

CHAPTER 3

Soil Health

JOHN LAMB
SHERI HUERD
KRISTINE MONCADA

Soil is a natural mix of weathered rock and organic matter that forms on the Earth's surface. It is the foundation for all crop production. It is biologically active and home to a wide range of living organisms including soil microbes, earthworms, and growing plant roots. Soil is composed of minerals, air, water, and organic matter that are important for healthy plant growth. The ability of soil to provide essential nutrients is called fertility. This chapter reviews some of the general properties of soil, soil conservation, and plant nutrient needs.

Soil Profile

A soil profile consists of a number of horizontal layers, or horizons in a vertical arrangement down from



LYNN BETTS, NRC

Figure 3-1. *The topsoil contains most of the plant roots, organic matter and plant nutrients that are present in soil.*

the soil surface. The top layer is usually an A (mineral), or O (organic matter) horizon that overlays the A horizon (Figure 3-2). The A horizon, considered the topsoil, is the darkest, contains the most organic matter, is biologically active, and has the most available nutrients for plant growth (Figure

3-3). Most tillage operations affect the A horizon. Its depth will vary depending on the history of its formation and recent use. Most plant roots are in the top foot of soil; however, some crops like alfalfa have roots that penetrate to lower levels of the soil profile.

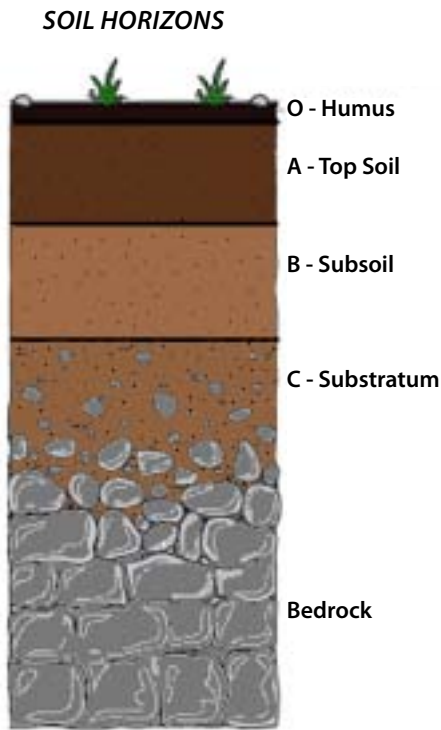


Figure 3-2. Horizons of a soil profile.

Soil organisms

Healthy soils contain numerous living organisms that affect soil structure and nutrient cycling. These microorganisms live in the rhizosphere, or root zone, the area of partnership between plant roots, soil, and soil organisms.

There are three broad groups of below-ground organisms—microfauna, mesofauna, and macrofauna. Microfauna are a huge, microscopic class that includes protozoa and fungi (primary agents of organic matter decay; bind soil aggregates), actinomycetes (decomposers of organic matter; the ‘smell’ of soil), and bacteria (decomposition of organic and inorganic material, fixation of nitrogen). Mesofauna (nematodes and rotifers) help regulate microbial populations.

Agricultural soil can have a surprising number of microfauna and mesofauna (Table 3-1). Macrofauna (earthworms, insects) accelerate organic matter decomposition, mix organic matter and soil together, and aerate the soil by channeling and burrowing.

Some soil organisms such as insects (e.g. corn root worm) and plant disease pathogens (e.g. seed rotting fungi) can be harmful to crops, but some bacteria (rhizobia) and fungi (mycorrhizae) associated with roots are beneficial. Other bacteria and fungi are responsible for essential soil processes like plant residue degradation and nitrogen mineralization from organic matter. Earthworms are a positive indicator of soil quality and productivity. Reduced tillage systems have more earthworms than conventional tillage systems. Likewise, other beneficial organisms can be promoted through organic practices.

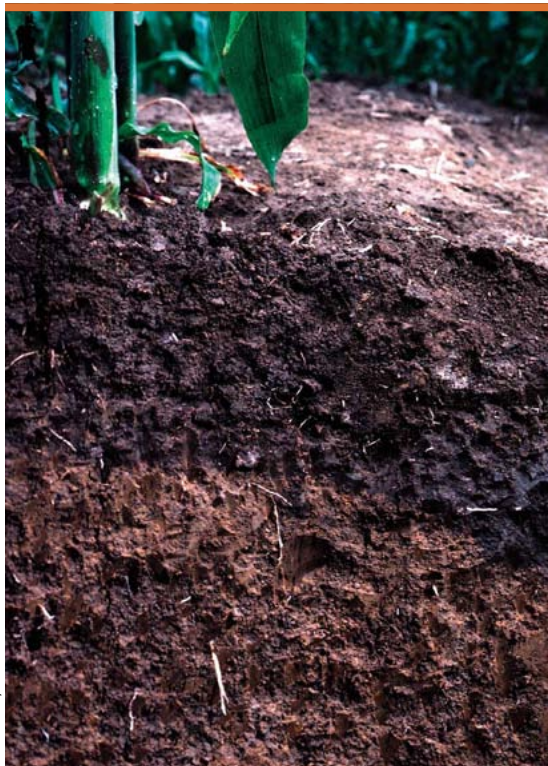


Figure 3-3. Soil profile in central Iowa shows the dark color of the topsoil (A horizon).

Table 3-1. Number of organisms in topsoil.

SOIL ORGANISM	Number per gram of soil (dry weight)
Bacteria	100,000,000 to 1,000,000,000
Actinomycetes	10,000,000 to 100,000,000
Fungi	100,000 to 1,000,000
Protozoa	10,000 to 100,000
Nematodes	10 to 100

LYNN BETTS, NRCS

Reducing risk: soil organisms. Earthworm and other beneficial soil organism populations can be increased by reduced tillage, increasing crop residues, and diverse crop rotations including perennial forages.

Soil Properties

Soil has many physical and chemical properties. Some are changeable, while others are difficult or impossible to adjust. Texture, structure, drainage, and organic matter content are physical properties. Soil also has many chemical properties that affect plant growth, including cation exchange capacity and pH.

SOIL TEXTURE

Texture is determined by the proportion of sand, silt and clay. These fractions vary greatly in size (Table 3-2). Soil texture affects soil physical, chemical, and biological properties (Table 3-3).

Table 3-2. Soil particle sizes.

PARTICLE	DIAMETER
Sand	0.05-2 mm
Silt	0.002-0.05 mm
Clay	<0.002 mm

UNIVERSITY OF MINNESOTA EXTENSION.

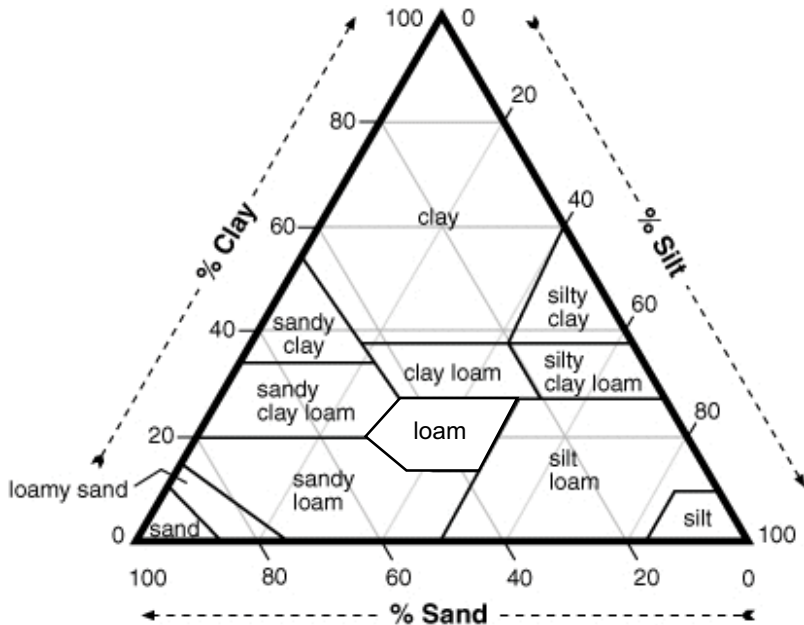


Figure 3-4. Soil textural triangle. The proportion of clay, silt, and sand particles determines soil texture.

Water-holding capacity is an important soil property influenced by texture. Soil water fills small spaces around the soil particles. Sandy soils have a large pore space between particles and hold less water than clay soils. Clay soils have the greatest water

content at field capacity. Plant available water is greatest in silt loam and silty clay loam soils. Although farmers cannot change soil texture, knowing soil texture can aid decisions regarding crop selection, use of landscape position/site aspect, manure man-

Table 3-3. The relative amounts of each soil particle influence soil properties.

PROPERTY	SAND	SILT	CLAY
Porosity	Low	Moderate	High
Infiltration rate	High	Moderate	Low
Good drainage	High	Moderate	Low
Aeration	High	Moderate	Low
CEC	Low	Moderate	High
Storing plant nutrients	Low	Moderate	High
Resistance to pH change	Low	Moderate	High
Organic matter level	Low	Moderate	High
Compactibility	Low	Moderate	High
Good root penetration	High	Moderate	Low
Ease of cultivation	High	Moderate	Low
Suitability for tillage after rain	High	Moderate	Low
Warm-up in spring	High	Moderate	Low
Susceptibility to wind erosion	Moderate	High	Low
Susceptibility to water erosion	Low	High	Low

agement, tillage equipment, and planting dates. Soil texture can be determined by feel (see <http://soils.usda.gov/education/resources/lessons/texture/>) or by a soil testing laboratory. Soil texture categories are described using the textural triangle and knowledge about the relative proportion of sand, silt, and clay (Figure 3-4).

 **Reducing risk: soil texture.** Soil texture cannot be changed by management but texture should influence crop and soil management decisions.

SOIL DRAINAGE

Some soils are poorly drained because of their texture, the landscape position, and the height of the water table. Poorly drained soils tend to be cooler in the spring and they may limit plant root growth because of lack of aeration. Drainage is affected by soil texture. Sandy soils are well-drained and retain less moisture. Clay soils can be poorly drained and lack aeration, which negatively impacts plant growth. Subsurface tiling is a practice to enhance drainage and promote soil aeration. See regional publications such as *Planning an Ag-*

ricultural Subsurface Drainage System <http://www.extension.umn.edu/distribution/cropsystems/components/07685.pdf>.

 **Reducing risk: soil drainage.** Ensure that drain tiles are properly installed to maximize their efficiency while protecting water resources. Soil tillage and crop management practices should take into account soil drainage.

SOIL STRUCTURE

Soil structure refers to the clustering of soil particles into larger masses called aggregates, which are held together by organic matter. These aggregates vary in size and provide a configuration for soil pores that allow air and water to occupy space. Soil structure is fragile and can be damaged by compaction, excessive tilling, tilling when the soil is too wet, and loss of organic matter. Soils that are primarily clay or that have been damaged by excessive compaction do not have good soil structure, are impermeable to water, and are hard to till. Soils compacted by excessive traffic and tillage do not allow for penetration of roots or movement of water. A soil with a good



A producer from Redwood County says that since going organic, his soil is easier to plow. Another producer, also from Redwood County, described how his son bought a new farm that was conventionally farmed. He thought something was wrong with it because he had to go one gear down on the tractor because the soil was of poor tilth.

structure is well-aerated and has good ‘tilth’. Tilth refers to soil having beneficial qualities related to crop growth. A soil with good tilth will have high organic matter, high aggregation, and low compaction (Figure 3-5).

 **Reducing risk: soil structure.** Hard pans or compaction zones can develop in portions of the soil profile in some soils because of excessive tillage or harvest of wet soils. Although compaction does not occur on all soils, to reduce the risk of compaction it is best to avoid use of heavy machinery and tillage in wet soils.

SOIL ORGANIC MATTER

Soil organic matter is promoted by diverse rotations, crop residue, cover crops and conserva-



Figure 3-5. Three soil profiles. The dark-colored soil on the left has good tilth and is productive. The two soils on the right have been eroded.

tion tillage. Organic matter is beneficial to agricultural soils because it enhances soil water holding capacity, water infiltration, fertility, and microbial activity.

Farming techniques that preserve and improve organic matter content promote long-term soil fertility and produce healthy crops. Organic matter is derived through the decomposition of plant residues, manures, and soil

organisms. Soil organic matter is a source of both macronutrients like nitrogen and phosphorus, as well as micronutrients including iron, copper, and zinc. Organic matter contains 95 percent of all soil N. Fertile soils contain 3-6 percent organic content, with a good goal around 4 percent. There are several ways to increase the level of organic matter in the soil (Table 3-4).

Humus, or stable organic matter, is a product in the decomposition process. Humus confers a dark color, aggregation, crumbly structure, and characteristic ‘earthy’ smell of soil. Decomposition of humus leads to release of plant nutrients. Thus, humus provides long-term nutrient reserves (Table 3-5). It also improves structure and increases cation-exchange capacity.

Table 3-4. Ways to increase organic matter in cropping systems:

- ✓ Use grains and grasses as green manures
- ✓ Keep crop residue/stubble on fields
- ✓ Use grains, grasses, and perennial forages in crop rotation
- ✓ Minimize tillage
- ✓ Reduce bare soil
- ✓ Compost or manure additions
- ✓ Use cover crops
- ✓ Minimize soil erosion

Table 3-5. Functions of humus:

- ✓ Supplies plant nutrients, especially N, P, and S
- ✓ Holds nutrients, thus reduces leaching
- ✓ Increases tilth of heavy soils
- ✓ Binds soil particles together, thus reduces soil erosion
- ✓ Improves porosity, increases air and water movement through soil
- ✓ Increases soil water-holding capacity
- ✓ Provides nutrients to soil micro-organisms



Reducing risk: soil organic matter. Add organic matter to soil through diverse rotations which includes perennial crops. Allow crop residue to remain on the soil surface. Utilize green manures and cover crops. Conservation tillage practices that leave greater than 30 percent residue on the soil surface will over time increase the soil organic fraction. Moldboard tillage will result in the greater loss of soil organic matter compared to chisel plowing and conservation tillage.

CATION EXCHANGE CAPACITY

Cation exchange capacity (CEC) describes the amount of exchangeable cations (positively charged ions such as H⁺, K⁺,

Table 3-6. Cation exchange capacity values for different soil types

SOIL TYPE	CEC (MEQ/100G)
Sand	1 - 5
Fine sandy	5 - 10
Loam	5 - 15
Silty loam	15 - 25
Clay loam	30 - 35
Clay	> 35
Organic	50 - 100

Ca⁺⁺, Mg⁺⁺) a soil can hold. Chemically, CEC is the negative surface charge of small, crystal-line clay particles and organic matter in the soil (Figure 3-6). CEC is used by some as a measure of the potential fertility of a soil (Table 3-6); however, the CEC capacity of most soils in the Midwest is adequate and not to be a factor limiting fertility.

pH

Soil pH describes the concentration of hydrogen ions (H⁺) in a soil. The pH scale runs from 0 to 14. A pH of 7 is neutral, less than 7 is acidic, and greater than 7 is alkaline or basic. Soil pH is critical because plants vary in the required pH range for best growth and yields. Most important field crops grow best at a pH of 6–7. Additionally, pH influences the availability of nutrients to plants. A soil pH of below 5.5 or above 7.3 may limit phosphorus available to plants even though soil phosphorus levels are adequate. Low soil pH may cause toxic levels of available aluminum

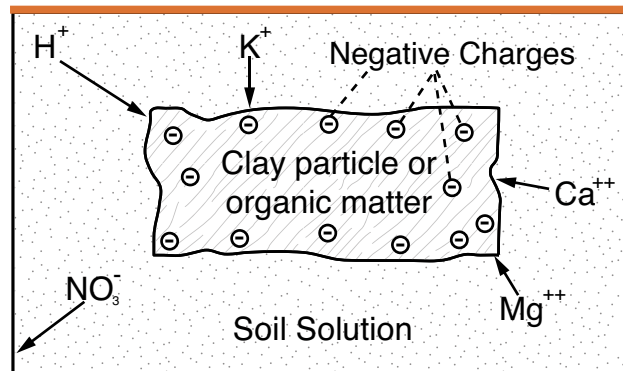


Figure 3-6. Clay particles and organic matter in soil are negatively charged, so their surfaces attract positively charged ions such as K⁺, Ca⁺⁺, and H⁺. The negatively charged nitrate ion (NO₃⁻) is not attracted.

and manganese in the soil. Additionally, pH affects the growth of beneficial soil organisms that facilitate biological nitrogen fixation with legumes and of microbes mineralizing nitrogen from organic matter.

Reducing risk: pH. Adjust pH as necessary (see pH adjustment in Chapter 4)

Conduct regular soil testing. Be familiar with the pH requirements of your crops.

SOIL CLASSIFICATION

Soils throughout the United States are classified using a standard system. The classification is based on several factors including soil properties, geographical location, type of native vegetation, and topographical position. The system used to classify soils based on their properties is called Soil Taxonomy. The system is a

collaborative effort of the U.S. Department of Agriculture and University faculty from throughout the United States. Soil classification is valuable because it describes the characteristics of individual soils, defines relationships between soils, and also describes properties related to specific uses.

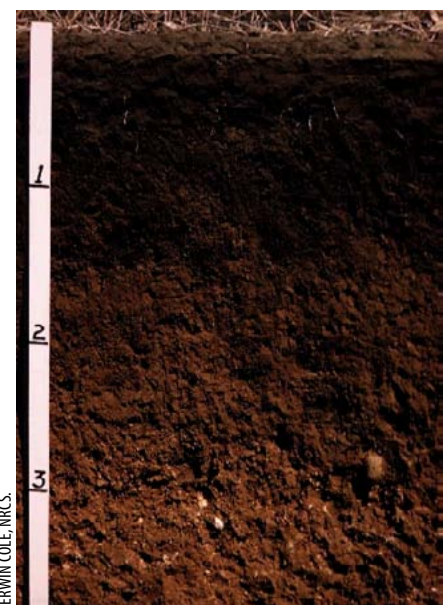


Figure 3-7. Soil profile of Clarion soil, one of Minnesota's soil series.

SOIL QUALITY

Soil quality and soil health are very general terms but generally describe a soil's potential for long-term productivity. Building healthy soils is a long-term process. Fortunately, organic soil management practices are designed to develop fertile soils with good tilth that will support crop health. According to National Organic Program regulations (205.203), organic producers must:

- ✓ Implement sustainable tillage and cultivation practices that

improve or maintain the soil and minimize erosion.

- ✓ Manage fertility through rotations, cover crops, and organic amendments.
- ✓ Not contribute to soil, water, or crop contamination through use of amendments.

Organic farmers realize the importance of maintaining soil quality on their land and are proud of the soil improvements that their production methods

generate. Most consider stewardship of the land critical to their vocation.

Reducing risk: soil quality. Follow NOP rules on soil management. Check with certifier about a soil management plan, particularly when using amendments.

WEB SOIL SURVEY

The Natural Resource Conservation Service has a valuable database program for producers called the Web Soil Survey. Producers can map the soils on their farms and learn about the suitability of the soil types. For example, Figure 3-8 shows research plots near the University of Minnesota's St. Paul campus. This area consists of primarily a Waukegan silt loam (411 and 411b). The report describes the soil and some of its attributes like parent material, drainage class, profile, and available water capacity. For more information, visit <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>



Figure 3-8. Soil map of the research plots.

Conservation tillage

Conservation tillage is any tillage practice that leaves the soil with greater than 30 percent ground cover after spring planting. Residue is especially important to have on the soil during early spring when the probability for soil erosion and nutrient runoff is high. Newly planted crops do not offer much protection until later in the season and in the spring the soil moisture is generally at capacity. Residue that remains on the soil during this time will reduce soil erosion. One drawback to conservation tillage is that the residue will result in slower soil warm-up in spring, which can delay planting. At the same time, residue can preserve soil moisture when it is lacking.

Reducing the intensity of tillage is another aspect of conservation tillage (Figure 3-9). Fewer tillage operations and/or less aggressive types of tillage can lead to better soil structure, increased moisture infiltration, less soil compaction, increased soil organic matter, and increased biological activity.

Ways to reduce risk in conservation tillage systems (adapted from DeJong-Hughes, 2008) include:

- ✓ Use harvesting equipment like chaff spreaders or choppers that evenly spread residue to prevent overly thick mounds of residue that hamper spring planting
- ✓ Add a residue manager to your planter
- ✓ Plant with a reduced tillage planter to increase plant populations



TIM MCCABE, NRCS

Figure 3-9. Conservation tillage.

PLANT FERTILITY NEEDS

Essential elements are those that are necessary for a plant to complete its growth cycle, whose functions cannot be replaced by other elements, and that are components of a molecule or an enzyme within the plant. Minerals in the soil provide many of the essential nutrients for plant growth. Based on their average concentrations in plant tissue, elements are classified as either macronutrients or micronutrients (Table 3-7).

MACRONUTRIENTS

Macronutrients include carbon, hydrogen, oxygen, nitrogen, phosphorous, potassium, calcium, magnesium, and sulfur. Plants obtain carbon, oxygen, and hydrogen from the air and the other nutrients from the soil.

Table 3-7. Macronutrients and micronutrient functions in plants. Other macronutrients include carbon, oxygen, and hydrogen, which plants obtain from the air.

CATEGORY	ELEMENT	INVOLVED IN:
Primary macronutrients	Nitrogen	Proteins, nucleic acids, coenzymes, chlorophyll
	Phosphorus	ATP, nucleic acids, proteins, phospholipids
	Potassium	Enzyme activation, stomata movement, meristems
Secondary macronutrients	Sulfur	Amino acids, coenzymes
	Calcium	Movement of substances through cell membranes, enzymes
	Magnesium	Chlorophyll, enzymes
Micronutrients	Iron	Photosynthesis, oxygen transport
	Manganese	Enzymes
	Copper	Metabolism, photosynthesis
	Zinc	Auxin, enzymes
	Boron	Sugar movement, RNA and DNA synthesis
	Molybdenum	Nitrogen fixation, metabolism, chloroplasts
	Chlorine	Photosynthesis

Nitrogen, phosphorus, and potassium are often added to soils through amendments.

Nitrogen

Nitrogen is the most common nutrient limiting growth and production of many crops especially grasses like corn and small grains. Its effect on vegetative (leaf and stem) growth are pronounced and later impact grain formation. Legumes like alfalfa and soybean that form a symbiotic relationship with soil *Rhizobium* have potential for conversion of atmospheric N to amino acid forms and therefore should not require nitrogen fertilizers (Table 3-8). Most of the N in the soil is

in organic forms. Plants cannot use atmospheric N or organic N in the soil, but take up N mostly as nitrate (NO₃⁻) or ammonium (NH₄⁺). Nitrate or ammonium are supplied by mineralization of organic matter, manures, or fertilizers. Nitrogen is mobile in the plant and symptoms of nitrogen deficiency in grasses include yellowing of older leaves as N is translocated to the growing points (Figure 3-10). While most plants (except legumes) respond to N fertilization, excessive fertilization beyond crop needs can lead to nitrogen loss from the soil through leaching. In addition, excessive N fertilization can cause crop lodging.



R.L. CROISSANT, COLORADO STATE UNIVERSITY

Figure 3-10. Leaves from nitrogen-deficient corn.

Table 3-8. The amount of nitrogen fixed by various legume species. Adapted from Sheaffer et al., 2003.

NITROGEN FIXED PER YEAR	
LEGUME	N FIXED (lbs/ac)
Alfalfa	70-200
Birdsfoot trefoil	44-150
Crownvetch	98
Cicer milkvetch	140
Crimson clover	57
Hairy vetch	99
Kura clover	17-158
Lentil	149-168
Red clover	60-200
Soybean	20-200
Sub clover	52-163
Sweetclover	120
White clover	115-180

Table 3-9. Possible nutrient deficiencies in Minnesota soils.*Adapted from Rehm et al, 1989, 1994, 1997 and 2002.*

NUTRIENT	SOILS WITH POSSIBLE DEFICIENCY	LOCATION IN MINNESOTA	CROP WITH POSSIBLE DEFICIENCY
Calcium	Sandy, acid, or dry soils	Not an issue for most of MN	Various
Sulfur	Sandy soils	See Figure 3-12	Brassicas, others
Magnesium	Sandy, acidic or excess K soils	Central, east-central	Various
Zinc	Fine-textured or excess P soils	West	Corn, beans
Copper	Organic soils	North	Small grains
Boron	Low organic matter soils	See Figure 3-13	Alfalfa, clovers

Phosphorous

Phosphorous has many roles in crop growth. Phosphorous increases seed production, increases winter survival (especially of legumes), stimulates root growth, promotes early maturity of crops, and produces strong stalks. Symptoms of phosphorus deficiency include purplish leaves and stunted growth (Figure 3-11).

Potassium

Potassium is especially important for crops with extensive root systems (e.g. legumes, tomatoes, potatoes). It is needed for photosynthesis, fruit formation, winter

hardiness, disease resistance, stalk strength, legume competitiveness, and increased microbial activity including nitrogen fixation. Symptoms of potassium deficiency in grasses include yellowing of leaf margins. Other crops like alfalfa display a white spotting on the leaves.

Sulfur, Calcium, and Magnesium

Sulfur, calcium, and magnesium are called secondary macronutrients because they are taken up in smaller quantities compared to nitrogen, phosphorus, and potassium.

Legumes require sulfur for nitrogen fixation and brassicas require sulfur for oil and protein formation. Sulfur deficiency symptoms include yellowing of leaves and light green foliage. Magnesium is part of chlorophyll and deficiency of this nutrient can lead to stunted growth. Calcium is contained in cell walls and deficiency will be seen in the new growth, which will fail to develop normally. Many soils in some areas have deficiencies in secondary macronutrients. For example, sulfur, calcium, and magnesium are generally not limiting in soils in Minnesota, except on sandy and/or acidic soils (Table 3-9 and Figure 3-12). The main sources for these nutrients are discussed in Chapter 4.

MICRONUTRIENTS

Micronutrients are needed in smaller quantities in plants than macronutrients and deficiencies are usually less widespread. These include iron, manganese, copper, zinc, boron, molybdenum, nickel, and chlorine.



Figure 3-11. The purplish leaves of phosphorus-deficient corn.

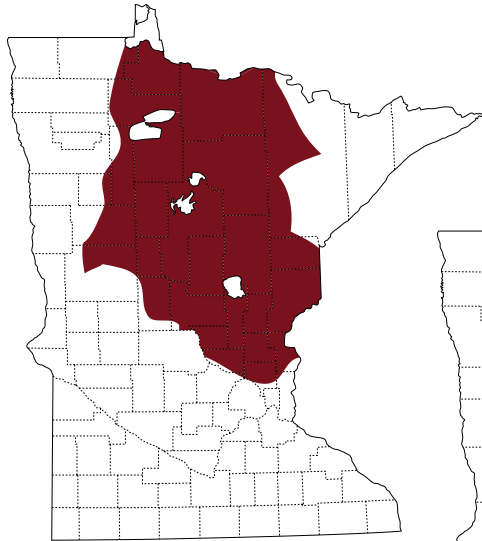



Figure 3-12. Possible sulfur-deficient soils (in red). Adapted from Rehm and Schmitt, 1989.

Potential micronutrient deficiencies can be dependent on soils and environment. See Table 3-9 and Figure 3-13 for examples of micronutrient deficiencies in Minnesota. Micronutrients can be added by compost, kelp, and other amendments on soils where deficiencies occur, but generally the use of manure and compost will supply adequate levels. Excessive use of micronutrients above those needed by plants can cause toxicities.

Reducing risk:
 **macronutrients and micronutrients. Test soil annually at the same time each year. Macronutrient and micronutrient tests may not be necessary when farming a soil in a region where nutrient deficiencies do not normally occur.**

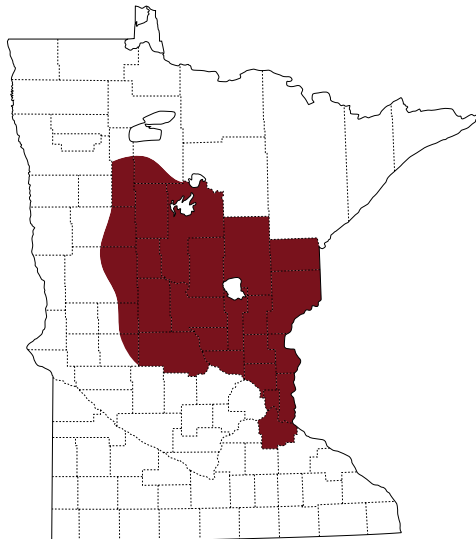


Figure 3-13. Possible boron-deficient soils (in red). Adapted from Rehm et al, 2002.

Soil testing

Routine soil nutrient monitoring is a key to successful soil fertility management. Soil testing involves sampling the soil and analyzing the pH and nutrient content. Monitoring changes in soil nutrient status over time will allow evaluation of crop production and fertilization effects on crop yields. For manure and compost application, testing prevents over-application which can contaminate the environment and increase farmer fuel/labor costs.

WHEN TO TEST AND HOW OFTEN

Soils can be sampled for pH, P, K, and micronutrients at any time during the year. Samples for nitrogen analysis should be taken when temperatures are below 50° F, usually in mid-to-late October in Minnesota. Fall also gives enough time to prepare for spring by making changes in management by applying amendments or making rotation changes. Consistency of timing soil sampling from year to year is important for noting trends; for example, spring samples may have higher nutrient values compared to fall.

For routine soil testing, farmers should develop a plan so that the whole farm gets soil tested over a three-to-five-year period.

TAKING SAMPLES

Taking a representative soil sample is a critical first step in soil testing. Directions for taking a sample may be different depending on the nutrient tested. For example, nutrient concentrations can vary with soil depth so instructions may vary for which depth to sample for different nutrients.

Each soil sample should be a composite of 15 to 30 subsample cores taken from different spots on a field in order to represent the

entire field. Sampling should be avoided at field edges (especially near gravel roads), eroded areas, and low spots. If a part of the field varies significantly in soil properties from the rest of the field, it should be sampled separately. If the site to be tested is

uniform, one sample can be taken for up to 20 acres. Otherwise, for non-uniform sites, one sample can represent 5 acres.

In taking the sample in the field, the soil surface residue should be scraped off, so as not to include crop residue or unincorpo-

rated manure. Sampling should be done in a zigzag pattern. Sample to a 6 to 8 inch depth for pH, P, K, and organic matter and sample to a two-foot depth for nitrate. The cores should be thoroughly mixed in a clean container. If wet soil is sampled, it needs to be dried before mixing and sending to the lab. Provide the quantity of soil that the soil laboratory requests or as much is needed to fill the sample bag or box. Producers should completely fill out the soil sample information sheet as specified by the laboratory. Sending samples to the same lab each year also provides consistent results that show changes in soil nutrient status in the same field from year to year.

Conventional soil testing for organic producers

Some organic producers may question the relevance of using soil tests geared to conventional systems because fertilizer recommendations do not directly translate to organic systems. Some have said that in their experience, yields did not suffer as predicted due to lack of nutrients that soil tests may indicate. Soil testing lab recommendations are focused on the fertilizers used in conventional systems rather than slow release organic compounds, so simple substitutions for organic systems are not available. Organic systems are more complex and producers primarily obtain nutrients released from decomposition of soil organic matter, manures, and crop residue. However, conventional soil testing and the resulting recommendations based on variable yield goals is based on years of research and still has considerable value in developing a soil fertility program. (Table 3-10).

Alternative soil laboratories that follow various soil philosophies exist; visit ATTRA's website for information <http://attra.ncat.org/attra-pub/soil-lab.html>.

Table 3-10. Benefits of conventional soil testing.


Adapted from Phillips, 2009.

- Develops baseline figures to evaluate trends; results will be relative
- pH and organic matter, included in standard soil testing, are important factors for organic producers, regardless of the laboratory source
- Helps avoid nutrient loading due to manure and compost
- Required by some certifiers
- Conventional laboratories often have a long history of operation and can provide consistent results
- Conventional testing is just one tool of several organic producers can use to monitor soil health
- Local laboratories will have results adapted to regional soils
- University laboratories have reasonable prices

INTERPRETING RESULTS

A basic soil test will provide information on soil texture, organic matter, pH, buffer index, phosphorus, potassium and nitrate. Most soil tests will give a range for the nutrients, such as low, medium, and high, to give an indication of relative amounts of nutrients in the soil. When a nutrient is in the low range, it means that added inputs of that nutrient will likely show a strong growth response in the next crop planted. A conventional soil laboratory will provide fertilizer recommendations based on the next crop

to be grown and yield goals. Table 3-11 shows actions organic producers can take based on basic soil test results.

 **Reducing risk: soil testing.** Follow soil laboratory instructions for taking representative samples to the proper depth. Use the recommendations based on the testing results to make input decisions.

TIM MCCABE, NRCS



Figure 3-14. Soil sampling in spring.

Table 3-11. Actions for organic producers to take based on basic soil test results.

SOIL TEST	RESULT	ACTION	
		SHORT TERM	LONG TERM
Soil texture	Various	Texture will not be changeable; choose adapted crops	Texture will not be changeable
Organic matter	Low	Building organic matter is a long term process	Manage soil to promote organic matter retention and to increase organic matter by following practices as outlined in Table 3-4
	High	None	Maintain current soil management practices
pH, buffer index	Low	Verify that next crop to be planted is suitable for existing pH; follow laboratory lime recommendations using NOP-approved amendments	Monitor pH and plan for future lime additions as needed
	High	Verify that next crop to be planted is suitable for existing pH	Monitor pH
Phosphorus	Low	Add compost, manure or NOP-approved amendment (See Tables 4-16 & 4-17.)	Monitor phosphorus levels
	High	If overly high, consider not using compost and manure which can lead to phosphorus loading; if other nutrients are deficient, use amendments without P	Monitor phosphorus levels and ensure that there are not too many additions of phosphorus; include green manures in rotation; minimize soil erosion to reduce leaching
Potassium	Low	If low, add compost, manure or NOP-approved amendment (See Tables 4-16 & 4-17.)	Monitor potassium levels
Nitrate	Low	If low, add compost, manure or NOP-approved amendment (See Tables 4-16 & 4-17.)	Monitor nitrogen levels; add green manures to rotation

PRODUCER PROFILE

An organic producer from Lac Qui Parle discusses how he uses soil testing in his fertility management. He says the part of the analysis he pays most attention to are the nitrogen, phosphorus, potassium, pH and organic matter results. When he has questions on other details (like cation exchange capacity), he asks a soil consultant. For his farm, he pays particular attention to phosphorus, which can have high content but low availability in his fields. As far as nitrogen is concerned, he simply expects that it will need to be supplied and uses green manures and animal manures as a regular part of his system. He will consult data on nitrogen credits and availability over the longer term for these amendments. As an established organic grower, he finds that he uses soil testing as an indication that his system is working appropriately and will adjust things only when necessary.

Conclusion

This chapter provides an overview of soil health, which can be a complex topic. See the next chapter on Soil Fertility for more information. Take the following quiz to determine your risk on soil health.

Plant analysis

Plant analysis determines the levels of specific elements present in plant tissue. It includes results for nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, zinc, and boron.

Reasons producers use this test:

1. When there is suspected nutrient deficiencies
2. To verify effectiveness of current nutrient management practices

The levels of nutrients will vary depending on crop and maturity (Table 3-12). While plant analysis can tell much about current fertility, producers should use tissue analysis in conjunction with soil testing.

Table 3-12. Nutrient sufficiency levels for various crops. *Adapted from Rehm, 2006 and others.*

		N	P	K	S	Ca	Mg	B	Cu	Fe	Mn	Zn
Growth stage		%					ppm					
Corn	Silking	2.7 to	0.2 to	1.7 to	0.1 to	0.4 to	0.2 to	4 to	3 to	50 to	20 to	50 to
		3.5	0.4	2.5	0.3	1.0	0.4	15	15	200	250	150
Soybean	Early to mid-bloom	4.26 to	0.26 to	1.71 to	0.25 to	0.36 to	0.26 to	21 to	10 to	51 to	21 to	20 to
		5.50	0.50	2.50	0.60	2.00	1.00	55	30	350	100	50
Small grains	Prior to heading	2.20 to	0.30 to	1.80 to	0.20 to	0.25 to	0.20 to	8 to	6 to	35 to	30 to	20 to
		3.50	0.50	3.00	0.30	0.45	0.40	20	15	120	60	50
Alfalfa	At bud (top 6")	2.50 to	0.25 to	2.25 to	0.25 to	0.70 to	0.25 to	25 to	3 to	30 to	20 to	20 to
		4.00	0.45	3.40	0.50	2.50	0.70	60	30	250	100	60

Quiz: Soil Quality

	Points	Score
1. Have you developed a long-term plan to manage soil quality?		
Yes	5	
No	0	
2. Do you know if your soil has high levels of macrofauna (earthworms and/or insects)?		
Yes	1	
No	0	
3. Do you know what your soil texture is?		
Yes	3	
No	0	
4. Do you adapt your management practices to account for soil texture?		
Yes	3	
No	0	
I wouldn't know how	0	
5. Do you know what your soil drainage is?		
Yes	2	
No	0	
6. Do you adapt your management practices to account for soil drainage?		
Yes	2	
No	0	
I wouldn't know how	0	
7. How many tillage operations do you perform in a given field per year?		
1 or less	5	
2	4	
3 or more	0	
8. Do you till when the soil is wet?		
Yes, sometimes unavoidable	0	
No, avoid at all costs	4	
9. Do you consider your soil well-drained?		
Yes	3	
No	0	
10. Do you consider your soil to have good tilth?		
Yes, definitely	5	
Somewhat good tilth/is improving	3	
No	0	
I don't know	0	

	Points	Score
11. Do you monitor soil organic matter?		
Yes	5	
No	0	
12. What is your soil organic matter content?		
Less than 2%	0	
2 - 3 %	2	
3 - 4%	4	
Greater than 4%	6	
I don't know	0	
13. Do your management practices maintain or increase your soil's organic matter?		
Yes	3	
No	0	
I don't know	0	
14. Which of the following practices do you use? Choose as many practices as apply. Add 1 point for each choice.		
Green manures	1	
Cover crops	1	
Diverse rotations	1	
Perennials crops	1	
Manure application	1	
Compost application	1	
Conservation tillage	1	
Leaving crop residue on field	1	
15. Do you know what your soils are classified as?		
Yes	3	
No	0	
Not sure	0	
16. Do you know and follow the NOP rules on soil management?		
Yes	7	
No	0	
Not sure	0	

TOTAL

If your score is:	Your risk is:
0-16	High
17 - 46	Moderate
47 - 65	Low

FOR MORE INFORMATION

Web Soil Survey, NRCS-USDA. <http://websoilsurvey.nrcs.usda.gov/app/>

Soil management: National Organic Program regulations. ATTRA. http://attra.ncat.org/attra-pub/PDF/organic_soil.pdf

Sustainable soil management: Soil systems guide. ATTRA. <http://attra.ncat.org/attra-pub/PDF/soilmgmt.pdf>

Soil quality: Improving how your soil works. NRCS-USDA. <http://soils.usda.gov/sqi/>

Soil testing laboratory. University of Minnesota. <http://soiltest.cfans.umn.edu/index.htm>

University of Minnesota Extension. Conservation tillage. <http://www.extension.umn.edu/topics.html?topic=4&subtopic=15>

REFERENCES

Bellows, B.C. 2005. Soil Management: National Organic Program Regulations. Appropriate Transfer of Technology to Rural Areas, National Sustainable Agriculture Information Service. http://attra.ncat.org/attra-pub/PDF/organic_soil.pdf

Birkeland, P.W. 1984. Soils and Geomorphology. Oxford University Press.

Canadian Organic Growers. 2001. Organic Field Crop Handbook, 2nd edition.

Cogger, C. 2000. Soil Management for Small Farms. EB1895. Washington State University Cooperative Extension.

Coyne, M. 1999. Soil Microbiology: An Exploratory Approach. Delmar Publishers.

DeJong-Hughes, J. 2008. Conservation tillage is a low-risk way to reduce soil erosion. University of Minnesota Extension News.

Delate, K. Soil quality in organic agriculture. Iowa State University.

Diver, S. 2002. Alternative soil testing laboratories. Appropriate Transfer of Technology to Rural Areas, National Sustainable Agriculture Information Service. <http://attra.ncat.org/attra-pub/soil-lab.html>

Kuepper. 2001. Pursuing conservation tillage systems for organic crop production. ATTRA's Organic Matters Series. http://attra.ncat.org/attra-pub/PDF/consertill_organic.pdf

Kuratomi, M., D. Allan, and E. Dyck. 2004. Long term effects of crop management: Soil quality. Results from VICMS study at the Southwest Research and Outreach Center in Lamberton, Minnesota.

Peters, J.B., K.A. Kelling, and L.G. Bundy. 2002. Sampling soils for testing. Publication A2100. University of Wisconsin Extension. <http://www.datcp.state.wi.us/arm/agriculture/land-water/conservation/nutrient-mngmt/pdf/uwex-a2100.pdf>

Phillips, E. 2009. Conventional chemical soil testing within organic systems. eOrganic, University of Illinois Extension. <http://www.extension.org/article/18566>

Rehm, G. 2006. Plant analysis in today's agriculture. Minnesota Crop News. University of Minnesota Extension.

Rehm, G. and M. Schmitt. 1997. Copper for crop production. FS-06790-GO. University of Minnesota Extension Service.

Rehm, G. and M. Schmitt. 1997. Zinc for Crop Production. Minnesota Extension Service Publication FO-0720-B.

Rehm, G. and M. Schmitt. 1989. Sulfur for Minnesota Soils. Publication AG-FO-0794. University of Minnesota Extension Service.

Rehm, G.W., W.E. Fenster, and C.J. Overdahl. 2002. Boron for Minnesota soils. University of Minnesota Extension Service. St. Paul, Minnesota.

Rehm, G., C. Rosen, and M. Schmitt. 1994. Magnesium for Crop Production in Minnesota. FO-0725-D. University of Minnesota Extension Service.

Rodale Institute. 2009. Organic Transition Course. <http://www.tritrainingcenter.org/course/>

Rosen, C. 2000. Calcium and Magnesium Management, MN-Vegetable IPM Newsletter. Vol. 2 No. 4, May 2000. <http://www.vegedge.umn.edu/mnveg-new/vol2/0505scar.htm>

Sheaffer, C.C., N.J. Ehlke, K.A. Albrecht, and P.R. Peterson. 2003. Forage Legumes: Clovers, Birdsfoot Trefoil, Cicer Milkvetch, Crownvetch and Alfalfa. 2nd edition. Minnesota Agricultural Experiment Station, University of Minnesota. Station Bulletin 608-2003.

Sheaffer, C.C. and K.M. Moncada. 2008. Chapter 11 in *Introduction to Agronomy: Food, Crops, and Environment*. Cengage Learning.

USDA-NRCS, Soil Quality Institute. March 1998. Legumes and Soil Quality. Soil Quality—Agronomy Technical Note, No. 6.