



Steve Culman

introduction to soils

Soil Quality

Healthy soils yield healthy crops, But what is healthy soil and how do we achieve it?

Soil health is the foundation of productive farming practices. Fertile soil provides essential nutrients to plants. Important physical characteristics of soil-like structures and aggregation allow water and air to infiltrate, roots to explore, and biota to thrive. Diverse and active biological communities help soil resist physical degradation and cycle nutrients at rates to meet plant needs. Soil health and soil quality are terms used interchangeably to describe soils that are not only fertile but also possess adequate physical and biological properties to “sustain productivity, maintain environmental quality and promote plant and animal health” (Doron 1994).

According to the (USDA) Natural Resource Conservation Service, “Soil quality is how well soil does what we want it to do.” In order to grow our crops, we want the soil to hold water and nutrients like a sponge where they are readily available for plant roots to take them up, suppress pests and weeds that may attack our plants, sequester carbon from the atmosphere, and clean the water that flows through it into rivers, lakes, and aquifers.

Healthy, high-quality soil has:

- Good soil tilth
- Sufficient depth
- Sufficient, but not excessive, nutrient supply
- Small population of plant pathogens and insect pests
- Good soil drainage
- Large population of beneficial organisms
- Low weed pressure
- No chemicals or toxins that may harm the crop
- Resilience to degradation and unfavorable conditions

—from *Soil Health Training Manual*

Remember, soil fertility is only one component of soil quality. Fertile soils are able to provide the nutrients required for plant growth. These are the chemical components of soil. Some plants need certain nutrients in large amounts, like nitrogen, phosphorus, and potassium, which are called macronutrients. Other nutrients, like boron and manganese, plants only need in very small amounts. In high-quality soil, nutrients are available at rates high enough to supply plant needs, but low enough that excess nutrients are not

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leached into groundwater or present at high levels toxic to plants and microbes. For more information on soil fertility, see *Start Farming—Introduction to Soils: Managing Soils*.

All these characteristics sound great. But when you look at your field, how do you tell whether you have high-quality soil and how do you improve it? The first step is to learn about the properties of your soil. The following describes soil properties and indicators of soil quality that are important for healthy, productive crops. Indicators are easily measurable things that allow us to see what is happening in soil.

SOIL TEXTURE

We cannot change certain aspects of a given soil. Soil texture is one such aspect. Soil texture is a good place to start when you look at your soil. When you understand your soil's texture, you know more about the possible restrictions on your particular piece of land as well as any advantages. (Find where your farm is on the soil texture triangle, right.)

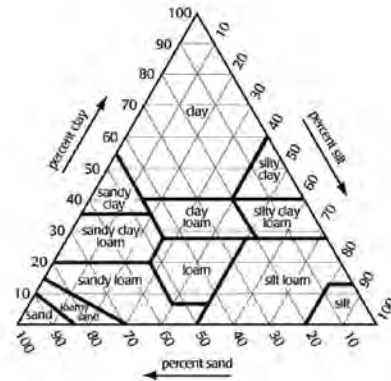
The terms sand, silt, and clay refer to particle size; sand is the largest and clay is the smallest. Gravel particles are larger than 2 millimeters (mm), sand particles are 0.05–2 mm, silt particles are 0.002–0.05 mm, and clay is smaller than 0.002 mm. To put this in perspective, if a particle of clay were the size of a BB, then a particle of silt would be the size of a golf ball and a grain of sand would be the size of a chair (FAO 2007). (See Illustration 2, right.)

Even though the definition is based on particle size, the shape of the particles is important for thinking about how soil texture relates to soil quality. Sand particles are generally round, while silt and clay particles are usually thinner and flatter. In a soil with larger, round particles, more space is available for the water and air that our plants need. Also, the air space between the particles is larger, providing good aeration. However, in a sandy soil, many of the air spaces are too large to hold water against the force of gravity, creating a soil with low water-holding capacity that is prone to drought.

How Do I Tell What Texture My Soil Is?

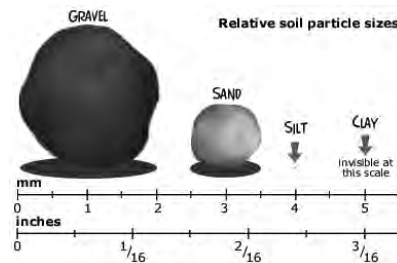
You can determine a soil's texture by how the soil feels. Does it feel gritty, greasy, or floury? Gritty soils are sandy. Silty soils feel floury when they are dry and greasy when they are wet. Clay will always feel greasy. Take a small handful of soil and drop enough water on it that you can form a ball. When you rub it in the palm of your hand, it will fall apart and you will feel the grit rub into your palm if it is sand. A silt will form a ball, but when you try to roll it out into a ribbon it will crack. A clay soil will roll out into a long ribbon.

ILLUSTRATION 1: SOIL TEXTURE TRIANGLE



The soils texture triangle shows different amounts of water and air in soil with different sized and shaped particles. Illustration courtesy of C. Saylor.

ILLUSTRATION 2: PARTICLE SIZE



To put particle size in perspective, if a particle of clay were the size of a BB, then a particle of silt would be the size of a golf ball and a grain of sand would be the size of a chair.

Differences Between Sand, Silt, and Clay

You are probably familiar with the characteristics of a clay soil. We call them heavy soils for a reason. They can be difficult to work. They dry out slowly and can leave a hard crust that does not allow the rain to penetrate. Clays are made up of very small particles. Some kinds of clay are layered together in sheets. Think of a piece of baklava or a deck of cards with many thin layers stacked on top of one another. Clay can hold water and nutrients between those fine layers. Another important aspect of clays is that each of these individual layers has many “parking spaces” for plant nutrients. In reality, these “parking spaces” are negatively charged sites on the surface of the layer, as well as within the structure of the clay layer. Many of the nutrients are positively charged (called “cations”) and, therefore, are attracted to the negatively charged “parking space,” just like the opposite ends of a magnet are attracted to each other. Tiny clay particles have more surface area than larger particles of sand or silt (FAO, 2007). That means more area is available for positively charged plant nutrients to stick to. (See Illustration 3.)

Sand is loose and single grained. The individual grains can be easily seen and felt. If you squeeze a handful of dry sand, it will fall apart. If you squeeze wet sand, it will form a cast and then crumble when you touch it. Loam is a mix of sand, silt, and clay. It is mellow with a somewhat gritty feel, yet fairly sticky and slightly plastic (Russell 2005).

SOIL STRUCTURE

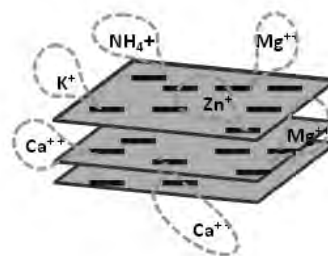
In pursuit of high-quality soil we generally try to build highly “structured” soils. While the texture of the soil is inherent and difficult, if not impossible, to change, we can influence the structure of the soil with our management practices. When we plow, cultivate, lime, add organic matter, and stimulate biological activity, we change soil structure.

Whereas texture is the composition or relative proportion of three soil particle types (sand, silt, clay), soil structure is the arrangement or geometry of these soil particles. Soil with good structure has a wide range of pore spaces or empty space between the soil particles. For example, in a good loam soil, 40–60 percent of the soil volume is pore space filled with air and water (Brady 1996).

To understand this concept, compare your soil to a building. If a building is made out of bricks, the “texture” of the building would be the proportion of cement, sand, and brick (clay, silt, and sand) that makes up the building. The “structure” would be the arrangement of these bricks to form large rooms, small rooms, hallways, etc. If an earthquake should cause the building to collapse into a pile of bricks, the texture would remain the same, but the structure would have been radically altered. To follow on our analogy, just as before the earthquake, the structure of the building provided much better living conditions than after (big and small rooms in which to move and live); similarly, a soil that has a good structure provides better living conditions for soil organisms and roots. It has many large and small pore spaces through which air, water, roots, and living organisms can move freely (FAO 2007). Soil scientists call soils with good structure “granular” or “crumb” type soils. These soils are loose and fluffy. Generally they are high in organic matter and have large soil aggregates. Think about what the soil looks like when you dig under a thick layer of sod. It has many crumbly pieces, large pores, clumps, roots, and decaying pieces of organic material.

In contrast, platy soils have thin layers of horizontal plates or leaflets. These plates are often inherited by the way the soil was formed, but we can also create them by overuse of heavy machinery on clayey soils. Deeper soil layers may be prismatic, columnar, or block-like. (See Illustrations 4 and 5.)

ILLUSTRATION 3: CLAY PARTICLES HOLDING NUTRIENTS



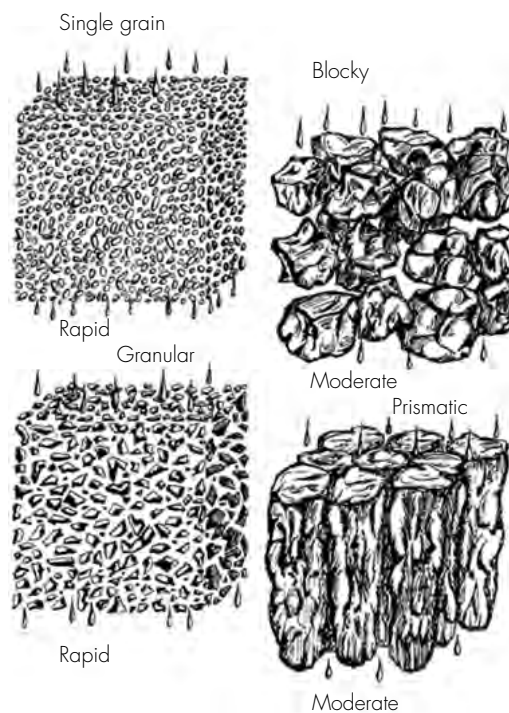
Some clays hold water and nutrients between fine layers. Negative charges act like “parking spaces” holding positively charged plant nutrients in place. Illustration adapted from FAO, Farmer Field Schools.

ILLUSTRATION 4: SOIL STRUCTURE



Soil particles are arranged in different ways to constitute the soil’s structure.

ILLUSTRATION 5: SOIL STRUCTURE AFFECTS WATER MOVEMENT



Soil structure affects how quickly water moves through soil. Water moves quickly through soils with many small grains. Soils with larger aggregates in the form of blocks or prisms have moderate drainage.

We don't generally change the structure of deeper soil layers with our management practices, but it is good to check the soil survey to find out what lies beneath your soil layer because it may affect drainage and root penetration.

SOIL AGGREGATES

The aspect of soil structure that often interests us most as soil managers and that we can most easily change is soil aggregation. Bacteria and roots produce sticky substances that glue soil particles together. Fungi and root hairs wrap soil particles into balls. These groups of soil particles are called aggregates. (See Illustration 6.)

One important type of soil aggregate is water-stable aggregates. Water-stable aggregates are measured by the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. (Gugino 2007)

Why Does It Matter?

The number of water-stable aggregates in your soil shows its capacity to sustain its structure during the most extreme conditions (e.g., a heavy rainstorm after weather had dried the surface). Soils with low aggregate stability can constrict crops because they form surface crusts—which can reduce both water infiltration and air exchange, make the soil more difficult to manage, and reduce its ability to dry off quickly—and often have low biological activity. Aggregates are formed in part by exudates from bacteria, entanglement of soil particles in fungal hyphae, and digestion by earthworms. (See Illustration 6.) Low biological activity means reduced mineral cycling and competition with pest organisms. (Gugino 2007)

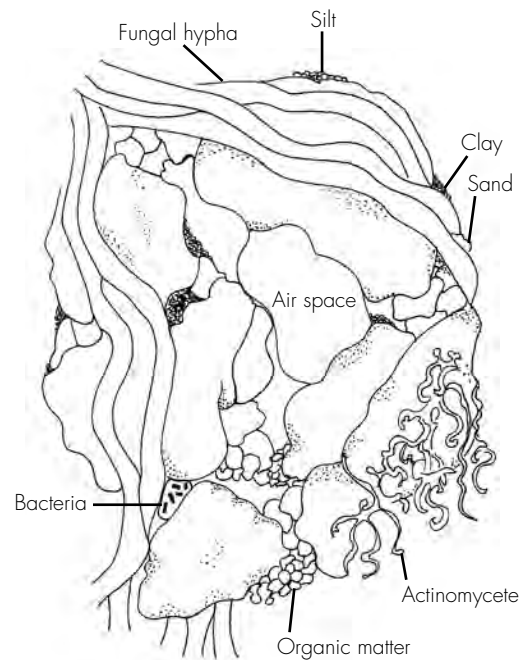
How Can I Improve It?

As soil managers we can help build soil aggregates by growing green manure cover crops or adding animal manure. Also think about your tillage regime. Over the long term, repeated soil tillage can reduce soil tilth and break down stable soil aggregates. Such soils can be so degraded that they become addicted to tillage and crop establishment requires a soil-loosening operation. If you can reduce your tillage operations, you may reduce the disturbance to the soil biota that are essential for building aggregation. Feeding the soil food web with cover crops or other organic materials also increases the numbers of these organisms. Then bacteria and fungi work to help make aggregation happen.

COMPACTION

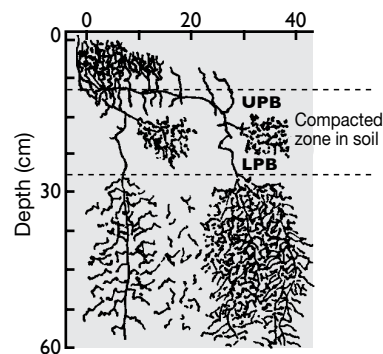
When soil has poor structure or we mistreat it, we compact the soil. A good loam soil is about 50 percent soil particles and 50 percent pore space filled with air and water (Brady 1996). When we run over the soil when it is too wet or with equipment that is too heavy, we are pushing the soil particles closer together.

ILLUSTRATION 6: SOIL AGGREGATE



Bacteria and roots produce sticky substances that glue soil particles together. Fungi and root hairs wrap soil particles into balls called aggregates.

ILLUSTRATION 7: COMPACTION REDUCES ROOT GROWTH



Roots occupy a larger soil volume in noncompacted soil layer (30–60 cm) than in compacted soil (15–30 cm). Source: Adapted by Sjoerd Duiker from Keisling, Batchelor, and Porter, "Soybean root morphology in soils with and without tillage pans in the lower Mississippi River Valley," *Journal of Plant Nutrition* 18 (1995): 373–84.

As a result, the pores are small and can hold less air and water for plants. When soils become extremely compacted, roots can no longer penetrate the soil. Compacted soils have fewer and smaller roots. In a normal soil, crop roots are only in contact with less than 1 percent of the total soil volume. The roots have to be able to continually grow and explore to find new nutrient reserves, and water needs to be able to move easily through the soil where it can reach roots and wash nutrients to where roots are. Compaction not only directly affects root growth, it also reduces the amount of air-filled pores and thus oxygen in the soil. The increase in carbon dioxide (CO_2) in relation to oxygen can be toxic to plant roots. For more information see Duiker publications listed in References.

Managing soil compaction can be achieved through appropriate application of some or all of the following techniques: (a) adding organic matter; (b) controlling traffic; (c) mechanically loosening (e.g., deep ripping); and (d) selecting a rotation that includes crops with strong taproots able to penetrate and break down compacted soils. Deep ripping can reduce compaction initially. Unfortunately, unless it is combined with additions of organic matter or reduction in traffic, the benefits of ripping may only be seen for one to two years before the soil settles and recompact.

WATER-HOLDING CAPACITY

High-quality soils have a high available water-holding capacity.

Plants are like people, right? They need food, water, and oxygen to grow. Soils with a high available water-holding capacity have a larger reservoir and can supply water over time when plants need it. Technically, a soil's available water-holding capacity is the amount of water the soil can hold between field capacity (after gravity has drained the soil) and the permanent wilting point. So what is field capacity? Imagine you just had a heavy rain that fully saturated the soil. Then you wait two days just until the point that the soil has stopped draining. That is field capacity. The permanent wilting point is defined as the soil moisture level at which a wilted plant cannot recover even after 12 hours in a remoistened soil. So, available water-holding capacity is the amount of water a soil can hold between the time it is fully saturated but drained and when it is so dry that plants die.

Clay and sandy soils will have different water-holding capacities. The available water-holding capacity is an indicator of how much water the soil can store. Sandy soils often cannot store as much water for crops between rains.



Soil compaction causes reduced infiltration. Source: Duiker, *Effects of Soil Compaction* (University Park: Penn State Extension, 2004).

ILLUSTRATION 8: PLANT GROWTH IS LIMITED IN COMPACTED SOILS.

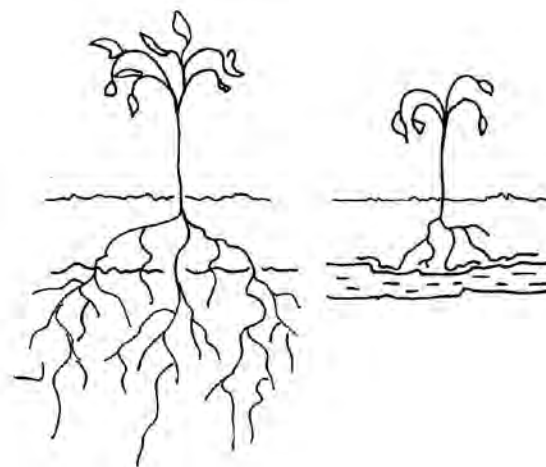
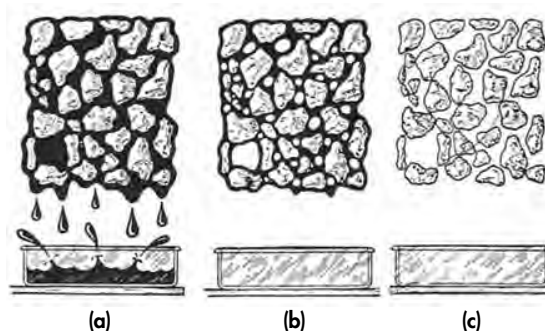


ILLUSTRATION 9: WATER-HOLDING CAPACITY



- (a) Saturated soil
 (b) Field capacity
 (c) Permanent wilting point

The water-holding capacity is the amount of water in soil field capacity (b) minus wilting point (c).

How Can I Improve Its Water-Holding Capacity?

The addition of organic matter to soils either from manure, compost, or cover crops can improve the soil's capacity to hold water. In the short term, you may want to consider adding stable organic materials like compost or crop residue high in lignin or cover crops high in carbon. In the long term, rotation to sod and reduced tillage are known to help.

ORGANIC MATTER

Soil organic matter (SOM) is a complex of diverse components, including plant and animal residues, living and dead soil microorganisms, and substances produced by these organisms and their decomposition. SOM influences the chemical, biological, and physical properties of the soil in ways that are almost universally beneficial to crop production. The most common sources of SOM in farming are crop residues, cover crop residues, manures, and composts.

Why Is Soil Organic Matter So Important?

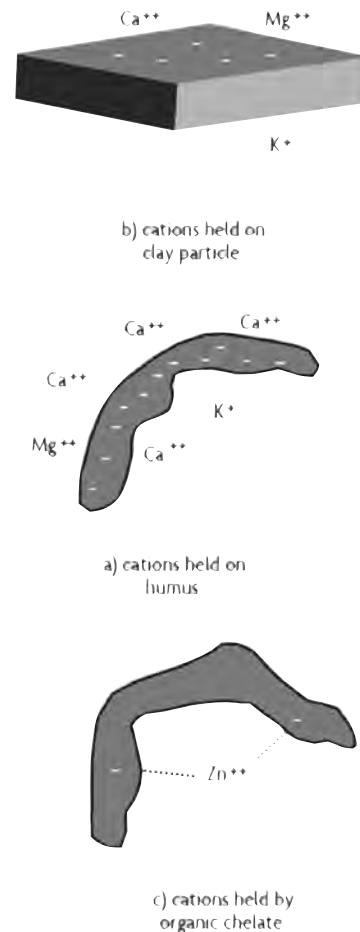
This tiny fraction of the soil volume (agricultural soils average 1–6 percent) has an overwhelming influence on most other soil properties. Often classified as “the living, the dead, and the very dead,” it is composed of three components: living organisms, fresh residue, and well-decomposed residue. Each of these components contributes to the vital functions of soil.

Bacteria, fungi, protozoa, earthworms, tiny insects, and other organisms form the living fraction of soil organic matter. Much to the surprise of anyone who considers soil to be dead dirt, living organisms compose about 15 percent of total soil organic matter, weighing between 2,000 and 30,000 pounds per acre (Gugino 2007; Brady 1996). This live fraction of the soil does a host of functions described below.

The second fraction of soil organic matter is the “dead”—fresh residues that have been recently added to soil. This is active, easily decomposed material that provides the fuel for soil organisms. When fresh SOM is added to the soil, most of it decays to CO_2 , water, and minerals within a few months to years. This process provides energy (e.g., via respiration) for soil microbes and mineral nutrients for both microbes and plants (e.g., crops). Just like cornflakes provide sugar and carbohydrates for humans, decaying leaves, manure, and plant roots provide sugars and carbohydrates for bacteria, fungi, and the soil food web.

Some soil organic matter is very resistant to (further) decay and can last (often bound tightly to clay particles) for hundreds of years. This very stable form of SOM is commonly referred to as humus. In fact, the average humus particle is one thousand years old. Humus is typically about 70 percent of the

ILLUSTRATION 10: ORGANIC MATTER HOLDS NUTRIENTS



Cations held on negatively charged organic matter and clay. Source: Magdoff and van Es, *Building Soils for Better Crops* (Beltsville, Md.: Sustainable Agriculture Research and Education Program, 2009), 15.

total SOM in agricultural soils. Humus, in particular, and SOM, in general, are important in enhancing soil nutrient-holding (especially cation) and water-holding capacities, soil structure and tilth, and general fertility (see Illustration 10). Organic matter management is an important part of farming, but our understanding of it is quite elementary. We know that soil fertility tends to increase with increasing SOM and that continual depletion of SOM eventually leads to very poor soils.

SOIL BIOTA

The soil is alive. In just one teaspoon of agricultural soil there can be one hundred million to one billion bacteria, six to nine feet of fungal strands put end to end, several thousand flagellates and amoeba, one to several hundred ciliates, hundreds of nematodes, up to one hundred tiny soil insects, and five or more earthworms. These organisms are essential for healthy growth of your plants.

For example, tiny insects in the soil rip and shred leaves and other organic material, breaking it down into smaller pieces that are then consumed by bacteria and fungi. These bacteria and fungi excrete sticky substances that hold the soil together into aggregates and provide food for an entire web of organisms in the soil. When these bacteria and fungi are consumed by other soil organisms, like the microscopic worms called nematodes, the nematodes excrete ammonia, an important source of nitrogen for plants.

Adding organic matter to soil is essential for all these soil organisms. Cover crops, leaves, compost, and other organic materials that we add to soil are food for these organisms. Which type of organic material we add to the soil changes which type of organisms will have the largest numbers. For example, adding material very high in carbon will encourage fungi that excrete enzymes such as chitinase, which can break down tough-to-digest material.

REFERENCES

- Brady, N. C., and R. R. Weil. *The Nature and Properties of Soils*. 11th ed. Upper Saddle River, N.J.: Prentice Hall, 1996.
- Doran, J. W., et al. *Defining Soil Quality for a Sustainable Environment*. Madison, Wis.: Soil Science Society of America, 1994.
- Duiker, S. W. *Avoiding Soil Compaction*. University Park: Penn State Extension, 2004.
- . *Diagnosing Soil Compaction Using a Penetrometer (Soil Compaction Tester): Agronomy Facts 63*. University Park: Penn State Extension, 2002.
- . *Effects of Soil Compaction*. University Park: Penn State Extension, 2004.
- Food and Agriculture Organization of the United Nations (FAO). *Farmer Field Schools: The Soil System*. 2007.
- Gugino, B. K., et al. *Soil Health Training Manual*. Ithaca: Cornell University, 2007.
- Magdoff, F., and H. M. van Es. *Building Soils for Better Crops*. Beltsville, Md.: Sustainable Agriculture Research and Education Program, 2009.
- Russell, E. "Soil Texture Descriptions." In *Teaching Organic Farming and Gardening*, edited by A. Miles and M. Brown. Santa Cruz: University of California, 2005.
- USDA. "Soil Quality Concepts." soils.usda.gov/sqi/concepts/concepts.html.

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