. Rock fragments tend to be rounded because of the grinding action of the glacier.

### Colluvium

**Colluvium** is made up of loose soil material and rock fragments that have been transported down steep slopes. Colluvium can move several inches or feet, or to the base of the slope. Gravity is its main moving force, but water helps by weakening the strength of the soil mass upslope, or by carrying soil in local, unconcentrated runoff. Slope wash (by water) and slope creep (by gravity) help colluvium to form. Colluvium has a close resemblance to the parent material in which it formed, and it is very difficult to distinguish between the two in most places. Position and steepness of slope are the best clues for distinguishing between colluvium and the underlying parent material. Colluvium is common on foot slopes and very steep upland slopes. See Plates 9 and 28, pp. 50-C and 50-G.

## Stoniness and Rockiness

### Stoniness

**Stoniness** refers to the amount of individual rock fragments larger than 10 inches (25 cm) in diameter exposed at the soil surface. The classes of stoniness are based on a stone size with a diameter of about 12 inches. If stones average much larger in diameter, the area of stone coverage may be 2.5–5 times as much, depending on their size.

# Soil Science

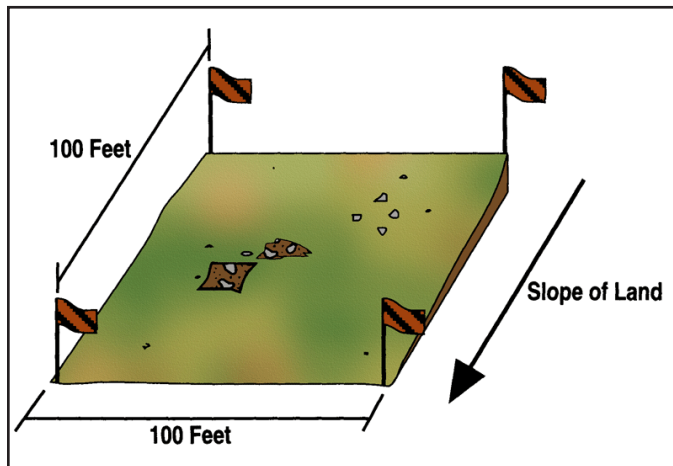
Stoniness is defined not only quantitatively but also in terms of its impact on agricultural management. Stoniness is evaluated according to the percentage of the soil surface covered by detached stones. Five general classes are used:

1. Not stony
2. Stony
3. Very stony
4. Extremely stony
5. Rubbly

## Classes of Stoniness

For soil judging contests, this is based on a site area 100 feet square (10,000 square feet) marked by judges. See Figure 11.5. (Note: Distances given below do not quite match USDA guides, which are given in meters.)

Figure 11.5 – Stones at a Site



- ◇ **Not stony** – No stones or rocks are present, or there are too few (>100 feet apart) to interfere with tillage. Stones cover less than .01 percent of the area.
- ◇ **Stony** — There are enough stones to interfere with tillage, but not enough to make cultivated crops impractical. Stones cover .01–.1 percent of the area. Stones about 1 foot in diameter are spaced 30–100 feet apart.
- ◇ **Very stony** – There are so many stones that tillage of crops is impractical. The soil can still be worked

for hay crops or improved pasture. Stones cover .1–3 percent of the area. Stones about 1 foot in diameter are spaced 5–30 feet apart.

- ◇ **Extremely stony** – Stones are so widespread that no agricultural improvements are possible. Some soils still have limited value as native pasture or range. Stones cover more than 3 percent of the area and are less than 5 feet apart.
- ◇ **Rubbly** – Stones cover more than 15 percent of the area and are less than 2.5 feet apart.

## Rockiness

**Rockiness** refers to the amount of the land surface that consists of bedrock outcrops. A bedrock outcrop is not considered part of the soil, because (like stoniness) the pieces are so large that both fine earth and pore space are excluded from a large volume of the soil. Rockiness is an important site characteristic, however, because it influences cultivation and other forms of agricultural management.

## Classes of Rockiness (Surface)

For soil judging contests, this is based on a site area 100 feet square (10,000 square feet) marked by judges.

- ◇ **Not rocky:** Rock outcrop covers <.1 percent of the area (<10 square feet or an area 2 x 5 feet).
- ◇ **Rocky:** Rock outcrop covers .1–2 percent of the area (10–200 square feet or an area 10 x 20 feet).
- ◇ **Very rocky:** Rock outcrop covers 2–10 percent of the area (200–1,000 square feet or an area 20 x 50 feet).
- ◇ **Rock outcrop complex:** Rock outcrop covers >10 percent of the area (>1,000 square feet or an area 20 x 50 feet, or one-tenth of the area). If rock outcrop makes up more than 10 percent of an area, it is usually mapped out on a soil map or included as a complex map unit (e.g., Clarksville-Rock outcrop complex).



## Water Erosion

Water erosion is the removal of topsoil by runoff water on uplands. The hazard of soil erosion by water is a major concern for the management of cultivated soil because erosion damages both the productivity of the soil and the quality of the water in rivers and streams. Soil properties that affect water erosion are slope (steepness and length) and runoff. As both the steepness and the length of the slope increase, so does runoff and the rate of erosion.

Steepness and length of slope are the dominant soil properties causing erosion. When heavy rain falls on sloping soils, it does not have time to infiltrate the surface layer. So the steeper the slope, the greater the runoff. As the length of the slope increases, the runoff water increases in volume and speed, thus removing soil particles and carrying them down the slope.

Runoff is difficult to measure. Runoff is directly related to the surface soil texture, permeability and infiltration, soil depth, vegetative cover, and climate. See Table 11.2.

Table 11.2 – Soil Erosion

Soil Factors Affecting Erosion
<b>Slope</b> <ul style="list-style-type: none"> <li>◇ Steepness</li> <li>◇ Length</li> </ul>
<b>Runoff</b> <ul style="list-style-type: none"> <li>◇ Surface texture</li> <li>◇ Permeability and infiltration</li> <li>◇ Soil depth</li> <li>◇ Vegetative cover</li> <li>◇ Climate</li> </ul>

### Texture

Of all the soil textures, silt loam is the most erodible. That is because the size of silt particles is just right for water to loosen and carry over the soil surface. Sand particles are too big to easily dislodge and move. Clays are so small and flat that they, too, are not easily dislodged.

## Permeability and Infiltration

The infiltration (downward entry of water into the surface layer) of the surface horizon when the soil is thoroughly wet is closely related to the permeability. Deep, well-drained to excessively drained sands and gravel have rapid permeability and high infiltration rates. As soils become more clayey, the permeability rate is lower as is the infiltration rate of the surface. Addition of organic matter is the only effective way to improve the permeability and infiltration rate of the surface horizon.

## Soil Depth

Another soil property that may affect erosion is soil depth. Soils that are shallow or very shallow (i.e., less than 20 inches to bedrock) are more erodible than deeper soils. The restrictive layers, like bedrock, fragipans, or heavy clay (e.g., montmorillonite) restrict water infiltration. The capacity of shallow soils to hold water is so low that the extra water quickly runs off. The less time it takes a soil to become saturated, the quicker erosion starts to take place. This increases the length of time during which additional rainfall could cause damaging erosion.

## Vegetative Cover

Vegetation influences the erosion hazard. Solid-cover crops like pasture and hay reduce erodibility. They promote water entry, absorb the impact of falling raindrops, reduce the velocity of flow across the surface, and tend to bind soil particles together and hold them in place.

Forest clearcuts and clean-tilled row crops tend to increase erosion. In both cases, water drops strike soil particles directly, causing some breakdown of soil structure and reducing the rate of water entry into the soil. And without vegetation, there are no roots to hold the soil in place and no stems and leaves to slow down the velocity of water falling and running over the soil surface. Natural forests provide the best erosion protection, even on very steep slopes, because the O horizons have rapid infiltration rates.

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## Climate

Rainfall is an important climatic factor, but the total amount of yearly rainfall is far less important than the intensity of each storm. The intensity of individual rain storms affects erosion. Many storms are not particularly erosive because the rate of rainfall is slow enough to allow all the water to soak in.

Occasionally, however, it rains so hard that the soil cannot absorb the water fast enough. Runoff starts almost immediately, and the volume of runoff can be large. When this happens, tremendous volumes of soil not protected by vegetation can be lost by erosion. The result can be economic loss to farmers and degradation of the environment.

## Summary

There are five major characteristics used in a site evaluation: landform, slope, aspect, parent material, and stoniness or rockiness. Landforms have characteristic shapes and are produced by natural geologic processes. Both slope steepness and slope shape are important considerations in a site evaluation. The six general landforms that commonly occur in Missouri are uplands, foot slopes, alluvial fans, flood plains, stream terraces, and sinkholes.

Slope is an important soil property because it affects the use and management of the soil. It is directly related to the soil erosion hazard, and influences a farmer's choice of crops and conservation practices. Percent slope is the percent of vertical change in elevation between two points, measured in the direction that the water flows over the surface. Steepness and length of slope are the dominant soil properties related to erosion. The steeper the slope, the faster the runoff, and the longer the slope, the greater the volume of water that removes soil particles and carries them down the slope.

Aspect is the compass direction that the slope faces. Vegetation on southerly aspects are exposed to the sun's rays for longer periods of time, which affects soil temperature, moisture, and vegetation.

Parent material can be identified by studying the landform and the properties of soil horizons (e.g., texture, color, rock fragments). Six kinds of parent materials are common in Missouri: residuum, alluvium, loess, eolian sand, glacial till, and colluvium.

Stoniness refers to the amount of rock fragments greater than 10 inches (25 cm) in diameter exposed on the soil surface. Stoniness has a great impact on agricultural management because it can interfere with crop tillage.

Slope (steepness and length) and runoff are the soil properties that affect erosion. As the steepness and the length of the slope increase, so does the runoff and the rate of erosion. Runoff is directly related to the texture, permeability of the surface horizon, soil depth, vegetative cover, and climate. Good vegetative cover can nearly eliminate soil loss, even on the steepest slope.

## Credits

Huddleston, J. Herbert, and Gerald F. Kling. *Manual for Judging Oregon Soils*. Corvallis: Oregon State University Extension Service, 1984.

Soil Survey Division Staff. *Soil Survey Manual, Handbook #18*, rev. Washington, DC: U.S. Government Printing Office, U.S. Department of Agriculture, Soil Conservation Service, 1993.

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# Interpretations and Management of Soil

## Lesson 12: Interpretations and Management of Soil

The first steps in evaluating soils involve learning how to identify horizons and site characteristics, and how to describe their important properties. The next steps examine the use and management of the soil. Management practices discussed in this lesson include the feasibility of artificial drainage, the suitability for irrigation, water erosion, evaluating the erosion hazard, conservation practices for erosion control, and hazards or limitations for cropping systems.

Management choices are sometimes difficult to make, because they depend on interactions among several soil factors: the specific crops being grown, the effects of climatic conditions, and site characteristics. Constraints of complying with a farm plan are complicated when winter-kill or chemical carryover limit choices of crops. Also, farmers must avoid growing some crops on a particular tract of land for more than 2 years in a row for control of disease and allelopathy (the suppression of growth of one plant species by another due to the release of toxic substances).

The materials in this manual have been generalized considerably for statewide use. The guidelines given in the sections that follow should be adequate for soil judging contests, but it should be recognized that there may be exceptions to these guidelines. Missouri has such as diversity of soils, climate, types of agriculture, and management practices that a general manual simply cannot account for every possibility.

### Suitability of Artificial Drainage

The growth of most agricultural and forest plant species is seriously affected by prolonged periods of free water on the land surface where oxygen is excluded from the root zone. Only aquatic plants or a few special plants, such as rice or cypress trees, can tolerate such conditions. Soils that are less than well-drained often can be improved by artificial drainage. The two major soil properties to consider for the need for **surface drainage** are the internal drainage class and slope (both shape and steepness). Since evaluating the soils for underground

tile drains is very difficult, only artificial surface drainage is considered. **Artificial surface drainage** can be provided by leveling or filling depressions, by land grading, and by digging shallow surface ditches to remove water.

The decision as to whether or not surface drainage is needed can be made from a study of the site. If surface water stands on a site for continuous periods of 8 hours or more during the growing season, surface drainage is needed.

Somewhat poorly drained, poorly drained, and very poorly drained soils (high water table <2 feet) that are nearly level, with no depressional areas, may not need surface drainage. However, many nearly level soils will have depressional areas or a concave slope that restricts the natural flow of surface water. Good judgment should be used to decide if surface drainage is needed. See Figure 12.1.

Figure 12.1 – Guide for Determining Artificial Surface Drainage

#### Drainage is needed for:

1. Soils that are somewhat poorly drained, poorly drained, or very poorly drained, and are nearly level with depressional spots.
2. Sloping soils below seepy areas.

It should be noted that before any artificial drainage is started, areas should be checked by the appropriate government agency for wetland regulations.

### Suitability for Irrigation

The best soils for irrigation are deep, nearly level, well-drained soils with high available water capacity. Any departure from these conditions will lower the irrigation suitability.

#### Primary Soil Properties Affecting Irrigation

The primary soil characteristics that affect the suitability for irrigation are surface texture, slope, available water capacity, depth to high water table, permeability, percent of rock fragments, and depth to bedrock. To evaluate the soil for irrigation suitability, these characteristics are

## Soil Science

considered assets or liabilities. Irrigation guidelines are summarized in Table 12.1.

**Surface texture** affects the intake of water into the surface layer. Soils high in sand content have a fast intake rate; silty and loamy soils have a moderate intake rate; and clayey soils have a slow intake rate. Although silty and loamy soils have a moderate intake rate, their property of high available water capacity gives them the best overall suitability for irrigation.

**Slope** affects the amounts and rates of water applied. This is most critical with furrow irrigation. Length of run is determined by the rate of water movement into the soil and the time it takes applied water to reach the lower end of the run. Sloping soil areas or depressional spots in soil areas will interfere with the desired surface run. A desirable grade enables the irrigation water to soak into the soil and move down the grade to the end of the run. Too much slope will move the water down the slope faster than it should. This may result in too little water soaking in at the upper end of the slope and too much water accumulating at the lower end of the run. This may cause erosion. Generally, slopes of less than 3 percent have the greatest potential for furrow irrigation. Where sprinkler and center-pivot systems are used, slope gradient is not as critical, but still has a great effect on water intake and runoff. Slopes less than 3 percent are considered an **asset**, those over 3 percent are considered a liability.

Many nearly level fields have depressional spots that need filling or smoothing for successful irrigation. The cost of grading and preparing the field may not be feasible. If the

field has depressional areas and grading is needed, this would be considered a **liability**.

**Available water capacity** is important to the frequency and amounts of water that can be applied to the soil. Those soils with low or very low available water are considered a **liability**.

**Depth to high water table** (internal drainage) is a factor that affects the rate at which internal free water leaves the soil to allow aeration. The gravitational water needs to move out of the profile quickly so the roots can obtain adequate aeration. This can be a problem if over-irrigation is followed by a rain. Soils that are moderately well drained or better (water table >2 feet) are considered an **asset**; those that are somewhat poorly drained or wetter (water table <2 feet) are considered a **liability**.

**Permeability** affects the rate at which water moves down through the profile to reach field capacity (see Lesson 10). Good permeability is effective only if the seasonal water table is below the rooting zone at the time of irrigation.

**Rock fragments** and **depth to bedrock** affect the available water capacity of the soil. This limits the amount of irrigation water that can be absorbed.

### Types of Water Erosion

Water erosion is the detachment and transportation of soil particles. There are three main types of water erosion: sheet, rill, and gully.

Table 12.1 – Irrigation Guidelines

Soil Characteristic	Asset	Liability
Surface soil texture	Loam, silt loam, silty clay loam, clay loam	All other textures
Slope	0–3%	>3%
Available water capacity	>6 inches	0–6 inches
Depth to high water table	>2 feet	0–2 ft
Permeability	>0.2 inches/hour	<0.2 inches/hour
Rock fragments >3 inches (surface layer)	<15%	>15%
Depth of soft or hard bedrock	>40 inches	0–40 inches



## Interpretations and Management of Soil

Detachment is caused by raindrop impact. See Figure 12.2. This is the major cause of sheet erosion. Some detachment of soil particles is caused by flowing water. Soil loss from sheet erosion is more or less uniform over a field. It may be barely detectable on a year-to-year basis. After soil particles are detached, they can be floated into rills and gullies and transported into low places or off the field.

Figure 12.2 – Raindrop Impact



*Soil particles and globules of mud are hurled in all directions when a water drop strikes wet soil.*

Rills are small channels where runoff water concentrates. The channels are shallow enough (generally less than 4 inches) that they are easily smoothed and filled in by ordinary tillage. After a field is tilled, it is not possible to tell whether soil losses resulted from sheet or rill erosion.

Gullies form in natural drainageways, plow furrows, animal trails, between crop rows, and below overtopped terraces. Gullies generally cannot be easily smoothed and filled by ordinary tillage.

Topsoil loss on cropland in Missouri averages about 10 tons (about 1/16 inch) per acre per year. If this amount of erosion (soil loss) is allowed to continue unchecked year after year, it can cause great losses of topsoil and crop productivity.

### Erosion Control

It is standard procedure to evaluate the hazard of erosion under the worst possible conditions. These conditions

include bare soil without vegetation and without any kind of soil conservation practice to slow down water running over the surface. Most soils are not managed so poorly. But the erosion hazard is always present, and it is essential that erodible soils are protected.

The need for erosion control depends on a soil's erosion hazard and the kind of crop that can be grown. Hay and pasture crops provide much of the erosion protection needed. Others, such as row crops and winter wheat, need specific management to minimize soil erosion.

Regardless of the size of the erosion problem, farmers should be aware of and practice conservation. A sloping soil, if managed improperly, is subject to erosion that reduces the quality of the soil resource for future generations. The USDA uses the Revised Universal Soil Loss Equation (RUSLE) to determine the soil loss under various vegetative cover and crops. This is the most accurate method and is used to estimate soil loss by sheet and rill erosion for the USDA. Steepness and length of slope, soil erodibility, rainfall energy and intensity, vegetative cover (both residue and growing crop), and type of mechanical erosion control practice are the key factors in the RUSLE.

The right kind of erosion control practice for any particular field, farm, or forest can be determined only by an on-site inspection. There are no magic formulas or prescriptions that fit every situation. Sometimes adequate erosion control can be achieved by the simple application of one of the general practices described below. In other cases, two or three different practices may be needed. In still other cases, there may be appropriate measures that are not included below. It is important to recognize the problem, know the various kinds of erosion control practices available, and use a healthy dose of common sense in managing soils to minimize erosion.

### Management Practices to Control Erosion

There are several management practices to control erosion. These include types of tillage, cropping sequences, and constructing terraces.

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## **No-Till**

No-till means exactly what it says. A crop is planted directly into the stubble from a previous crop, or into a sod or cover crop, without tilling the soil first. The soil is not cultivated during the growth of the crop. Instead, weeds are controlled with chemicals. Without a doubt, no-till planting of crops is the most effective erosion control system.

No-till is very effective for erosion control because bare soil is never exposed at the surface. In addition, roots from the previous crop help to keep the soil anchored in place. No-till helps to maintain high organic matter levels, and it eliminates the possibility of forming a tillage pan (hard layer caused by years of tillage at the same depth). All these factors combine to maximize water absorption into the soil.

No-till is difficult in some situations, and it does require special equipment and different kinds of fertilization and weed control practices. But in many areas, it can be the most effective erosion control method as well as an effective soil management practice to improve yields.

## **Conservation Tillage**

This system allows some cultivation of the crops to prevent weed growth. Conservation tillage ranges from no-till to a minimum of 30-percent residue cover on the surface after planting. Chisel or disc tillage equipment is used to prepare the seedbed. The best conservation tillage system uses as little tillage as possible and utilizes chemicals to control weed growth.

## **Contour Planting**

This is a way of planting on the contour of the land following established grades for terraces and diversions.

## **Contour Strip Cropping**

Contour crops are planted in a systematic arrangement of strips or bands that provide vegetative barriers to control erosion. Width of strips may vary, but usually are the

same for each crop and can be interchanged from year to year.

Contour buffer strips are somewhat similar to contour strip-cropping. However, the buffer strips are much narrower than the cultivated or cropped strips (20–30 percent of the slope) and are planted to grass. To be most effective, buffer strips should have tall vegetation in spring and early summer.

## **Grassed Waterways**

Grassed waterways are areas planted to grass where water usually concentrates as it runs off of a field. They slow the runoff water and guide it off of the field, thereby reducing gully erosion.

Grassed waterways can be used to collect excess runoff water from contours, buffer strips, and can serve as outlets for terraces.

## **Conservation Cropping Sequence**

An adapted sequence of crops is designed to provide adequate organic residue for maintenance or improvement of soil tilth. For example, a conservation cropping sequence used in conjunction with any of the tillage practices listed will enhance the effectiveness of the tillage system.

## **Terraces**

Constructing terraces is the most expensive way to control erosion on crop land. However, with very productive soils, terraces could be the choice of some farmers. There are three basic types of terraces: broad-base, narrow-base, and steep backslope. All three of these can either be **gradient** and/or **parallel**. Gradient terraces have a definite grade to the channel (low area for holding or draining water) ranging from level to 2 inches per 100 running feet. Parallel terraces run parallel to each other.

Although the erosion hazard is greatly reduced by shortening the length of the slope, the actual percentage

## Interpretations and Management of Soil

of the slope is increased by both broad-base and narrow-base terraces. The slope is decreased by steep backslope terraces.

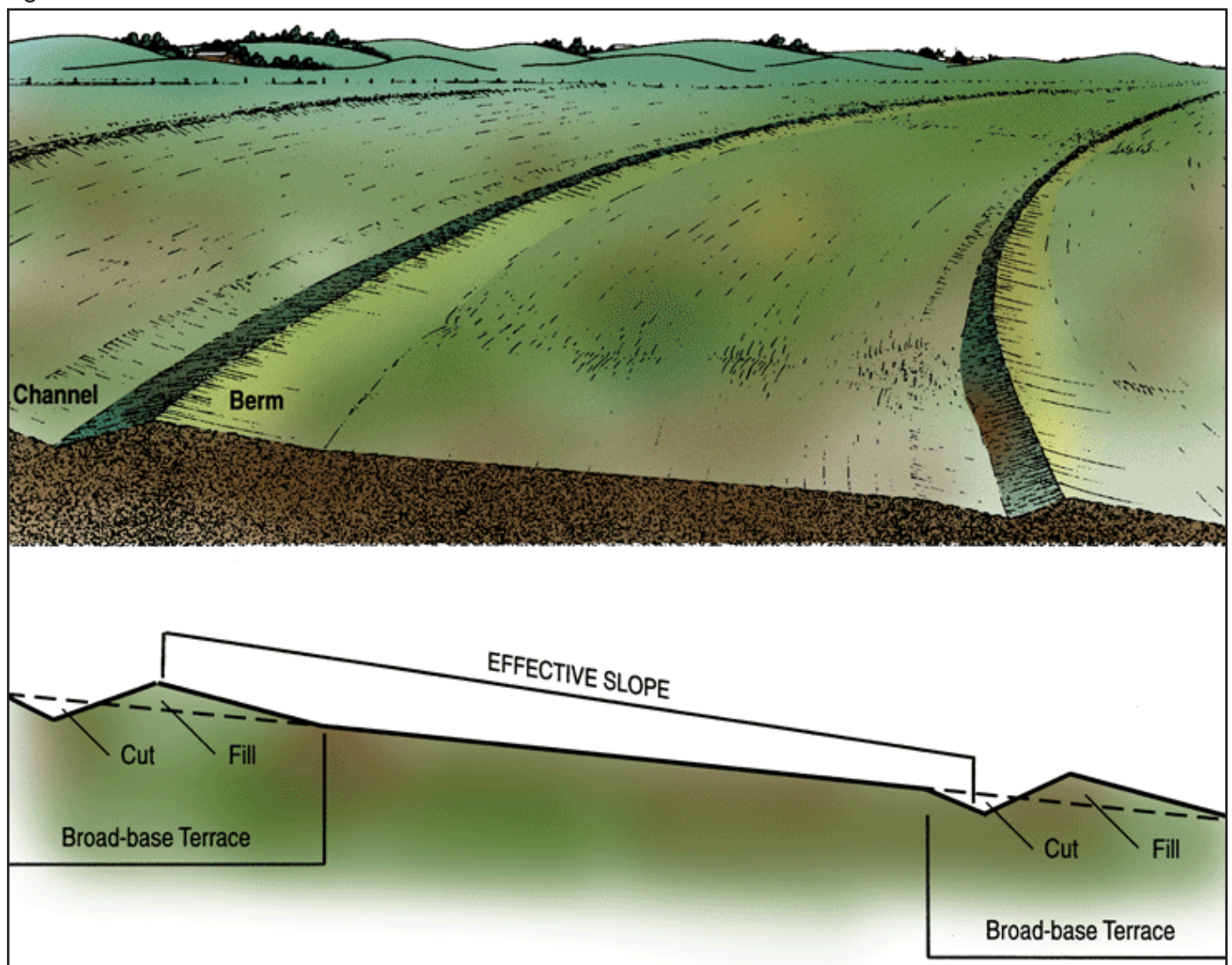
**Broad-base** terraces generally are constructed on slopes of 8 percent or less. The terrace channels and berms (ridges or embankments) are constructed broadly enough that large machinery can operate easily and crops can be planted, although the slope is increased. Construction cuts are made on the uphill side of the berm. See Figure 12.3.

**Narrow-base** terraces generally are constructed on slopes over 8 percent and have grass planted on both sides of the berm. Construction cuts are made on the uphill side of the berm.

**Steep backslope** terraces generally are constructed on slopes over 8 percent. They have grass on the back side of the berm. Berms are constructed by pushing up the soil only from the lower side. The big advantage of steep backslope terraces is the reduction of the slope of the land farmed. See Figure 12.4. The differences between effective slopes of broad-base and steep backslope terraces are shown in Figure 12.5.

Cost-effective methods for controlling erosion vary. No-till or the following methods used together may be the best options for land owners to choose among: a good cropping sequence, a good conservation tillage system, and contour planting.

Figure 12.3 – Broad-base Terrace





## Soil Science

Figure 12.4 – Steep Backslope Terrace

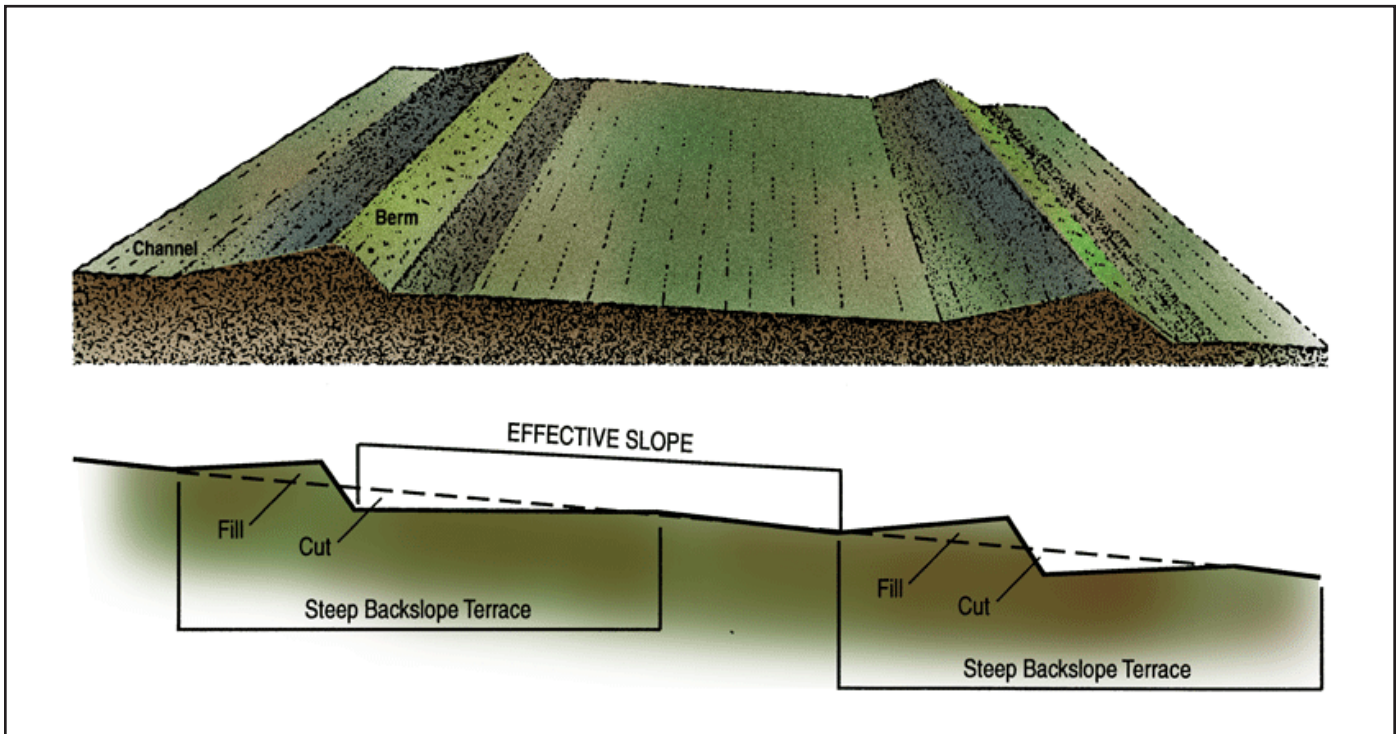
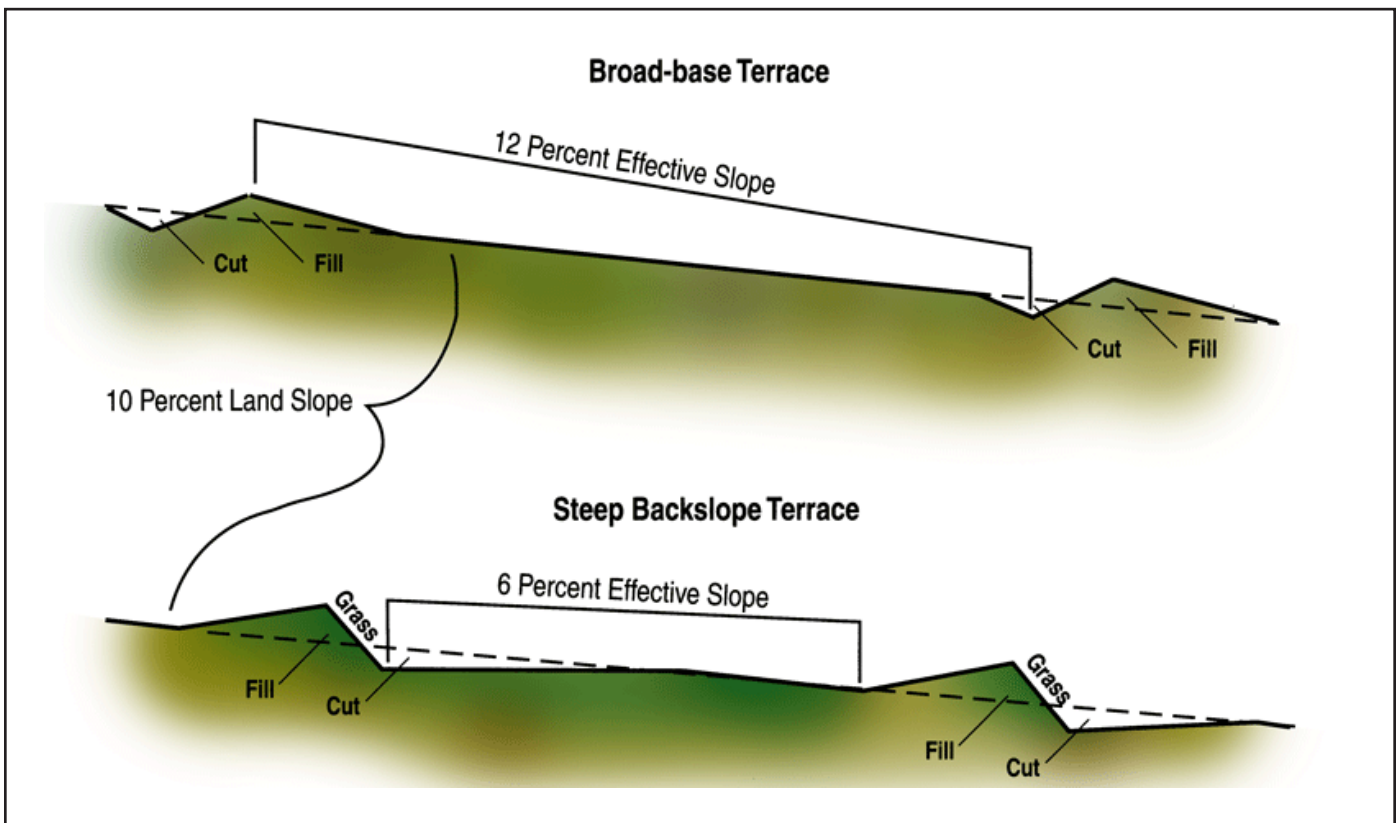


Figure 12.5 – Comparison of a Broad-base Terrace and a Steep Backslope Terrace





## Interpretations and Management of Soil

### Soil Characteristics as Hazards or Limitations for Cropping Systems

Many limitations or hazards may affect the cropping systems for a particular soil site. Six have been selected for evaluation here. They are: slope and erosion, available water capacity, surface drainage, internal drainage, rock fragment content (gravel, cobbles, channers, or flagstones), and surface stoniness. These are not the only important hazards or limitations that affect the choice of crops, but are probably the most significant and easiest to evaluate at a small site. See Table 12.2.

### Summary

Management practices in this lesson include the suitability of artificial drainage and irrigation, water erosion, evaluating the erosion hazard, conservation practices for erosion control, and hazards or limitations for cropping systems. The two major soil properties considered for surface drainage are the internal drainage class and slope (shape and steepness). Surface drainage is needed on all soils that are somewhat poorly drained, poorly drained, or very poorly drained, and are nearly level in slope with depressional areas, and soils that are on sloping areas

below seepy areas. The decision as to whether or not surface drainage is needed is determined after the site is studied.

The best soils for irrigation are deep, nearly level, well-drained soils with a high available water capacity. The primary soil characteristics affecting the suitability for irrigation are surface texture, slope, available water capacity, depth to high water table, permeability, rock fragments, and depth to bedrock. These characteristics are considered assets or liabilities.

The need for erosion control depends on the erosion hazard and the kind of crop that can be grown. The USDA uses the Revised Universal Soil Loss Equation to determine soil loss, and is based on steepness and length of slope, soil erodibility, rainfall energy and intensity, vegetative cover, and type of mechanical erosion control practice. Management practices for controlling erosion include no-till, conservation tillage, contour planting, terraces (broad-base, narrow-base, steep backslope), conservation cropping sequence, and contour strip cropping. Soil characteristics which may limit cropping systems include erosion, available water capacity, surface drainage, and rock fragment content.

Table 12.2 – Guide for Determining Hazards or Limitations for Cropping

Possible Hazard or Limitation	Soil Characteristics that Indicate a Hazard or Limitation Exists
Slope or erosion	1. All land slopes longer than 90 feet in excess of 2% slope. 2. Any eroded area where the upper 6–7 inches is either mixed topsoil and subsoil, mostly subsoil, or has gullies. See Plate 32, p. 50-H.
Available water capacity	Less than 10 inches of available water in the upper 60 inches of the profile.
Surface drainage	High water table <2 feet and nearly level with depressional spots. Also, sloping areas below seep spots.
Internal drainage	High water table <3.5 feet.
Rock fragments (volume upper 10 inches)	>15%
Stoniness (surface)	Stones <100 feet apart.
Rockiness	10 square feet of rock outcrop per 10,000 square feet of area.

## Soil Science

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### Credits

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### Lesson 13: Environmental Impact of Soil and Water Management

#### Effects of Soil and Water on Pesticide and Fertilizer Loss

Pesticides and fertilizers are widely used by farmers to help them grow more bountiful crops. The term **pesticides** refers to any substance or chemical applied to kill or control weeds, insects, and other undesirable pests. Pesticides and fertilizers can be lost from the soil by leaching and water runoff and can pollute underground and surface water supplies. Underground water supplies, such as large aquifers, deep wells, and springs, are affected by leaching. Surface water supplies, such as rivers, ponds, and lakes, are affected by water runoff.

Soil properties can be evaluated to determine the potential of the soil to transmit water-soluble pesticides and fertilizers through the soil profile, and the likelihood of contamination of underground water supplies. Soil properties can also be evaluated to determine potential water runoff, which carry soil solids made up of soil particles, organic matter, pesticides, and fertilizer.

#### Potential Chemical Loss by Leaching and Water Runoff

Leaching and surface runoff are the two main causes of the removal of pesticides and fertilizers from the soil.

##### *Leaching*

**Leaching** is the potential for chemicals to be transported by **percolating water** (water moving downward through the soil) below the soil root zone. Chemicals in groundwater solution are leached from the surface layer and transported vertically or horizontally through the soil. They have a potential to contaminate shallow or deep aquifers, springs, and local water tables. Chemicals that are applied to or incorporated into the surface layer of the soil are subject to leaching. Precipitation—as rain, sleet, or snow—is the major source of soil moisture in which materials are leached from the soil. However, in some areas, irrigation water may be the largest source of moisture during the growing season.

##### *Soil Properties that Affect Leaching*

The soil properties that affect surface infiltration and permeability also affect leaching. Soil properties that affect surface infiltration are soil texture, permeability, restrictive layers, soil depth, and shrink-swell potential. The soil properties that affect permeability are soil structure, particle size distribution, bulk density (ratio of dry soil weight to volume), and presence of and depth to a restrictive layer.

Soils with properties that help retain chemicals within the rooting zone present the lowest levels for potential contamination by leaching. These favorable soil properties are deep, moderately well-drained or well-drained soils with moderate to moderately rapid permeability, high organic matter content, and medium soil textures, such as silt loam, loam, silty clay loam, and clay loam.

##### *Runoff*

Surface water runoff (precipitation that is lost without entering the soil) has the potential to transport pesticides and fertilizers. Sometimes pesticides and fertilizers are carried off the field by water runoff where they contaminate ponds, lakes, streams, and rivers.

#### Soil Properties that Affect Water Runoff

The soil properties that affect water runoff are those that affect the rate of runoff and the erodibility of the surface layer. Some of these properties are the same as those mentioned for leaching, such as texture, permeability, restrictive layers, soil depth, and shrink-swell potential. Other properties affecting the rate of water runoff are slope and internal drainage.

The soil properties affecting soil erodibility are particle size distribution (the exact percentage of sand, silt, and clay in the soil texture class), organic matter content, structure, and permeability. When pesticides and fertilizers are applied to bare soil, water runoff and erodibility are the most severe contamination threats. However, large amounts of crop residue on the surface, left by minimum tillage or no-till, are very effective in reducing runoff. Flooding has the potential for catastrophic surface

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pesticide and fertilizer loss. Flooding can remove large quantities of pesticides, fertilizers, and solids in a single event.

The most favorable soil properties are those that help to retain pesticides and fertilizers within the rooting zone. The same properties that reduce leaching and water runoff losses will also improve the overall water quality.

### Water Holding Structures

**Pond reservoir** areas hold water behind a dam or embankment. Soils best suited to this use have low seepage potential in the upper 60 inches. The seepage potential is determined by the permeability in the soil and the depth to bedrock or other highly permeable material. Slope also affects the water holding area. A much larger water area can be obtained on gently sloping soils than on steep soils. See Table 13.1.

### Building Sites and On-site Waste Disposal

#### Dwellings With Basements

Soil limitations or features that affect the construction of dwellings are:

1. High water table
2. Flooding
3. Shrink-swell potential
4. Slope
5. Depth to bedrock
6. Rock fragments

A **high water table** will likely cause wetness problems around foundations, crawl spaces, and leaky basements.

Dwellings should not be constructed on a site if there is any possibility of **flooding**. Severe flooding can totally destroy houses.

**Shrink-swell potential** can cause severe damage to foundations and basement walls. See Plates 6 and 19, pp. 50-B and 50-E. The drying and wetting of the soils cause shrinkage when dry, and swelling when wet, exerting great force on roots, roads, foundations, and basement walls. Moderate or high shrink-swell ratings can cause damage to buildings and roads. However, proper design and construction can greatly minimize the possible damage. Shrink-swell is influenced by the amount and type of clay minerals in the soil. Kaolinite clay does not shrink and swell as much as other clays. See Table 13.2.

**Slope** can cause extra construction costs in excavation and design.

Table 13.1 – Guide for Rating Limitations for Pond Reservoir Area  
(For subsoil permeability, use permeability of most limiting layer.)

Property	Slight	Moderate	Severe
Permeability	<0.6 inches/hour	0.6–2.0 inches/hour	>2.0 inches/hour
Depth to hard bedrock	>60 inches	20–60 inches	<20 inches
Depth to soft bedrock	>60 inches	20–60 inches	<20 inches
Slope	<3%	3–8%	>8%

Table 13.2 – Guide for Determining the Shrink-Swell Potential  
(Use thickest layer, 10–60 inches, dominant percent of material.)

Soil Texture	Percent Clay	Shrink-Swell Rating
Sandy, loamy sand, sandy loam, loam, silt loam	0–26.99%	Low
*Silty clay loam, clay loam, sandy clay loam	27–39.99%	Moderate
**Silty clay, clay, sandy clay	>40%	High

\* Kaolinite/silty clay loam, clay loam, sandy clay loam use low shrink-swell rating.

\*\* Kaolinite/silty clay, clay, sandy clay use moderate shrink-swell rating.



**Bedrock** is nearly impossible to excavate for basements and foundations unless blasting is used.

**Rock fragments** cause extra construction costs to remove and/or prepare lawns.

Ratings of slight, moderate, and severe limitations for dwellings are interpretations based on the soil properties that affect construction and maintenance. Determine the correct rating for the site using the accompanying guide in Table 13.3. It should be noted that before any digging is started, on-site inspection and approval may be required by the local health department and/or the local planning and zoning committee. Planning and zoning and health department rules may vary from county to county. See Table 13.3.

## On-site Waste Disposal

Any home constructed in an area not served by public sewers must have some kind of on-site waste disposal system. The most common systems are a septic tank with an absorption field or a sewage lagoon.

### Septic Tank Absorption Fields

In a household not served by public sewers, wastes first go into the septic tank where anaerobic (not needing oxygen) bacteria decompose the solid and liquid wastes. See Figure 13.1.

Solid wastes sink to the bottom of the tank, and wastewater is drawn off the top for discharge into the absorption field.

The adequacy of these systems depends more than anything else on the properties of the soil. Soil must do three things for an absorption field to function properly: accept the wastewater, treat the waste, and dispose of the water. All three depend heavily on subsoil permeability.

Waste treatment is a biological process, and it requires plenty of oxygen. Wastewater must move through the soil quickly enough to prevent a buildup of saturated conditions, but slowly enough for microorganisms to do an effective job.

Septic tank absorption fields are subsurface systems with a series of tiles or perforated pipes that distribute effluent from a septic tank into natural soil. See Figure 13.2.

Wastewater flowing through the tile lines trickles into the soil, where further treatment and disposal occurs. The center line depth of the tile is assumed to be at least 24 inches. Only the soil between 24 and 60 inches is considered in making the rating. Ratings are for land conditions and do not consider present land use.

Prior to building a septic tank absorption field, soil properties and site features need to be considered, especially those that affect the absorption of effluent, affect the construction and maintenance of the system, and those that may affect public health.

### Soil Characteristics that Affect Septic Tank Absorption Fields

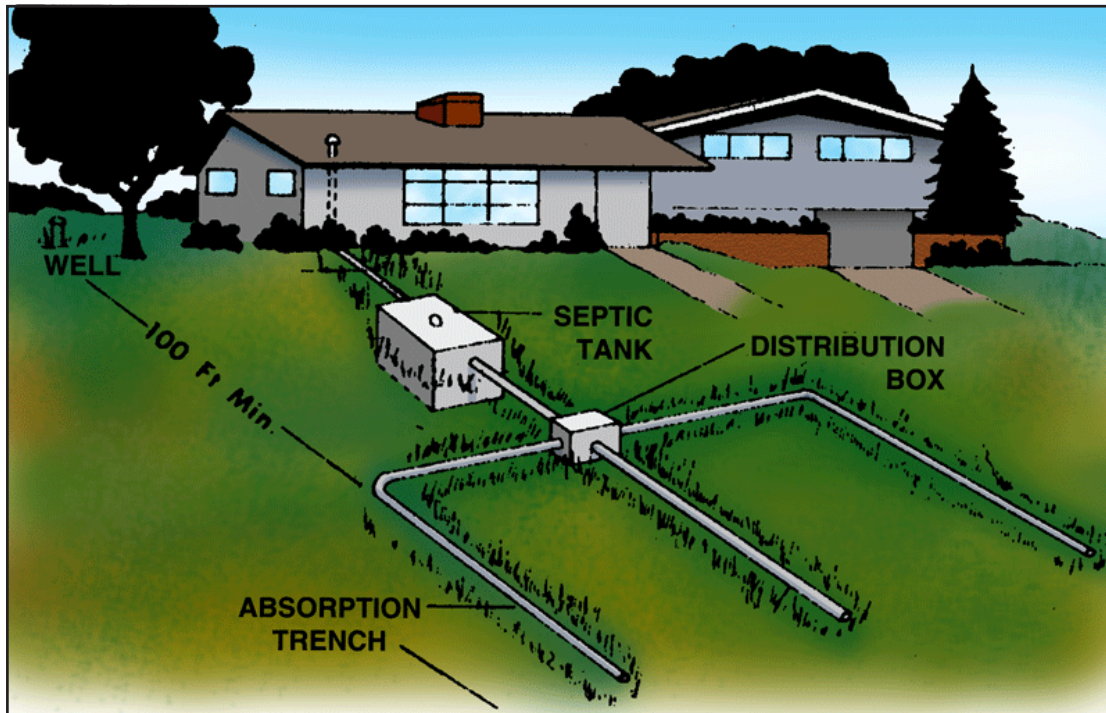
Soil properties and qualities that affect the absorption of the effluent are:

Table 13.3 – Guide for Rating Limitations for Dwellings With Basements

Property	Slight	Moderate	Severe
Depth to water table	>6.0 feet	2.5–6.0 feet	<2.5 feet
Flooding	None	—	Any flooding
Shrink-swell (thickest layer 10–60 inches)	Low	Moderate	High
Slope	<8%	8–15%	>5%
Rock fragments (percent >3 inches) (average percent volume to a depth of 40 inches)	<5%	15–35%	>35%
Hard bedrock (must be OK to hold a basement)	>60 inches	40–60 inches	<40 inches

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Figure 13.1 – Septic Tank With Absorption Field



1. Permeability
2. Depth to a seasonal high water table
3. Depth to bedrock or to a restrictive layer
4. Slope
5. Flooding
6. Rock fragments greater than 3 inches (to a depth of 40 inches)

Most absorption fields function satisfactorily in deep, well-drained soils with moderate to moderately rapid **permeability**. But if the soil has a slowly permeable layer, or a periodically high water table, septic tank wastewater may surface or not receive adequate treatment, and be the source of a health hazard.

Soils that have **seasonal high water tables** interfere with the proper functioning of the absorption field and may cause effluent to surface.

**Shallow soils** do not have enough volume of soil available for treatment, and the danger of effluent breaking out at the surface is increased.

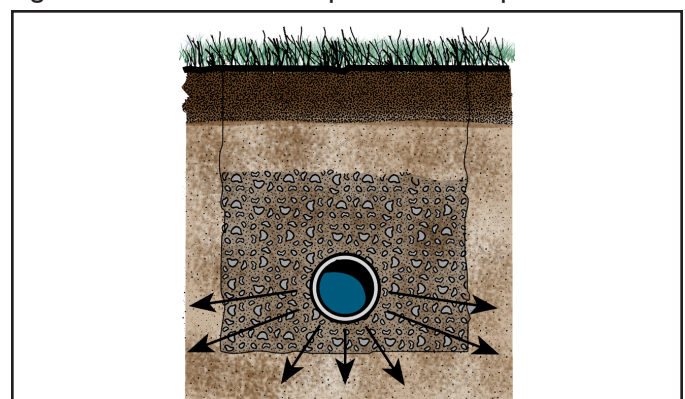
**Slope** is a limitation for absorption fields because wastewater may concentrate at the ends of tile lines and either

break out at the surface or flow too rapidly downslope in the soil. Soil erosion can also be a problem in sloping soils.

**Flood plains** generally are not suitable sites for absorption fields because flood waters can become contaminated with sewage wastewater and the system can also be badly damaged.

**Rock fragments**, along with a shallow depth to bedrock, interfere with the installation of a septic tank absorption field.

Figure 13.2 – Perforated Pipe in an Absorption Field



Soils with slight limitations generally can be used for absorption fields without modifications. Soils with moderate limitations generally can be used for absorption fields, but some special modification generally is needed, for example, increasing the size of the field, installing curtain drains to lower the water table, or adding extra soil to increase the depth. Soils with severe limitations are not suited for conventional septic tank absorption fields. Unique engineering designs may provide alternatives, but generally are too expensive to be feasible. Ratings of slight, moderate, and severe limitations for septic tank absorption fields are interpretations based on soil properties that affect absorption field performance. The rates used are based on the worst circumstances. For example if the depth to rock is 76 inches (slight limitation), but the permeability is very slow (severe limitation), then the site would have a severe limitation, and would probably be unsuitable for a septic tank system unless modifications could be made.

Determine the correct rating for the site using the accompanying guide in Table 13.4, which is based on soil properties and USDA guidelines. It should be noted that before any digging is started, on-site inspection and approval may be required by the local health department and/or the local planning and zoning committee. Planning and zoning and health department rules may vary from county to county. See Table 13.4.

### Sewage Lagoons

**Sewage lagoons** are shallow ponds constructed to hold sewage while aerobic (needing oxygen) bacteria decompose the solid and liquid wastes. Lagoons have

a nearly level floor surrounded by cut slopes or berms (embankments) of compacted, relatively impervious soil material. Aerobic lagoons generally are designed so that the depth of sewage is 2 to 5 feet. Relatively impervious soil for the lagoon floor and berms is desirable to minimize seepage and contamination of local ground water.

### Soil Properties that Affect Sewage Lagoons

Soil properties, qualities, limitations, and restrictive features used in rating soils for sewage lagoons are:

1. Permeability
2. Slope
3. Flooding
4. Seasonal high water table or internal drainage
5. Depth to bedrock
6. Rock fragments (percentage of cobbles and stones)

Sewage lagoons constructed on soils with moderately rapid or rapid **permeability** may need sealing to function properly and to prevent contamination of the groundwater. Soils with rapid permeability generally are unsuitable because of seepage.

**Slope** is a limitation only in the construction cost of leveling a site and building the berms.

**Flooding** is a hazard if there is a possibility of flood waters overtopping the lagoon.

A **seasonal high water table** is a limitation, especially on flood plains if seepage causes effluent to get into the groundwater.

Table 13.4 – Guide for Rating Limitations for Septic Tank Absorption Fields  
(Use most limiting layer in 24–60 inches.)

Property	Slight	Moderate	Severe
Permeability (24–60 inches)	2.0–6.0 inches/hour	0.6–2.0 inches/hour	<0.6 or >6 inches/hour
Depth to water table	>6 feet	4–6 feet	<4 feet
Depth to bedrock (both soft and hard bedrock)	>60 inches	40–60 inches	<40 inches
Slope	<0–8 %	8–15%	>15%
Flooding	None	—	Any flooding
Rock fragments >3 inches (average percent volume to a depth of 40 inches)	<15%	15–35%	>35%

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Table 13.5 – Guide for Rating Limitations for Sewage Lagoons  
(For subsoil permeability, use permeability of most limiting layer.)

Property	Slight	Moderate	Severe
Permeability	<0.6 inches/hour	0.6–2.0 inches/hour	>2.0 inches/hour
Slope	<2%	2–8%	>8%
Flooding	None	—	Any flooding
Depth to water table	>5 feet	3.5–5 feet	<3.5 feet
Depth to bedrock (both soft and hard bedrock)	>60 inches	40–60 inches	<40 inches
Rock fragments >3 inches (average percent volume to a depth of 40 inches)	<15%	15–35%	>35%

If the **depth to bedrock** is less than 40 inches, not enough soil material is available to construct berms and leave sufficient soil depth to seal the bottom of the lagoon. Shallow soils with a slope of more than 1 percent add to this problem.

**Rock fragments** make construction more difficult by limiting the amount of slowly permeable soil material which is available to seal the bottom and berm of the lagoons. Fractured bedrock within 40 inches of the lagoon bottom may create a pollution hazard.

Ratings of slight, moderate, and severe limitations for sewage lagoons are interpretations of the soil properties that affect performance and construction. Determine the correct rating for the site using the accompanying guide in Table 13.5, which is based on USDA guidelines. It should be noted that before any digging is started, on-site inspection and approval may be required by the local health department and/or the local planning and zoning committee. Planning and zoning and health department rules may vary from county to county. See Table 13.5.

### Summary

Pesticides are substances or chemicals applied to kill or control weeds, insects, or other undesirable pests. Pesticides can be lost from the soil by leaching and water runoff.

Soil properties that affect surface infiltration and permeability also affect leaching. Soil properties that affect surface infiltration are soil texture, permeability, restrictive layers, soil depth, and shrink-swell potential;

soil properties that affect permeability are soil structure, particle size distribution, bulk density, and presence of and depth to a restrictive layer.

Soil properties that affect runoff are those that affect the rate of runoff and the erodibility of the surface layer. Those properties affecting the rate of runoff include texture, permeability, restrictive layers, soil depth, shrink-swell potential, slope, and drainage. Soil properties affecting soil erodibility are particle size distribution, organic matter content, structure, and permeability. Soil properties that reduce leaching and runoff losses also improve the overall water quality.

Soil characteristics affecting water-holding structures, such as pond reservoirs, include permeability, depth to hard or soft bedrock, and slope. Soil characteristics that affect building sites for dwellings are depth to water table, flooding, shrink-swell potential, slope, depth to bedrock, and volume of rock fragments greater than 3 inches. Soil characteristics that affect on-site waste disposal are soil permeability, depth to a seasonal high water table, depth to bedrock, slope, flooding, and rock fragments.

### Credits

Soil Survey Division Staff, Lincoln, Nebraska. *National Soils Survey Handbook* (Title 430-VI). Washington, DC: U.S. Department of Agriculture, Soil Conservation Service, 1993.

Soils Interpretation Help Sheet. Missouri Department of Elementary and Secondary Education. Accessed May 8, 2008, from <http://www.dese.mo.gov/divcareered/AG/CDE/SoilsInterpretation.pdf>.