A3588

Management of Wisconsin Soils

Fifth Edition

UW Extension

Physical properties of soil

There is a widespread popular acceptance of the importance of the physical properties of soil to plant growth, but a large proportion of the statements commonly made on this subject are vague, qualitative and frequently unsupported by factual evidence."

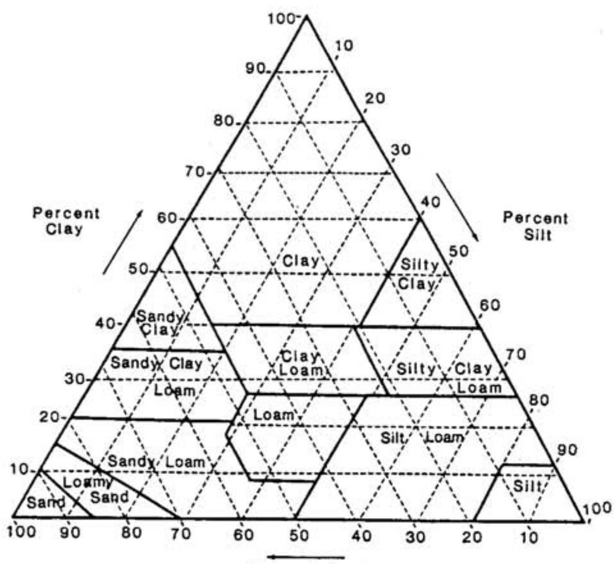
B.T. Shaw, Soil Physical Conditions and Plant Growth, *1952*

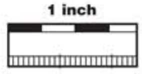
Spectacular advances in the use of fertilizers, pesticides, and other agricultural chemicals since the 1950s have placed a great deal of emphasis on agricultural chemistry. In the process, the importance of the physical properties of soils and their effects on plant growth have often been overlooked. For example, heavier equipment makes soil compaction an increasing problem. Also, few people understand the physical forces that control water retention and movement in soils. As a result, water is frequently the most mismanaged of all growth factors.

Texture

In its broadest sense, soil texture refers to the "feel" of the soil; that is, its coarseness or fineness. Soils are often referred to as being coarse-textured, medium-textured, or fine-textured. More specifically, soil texture is defined as the relative proportion of sand, silt, and clay in the soil. The textural triangle in figure 2-1 shows the ranges in the percentage of sand, silt, and clay associated with different textural classifications. A soil containing equal percentages (33.3%) of sand, silt, and clay would be classified as a clay loam,

Figure 2-1. Ranges in sand, silt, and clay for the different textural classes.





Size range in millimeters (mean diameter)

75 | 2 | 1 | .5 | .25 | .1 | .05 | .02 | .005 | .002 | .0002 | .0008

GRAVEL	SAND					SILT			CLAY		
	very coarse	coarse	medium	fine	very fine	coarse	medium	fine	coarse	medium	fine

not as a loam which many would guess. There is a tremendous difference in size between sand, silt, and clay particles. This is shown on the scale on the bottom of figure 2-1 and in the illustration of relative sizes presented in figure 2-2.

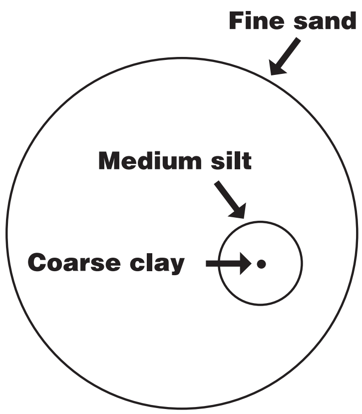


Figure 2-2. Relative sizes of fine sand, medium silt, and coarse clay particles enlarged 500 times. Coarse sand is about 1⁄25 of an inch or 1 millimeter in diameter.

Another way of visualizing the size of various soil particles is to look at their rate of sedimentation, or the rate at which they settle out of a suspension. If soils are dispersed by shaking them in water with a dispersing agent, the sand-sized particles will settle out of the suspension in about 40 seconds. The silt-sized particles will settle out in approximately 7 hours. Because of their extremely small size, most clay particles will remain in suspension for a very long period of time.

Importance of soil texture

Soil texture is important because it affects physical and chemical properties that influence crop growth. Soil structure, organic matter, aeration, bulk density, tilth, water movement and storage, weathering of minerals, and nutrient supply are all influenced directly or indirectly by soil texture. Clay soil may be termed "heavy"—even though it weighs less per cubic foot than a sandy soil—because it is harder to pull a tillage implement through clayey soil than through silty or sandy soil.

Soil texture has a substantial effect on the growth of crops. Sandy soils have large pores that hold little water and are, therefore, droughty. Wind erosion is also a serious problem on these soils when they are bare. Some plant nutrients rapidly leach through sandy soils. Clay soils are often hard to work up into a good seedbed. Water often moves through clay soils very slowly, making them excessively wet. Medium-textured soils, which are between sandy and clayey soils, are usually the best suited for crop production.

The amount of surface area that soil particles have is very important. Surface area determines the amount of available water and plant nutrients that a soil can hold. Clay particles, being extremely small, have a very high surface area in proportion to their volume. These particles are usually broad and flat, like flakes of mica. Most of them are composed of millions of thin layers, each separated by layers of water. The internal surface along these layers is much larger than the outside surface. In fact, an acre of clay 7 inches deep has a surface area equivalent to 25,000,000 acres (table 2-1). It is this vast surface area that causes a small amount of clay to have such a great effect on both the physical and the chemical properties of soils. The clay in most soils accounts for the bulk of the surface area that holds plant nutrients.

Table 2-1. Properties of sand, silt, and clay-sized soil particles.

Particle sizes	Physical properties	Surface area of soil particles in an acre plowed 7 inches deep
Coarse sand	Loose, non-sticky, gritty	500 acres
Fine & very fine sand	Loose, not sticky	5,000 acres
Coarse, medium, fine silts	Smooth and floury, slightly sticky	50,000 acres
Coarse, medium, fine clay	Sticky and plastic when wet; hard and cohesive when dry	25,000,000 acres[a]

[a] *Includes both external surfaces and surfaces between crystal plates.*

Determining soil texture by feel

A precise determination of soil texture requires laboratory analysis. For most practical purposes, the texture can be estimated accurately enough by hand texturing. In a mineral soil, the feel of the soil when rubbed between the thumb and forefinger is dependent primarily on the relative amount of sand, silt, and clay. While soils rarely consist entirely of one particle size range, learning the characteristic feel of each particle size helps in identifying the different size fractions (table 2-2). Mastering this method requires knowing how each soil texture feels. However, moisture and organic matter can change the feel of the different size fractions and thus the soil itself. For example, clay moistened to the consistency of workable putty feels like smooth satin, while dry clay feels rough and gritty. Organic matter makes clay feel less sticky and sand feel less gritty. Organic matter is also an important coloring agent in soil; however, soil color is not an indicator of texture.

Table 2-2. Textural properties of mineral soils.

Soil class	Feel and appearance of soil[a] — Dry soil	Feel and appearance of soil[a] — Moist soil
Sand	Loose single grains that feel gritty. Squeezed in the hand the soil mass falls apart when the pressure is released.	Squeezed in the hand it forms a cast or mold that crumbles when touched. Does not form a ribbon.
Sandy loam	Aggregates are easily crushed; very faint velvety feeling initially but as rubbing is continued the gritty feeling of sand soon dominates.	Forms a cast requiring careful handling to keep it from breaking. Does not form a ribbon.
Loam	Moderate pressure crushes aggregates; clods can be quite firm. Pulverized loam has a velvety feel that becomes gritty with continued rubbing.	Cast can be handled quite freely without breaking. Very slight tendency to ribbon. Rubbed surface is rough.
Silt loam	Aggregates are firm but may be crushed under moderate pressure. Clods are firm to hard. Smooth, flour-like feel dominates when soil is pulverized.	Cast can be freely handled without breaking. Slight tendency to ribbon with rubbed surface having a broken or rippled appearance.
Clay loam	Very firm aggregates and hard clods are difficult to crush by hand. Pulverized clay loam feels somewhat gritty due to the harshness of the tiny remaining aggregates.	Cast can bear much handling without breaking. Pinched between the thumb and forefinger it forms a ribbon. The ribbon's surface tends to feel slightly gritty when dampened and rubbed. Soil is plastic, sticky, and puddles easily.
Clay	Aggregates are hard and clods are extremely hard to crush by hand. Pulverized clay has a gritty texture due to the harshness of numerous very small aggregates.	Casts can bear considerable handling without breaking. Forms a flexible ribbon and retains its plasticity when elongated. Rubbed very smooth, surface has a satin feeling. Sticky when wet and easily puddled.

[a] *The properties described for the clayey soils refer to those found in the temperate regions.*

Structure

The arrangement of primary soil particles (sand, silt, clay) into aggregates of definite shape is known as soil structure. Soil structure affects water movement into and through soil, root penetration, porosity or aeration, and bulk density. In all soils other than sands, soil particles tend to stick together. The pieces that are formed are called structural aggregates or peds (figure 2-3). The major materials cementing soil particles together into peds are clay, organic matter, various bacterial gums, iron and aluminum oxides, silica, and lime. Root hairs and fungal mycelia also help stabilize soil aggregates.

Some soils, such as sands, have no structure and are described as single-grained. Another kind of structureless soil is one in which the structure has been physically destroyed or puddled when wet. The soil in the rut of a tractor that has been stuck in the mud is an example of such a structureless or massive soil.

Granular soils work up easily into a good seedbed. This is particularly true when the granules are well-cemented together and are fine. Many surface soils in Wisconsin were originally granular. Intensive row cropping, poor management, and erosion have destroyed much of this granular structure. The impact of raindrops can also break down aggregates near the soil surface. Moreover, the use of heavy equipment and excessive tillage when the soil is too wet can destroy soil structure. With modern four-wheel-drive tractors, fields can be tilled when they are too wet. The resulting compaction stunts crop growth by reducing aeration, restricting root growth, and inducing nutrient deficiencies. Plant roots will tend to grow horizontally when they encounter a compacted layer of soil.

In a Wisconsin study on a Plano silt loam, researchers compacted the soil by driving a loaded tractor with a 14-ton axle weight over plots in the spring before planting. Corn yields on the compacted plots were reduced from 129 bu/a to 98 bu/a the first year and from 167 to 156 bu/a the second year (table 2-3). Alfalfa yields were reduced by 0.97 and 0.81 ton/a in the first and second year, respectively.

When surface soils have been poorly managed, the natural aggregates in the surface soils are destroyed and large, hard, irregularly shaped clods are formed. Restoring good soil structure involves growing sod crops such as native grasses and grass-legume mixtures, returning barnyard manure and crop residues to the soil, controlling erosion, and minimizing tillage and traffic over the field with heavy equipment. The expansion and contraction caused by wetting and drying or freezing and thawing in Wisconsin winters will also help to restore soil structure. If excessively heavy loads cause deep compaction, freezing and thawing might not suffice to undo the damage, and deep chiseling or subsoiling may be needed.

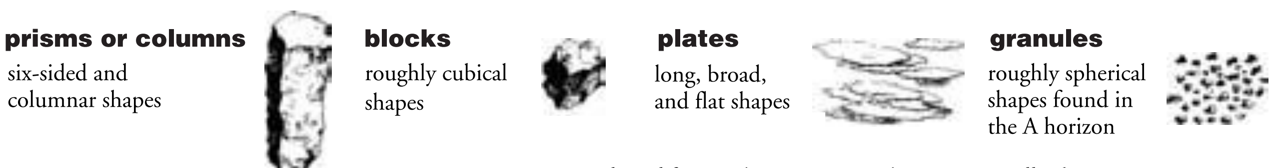
Many subsoils in Wisconsin have blocky or prismatic structure. Both of these kinds of peds aid the movement

Table 2-3. Effect of soil compaction on the yield of alfalfa and corn in Plano silt loam at Arlington, WI.

Compaction (axle weight)	Alfalfa Year 1	Alfalfa Year 2	Corn Year 1	Corn Year 2
tons	ton/a		bu/a	
Less than 5	2.27	4.13	129	167
14	1.30	3.32	98	156

Source: Wolkowski, R.P., and L.G. Bundy. 1990. Proc. 1990 Fert., Aglime & Pest Mgmt. Conf. 29:29-37. Wolkowski, R.P., and L.G. Bundy. 1992. New Horizons in Soil Sci. No. 3; Dept., of Soil Sci., UW-Madison.

Figure 2-3. The most common shapes for peds.



Adapted from Soil Survey Manual, *USDA Handbook No.18, 1951, p.227.*

of water, air, and plant roots through the subsoil.

Platy structure is the least desirable. Water and roots have to go back and forth to get between the plates, slowing their downward movement. Platy structure occurs naturally in some soils. It can also be created by farming. Use of the moldboard plow when the soil is too wet and plowing at the same depth year after year tend to create a platy structure (plow pan) just below the plowed layer of surface soil. Plow pans can be eliminated by varying the depth of plowing occasionally, by using a chisel plow or subsoiler, and by not working the soil when it is too wet.

Sometimes farmers attempt to improve poorly drained, tight subsoils by deep tillage. Deep tillage may provide some temporary benefit, but it won't give long-term improvement on soils that have drainage problems or in cases where improper management is not corrected.

Organic matter

The organic portion of the soil is extremely important. It stores plant nutrients and improves the water-holding capacity of soil. On the surface as a mulch, organic matter shades the soil and reduces the harmful effect of raindrop impact on soil structure. Organic matter improves soils for the growth of plants by promoting soil aggregation, thus improving soil structure and tilth.

The plants and animals living in soil feed on organic matter. Frequent additions of fresh organic matter are needed to maintain large and vigorous populations of bacteria, earthworms and other soil organisms. Organic matter also helps soil retain plant nutrients. This is most noticeable in sandy soils but is important in all soils. While adding fresh organic matter is very beneficial, it does not significantly increase the residual organic matter or humus content. For example, the incorporation of 6,000 pounds of crop residues into the soil results in about 90% of this dry matter returned to the air as carbon dioxide through microbial respiration or reduced to simple chemical salts and water. Only 600 pounds will remain as stable organic matter or humus. Since the soils of Wisconsin commonly contain 30,000 to 80,000 pounds/acre of organic matter (1.5 to 4.0%), adding a few hundred pounds per acre will have very little effect on the total organic matter content. It is not possible to quickly change the organic matter content of the soil in the same way that the content of available phosphorus or potassium can be modified by fertilization. Some typical organic matter contents of the plow layers of various kinds of Wisconsin soils are given in table 2-4.

Soils tend to have a natural equilibrium level of organic matter. This level is regulated mainly by soil temperature, moisture, aeration, pH,

Table 2-4. Approximate amounts of organic matter in various Wisconsin soils.

Soil color and texture	Approximate % organic matter
Light- and dark-colored loamy sands	0.4 – 1.2
Light-colored sandy loam	1.2 – 2.0
Dark-colored sandy loams and light-colored silt loams and loams	2.0 – 3.5
Moderately dark and dark-colored silt loams, loams and clay loams	3.5 – 5.5
Imperfectly drained soils	5.5 – 9.0
Poorly drained and very poorly drained soils	9.0 – 20.0
Peats and mucks	> 20.0

carbon:nitrogen ratio, and nutrient supply. These factors influence the microbial process that decomposes organic matter. Organic matter accumulates in swamps and poorly drained soils because aeration is restricted. It also accumulates in arctic soils, as in Alaska, because accumulation during the short growing season exceeds decomposition during the rest of the year.

Tillage accelerates organic matter decomposition by aerating the soil. A 30-year study of the effect of tillage on organic carbon in a Wooster silt loam soil in Ohio showed that organic matter decreased by 64% after 30 years of continuous corn (table 2-5.). The drop in organic matter was proportional to the number of years in corn, although there was some loss (37%) even with continuous oats or wheat. Some tillage is involved in seeding these crops. With good soil management and returning crop residues to the soil, organic matter can be maintained or slightly increased. For example, corn was grown continuously on Plano silt loam at Arlington, WI, since 1958. At that time the organic matter varied from 3.0 to 3.5%. In 1990, as a result of incorporation of the corn stover, the organic matter content had increased to 3.5 to 4.0%.

Mineral matter

Many kinds of minerals occur in soils. A mineral is a naturally occurring inorganic substance whose chemical composition varies only within prescribed limits and which has definite physical properties. Some of these minerals contribute little to plant growth. Others provide the main sources of many plant nutrients. Primary minerals are formed by the solidification of molten magma within the earth's interior. Secondary minerals are formed from pre-existing minerals by weathering.

Silicate minerals make up about 80% of the earth's crust (table 2-6). In this group, the most abundant class of minerals are the framework silicates, typified by feldspar and quartz. Quartz is silicon dioxide, a combination of silicon and oxygen (SiO_2), the two most abundant elements on earth. Quartz contains no plant nutrients. Feldspars contain potassium, calcium, magnesium, copper, iron, manganese, and zinc. The ferromagnesium silicates are high in iron and magnesium. The layer silicates are usually found in the clay fraction of soil, although mica can be found in large pieces several inches across in rocks. (A rock is a complex combination of two or more minerals.)

Oxides of iron, manganese, aluminum, and magnesium are commonly found in the clay fraction of

Table 2-5. Decrease in soil organic matter in a Wooster silt loam after 30 years under several cropping systems.

Cropping system	Organic carbon	Organic matter	Decrease in organic matter
	%	%	%
Initial	2.04	3.52	—
Continuous corn	0.74	1.28	64
Continuous oats or wheat	1.28	2.22	37
Corn-wheat-clover	1.16	2.00	43
Corn-oats-wheat-clover-timothy	1.55	2.67	24

Source: Salter and Greene, 1933. J. Amer. Soc. Agron., 25:622–23.

soils. They are important sources of magnesium, boron, copper, iron, manganese, molybdenum, and zinc. Some of these nutrients are adsorbed (bonded) onto the surfaces of these oxides.

Dolomite is the predominant carbonate mineral found in Wisconsin; dolomitic limestone is the rock formation quarried for use as aglime. It is a source of both calcium and magnesium. Apatite is the original source of native phosphorus in soils. Wisconsin soils have no native sources of gypsum (calcium sulfate).

The kinds of minerals in Wisconsin soils vary somewhat from place to place throughout the state. They also vary greatly among the different particle sizes in each soil. Sand and coarse silt particles are mostly quartz, a colorless mineral which contains no elements essential for plants. Medium and fine silt often contain significant amounts of feldspars and micas in addition to quartz. These minerals contain potassium, iron, zinc, copper, magnesium, manganese, and other elements essential for plants.

Some essential plant nutrients such as potassium and magnesium are structural components inside clay particles, but clay minerals also hold these and other essential elements in an available form on their surfaces by means of an electrical charge. This is one reason why clay is a very important part of the soil.

Table 2-6. Minerals common in Wisconsin soils.

Class of mineral[a]	Examples	Associated plant nutrients
Silicates (80% of earth's crust)		
Ferromagnesium (16%)	Amphibole	Calcium, magnesium, iron, boron
	Pyroxene	Calcium, magnesium, iron
	Olivine	Iron, magnesium
Framework (60%)	Feldspar	Potassium, magnesium, copper, zinc, manganese
	Quartz	None
Layer silicates (4%)	Montmorillonite	Calcium, potassium, magnesium
	Vermiculite	Calcium, potassium, magnesium
	Mica	Potassium, magnesium, iron, manganese
	Kaolinite	Calcium, potassium, magnesium
Oxides of aluminum, iron, magnesium, and manganese (13%)	Hematite	Iron, trace element impurities
	Goethite	Iron, trace element impurities
	Limonite	Iron, trace element impurities
	Magnetite	Iron, trace element impurities
	Gibbsite	Trace element impurities
	Pyrolusite	Manganese, trace element impurities
	Brucite	Magnesium, trace element impurities
Carbonates (<5)	Dolomite	Calcium, magnesium
	Calcite	Calcium
Other (trace)	Apatite	Phosphorus
	Tourmaline	Boron

[a] *The percentages indicate the approximate amount of each of the minerals in soil.*

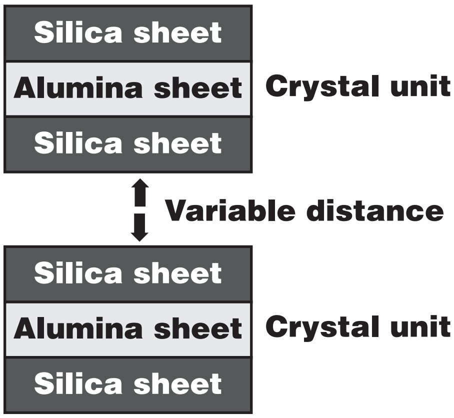


Figure 2-4. Schematic representation of montmorillonite, a common layer silicate mineral.

As previously mentioned, clay particles are layer-like crystals, with each layer separated by water. The exact kind of clay mineral found in soils depends upon the degree and length of weathering. Montmorillonite, the dominant clay mineral in Wisconsin soils, is composed of crystal units containing a layer of alumina sandwiched between two layers of silica (figure 2-4). Water separates each crystal unit. The changing water content causes the clay to swell when the soil is wet and shrink or contract when the soil is dry. Collapse of the crystal units of the clay particles is, in part, responsible for the cracking of soil during dry weather.

Bulk density

Bulk density is the dry weight of a given volume of soil. The bulk density of water is 62.4 pounds per cubic foot or 1.0 grams per cubic centimeter. Mineral soils have a bulk density heavier than water, but most organic soils are lighter than water. Bulk density is inversely proportional to pore space (table 2-7). That is, the greater the soil bulk density, the lesser the soil pore space.

Tilth

Tilth is a description of the physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration. It is a descriptive term that is difficult to quantify.

Table 2-7. Relationship between soil texture, bulk density, and pore space.

Soil texture	Bulk density	Pore space
	g/cc	%
Sand	1.6	39
Loam	1.3	50
Silt loam	1.2	54
Clay	1.1	58
Muck	0.9–1.1	Variable
Peat	0.7–1.0	Variable

Color

Soil color is determined mainly by the iron and organic matter in soil and the oxidation state of the iron. Soil minerals are mostly whitish to grayish in color when the iron and organic matter are removed. Humus and iron oxide are the principal pigments in soil, and like paint, a little goes a long way. Color bears little relationship to soil fertility, although it may give some useful clues to the nature of soils. A black or dark soil usually is high in organic matter. Yet a peat with 60% organic matter will not be as dark as a muck with only 30% organic matter because the peat is less decomposed. The reddish soils of eastern Wisconsin are red because of the presence of iron oxide coatings. This pigment coats the silt, clay, and humus and masks the dark pigmentation of the latter.

Highly oxidized iron oxide is red. Iron that's been exposed to both water and oxygen, called *hydrated iron oxide*, is yellowish. Iron in an oxygen-scarce environment (such as waterlogged soils), called *reduced iron oxide*, is blue-gray. Thus, when a wet mineral soil is drained and cultivated, the subsoil will have a blue-gray color. In time, with tillage and good drainage, the reduced iron slowly oxidizes, and the color turns yellowish-brown. Many tropical soils are brick-red because intense weathering results in accumulation of iron oxides. The pinkish-red soils of eastern Wisconsin are young; the iron oxide was removed from iron deposits by glacial activity and ground and mixed with the parent material that formed these soils. Soils that are subjected to alternate periods of wet and dry conditions often have reddish-yellow mottles in the subsoil because the oxidation and reduction of iron oxide is a slow process. While the color of a soil gives some clues to its organic matter content and state of iron oxidation, it is not a reliable indicator of soil fertility.

Temperature

The temperature of the soil is important for both root growth and microbial activity. Little microbial activity occurs below 45°F or above 90°F. A temperature difference of only a few degrees can be important when a crop is near the threshold temperature required for growth. For example, the difference in early season vigor between corn planted with conventional tillage and that planted no-till has been attributed to slightly cooler soil (2° to 4°F) under no-till.

Although we cannot control the weather, some management practices will affect soil temperature. It takes five times as many calories to heat a pound of water than it does to heat a pound of dry soil. Consequently, wet soils remain cold much longer than well-drained soils. Proper drainage, therefore, will facilitate soil warming in the spring. Also, surface residue shades the soil from direct solar radiation and tends to keep the surface soil moist. At 4 inches deep, soil temperatures of fields with substantial surface residue typically are a few degrees cooler than under bare soil. However, the advantage of a warmer soil must be weighed against the erosion potential of a bare soil.

North slopes are cooler than south slopes (in the northern hemisphere). Sometimes the difference is great enough to result in differences in cropping and native vegetation. In southern Wisconsin, for example, apples are often grown on northern slopes because the temperature fluctuates less, lessening the risks of premature bloom and subsequent frost damage.

Questions

1. What is meant by the texture of a soil? How is soil texture measured? Which soil texture offers ideal growth conditions for plants? Why?

2. The percentages of sand, silt, and clay are given below for several soils. What would be the textural classification of each of these soils?

	sand	silt	clay
		%	
a.	65	25	10
b.	50	20	30
c.	40	40	20
d.	30	40	30
e.	15	50	35

3. Why is soil structure important? What are some factors that contribute to the breakdown of soil structure?

4. How can the structure and tilth of a soil be maintained when the land is cropped to continuous corn?

5. Why is a sandy soil that weighs 100 pounds per cubic foot easier to plow than a silty clay loam that weighs only 72 pounds per cubic foot?

6. Explain why tilling silty or clayey soils when they are too wet reduces crop yields.

7. Discuss five reasons why organic matter is an important component of soil.

8. It is much easier to lose organic matter from soil than to increase soil organic matter. Why?

9. Why do cracks form in silt loam soils during periods of drought but not in sandy soils?

10. What can you tell about a soil from its color?

11. Why do dry soils warm up faster than wet soils?