Managing the Plant and Soil Ecosystem

Plants and soil form a complex ecosystem. In terms of nutrient management we have focused primarily on managing individual nutrients such as nitrogen, phosphorus, and potassium. It is important that farmers understand that soil fertility management goes beyond just managing these nutrients. This lesson will help give you a broader understanding of soil fertility as it exists within the context of the plant and soil ecosystem.

There are many variables integrally involved in sustaining a plant.

Soil fertility is defined as the ability of a soil to provide a physical, chemical, and biological environment for plants that is health-sustaining. In order for farmers to maintain soil fertility there are six basic principles to achieve:

- Soil organic matter levels
- Biological activity
- Soil tilth
- Minimal or no erosion
- Proper soil pH
- A balance of nutrients

We will describe these principles of soil fertility and demonstrate how they are critical to supporting the plant and soil ecosystem.

What's the Big Deal About Organic Matter?

Soil fertility and many of its principles are profoundly influenced by soil organic matter (SOM). Soil organic matter is the portion of soil that is derived from decomposing plants and animals. For example, when you plow down a grass field, the leaves and roots become part of the SOM. The soil organic matter is composed of several different fractions including the living organisms, the fresh residues, and the decomposed residues.

Living Organisms. Living organisms make up about 15% of the soil organic matter. The living portion of soil includes earthworms, insects, bacteria, fungi, plant roots, and animals such as voles and moles. These organisms help break down freshly added plant residues, manures, and other organic
debris. In the process of breaking down the debris, the organisms obtain energy and nutrients and release nutrients that become available for plant uptake. This process of nutrient release is called *mineralization*. These organisms also play a role in soil aggregation and disease suppression. These functions will be addressed later.

**Composition of soil organic matter.**

**Fresh and Decomposing Residues**
The fresh and decomposing residues are another fraction of the SOM. In most soils these residues consist of 30% or less of the organic matter. Fresh residues include partially decomposed once-living organisms. These residues are generally no more than three years old. Again, as these fresh residues are decomposed by living organisms the nutrients in the fresh residues are digested. In the process, some nutrients are released to surrounding living organisms (mineralization). The relative speed of decomposition of these materials is related to the carbon to nitrogen ratio of the fresh residues added to the soil. Residues that have a high carbon to nitrogen ratio (C:N) can be slow to decompose. This is because the microorganisms require additional nitrogen to decompose the high carbon materials. Often times these amendments will result in the microorganisms "tying-up" nitrogen that would have otherwise been available to the crop. Generally, residues with a C:N ratio of 20:1 or less have enough available nitrogen for rapid decomposition. In addition, the decomposition of fresh residues will also contribute to improving soil tilth.

*Decomposing organic residues provide food for soil organisms.*
**Well Decomposed Residues**
The well decomposed residues make up the majority of the soil organic matter (75 to 80%). As you might have guessed, the well decomposed residues were at one time living organisms. These residues have been thoroughly decomposed to unrecognizable carbon compounds. Essentially, these compounds are no longer considered food for the living organisms in the soil. This fraction of organic matter carries a negative charge and is considered essential for other soil functions including the cation exchange capacity. These residues are anywhere from five to thousands of years old.

**Fertility Principle 1 —
Maintaining Soil Organic Matter Levels**

It is critical to maintain sufficient levels of organic matter in the soil. This can be a difficult task for some farms and requires a diversified approach. Essentially, organic matter can be maintained through additions of a variety of types of organic matter while simultaneously decreasing losses of organic matter from the system. On dairy farms the primary organic matter addition is manure. Other organic matter additions can occur from cover crops and crop residues. Even farms with a readily available source of organic matter must work to reduce losses of organic matter from the cropped fields. For example, crop rotations that include perennial hay crops will reduce organic matter losses. Hay crops keep the soil from eroding and also do not require tillage. Aggressive and continuous tillage will reduce organic matter levels in soil. Lastly, it is important to remember that applying organic matter also adds nutrients to the soil. Therefore we must add organic matter in a manner as to not over-apply nutrients such as phosphorus. The SOM has a significant influence on several of the other physical and biological aspects of soil fertility.

**Fertility Principle 2 —
Maintaining Soil Biological Activity**

The second principle of soil fertility is to maintain biological diversity in the soil. The soil food web consists of a multitude of organisms that range in size but rely heavily on each other for survival. A biologically diverse soil can have up to 100,000 different types of living organisms.

The biology in the soil has many important functions that make it possible to have healthy plants and clean water. The primary activity of most soil organisms is to grow and reproduce. Soil organisms depend on interactions with each other to survive.

Mycorrhizal fungi are symbiotic associations between fungi and plant roots. The mycorrhizal fungus colonizes plant roots and allows the plant access to more nutrients.
The by-products that come from roots and fresh residues feed the soil organisms. In turn, the soil organisms will support plant health as they decompose organic matter, cycle nutrients, hold nutrients, degrade pollutants, improve soil structure, and control populations of crop pests. Earthworms, for example, break down large pieces of plant residues into smaller pieces for other soil organisms. Earthworms also burrow through soil providing lots of air channels for root growth. Lastly, earthworms secrete a mucigel as they burrow through the soils. This mucigel is one of the ingredients that help the soil bind together.

Fertility Principle 3 —
Maintaining Soil Tilth

The next fertility principle is to maintain soil *tilth*. Soils in good physical condition are considered to have good tilth. This means the soil is porous and allows easy infiltration of water and penetration of roots. The pore space is created by aggregated soil. Soil aggregates are formed when soil particles (sand, silt, clay) become glued together with organic matter, soil organisms, and plant roots. The glue that holds all of this together comes from the plants’ roots and soil microorganisms.

These aggregates come in all shapes, sizes, and levels of stability. The placement of aggregates in the soil ecosystem forms the soil structure. The space between the aggregates allows room for air and water. Therefore these soils have fewer issues with erosion and runoff. These porous soils also have ample air space. Roots and microbes require oxygen and open exploration of the soil for optimum growth. The ample pore space allows plant roots to explore the soil and access nutrients freely. Stable aggregates are preferred as they can resist stress that might afflict the soil. For example, a soil that is well aggregated can resist rainfall, harsh tillage, and compaction.
The problems start when these aggregates are broken and remaining soil particles are squished together. We refer to this as compaction. Once the pore space is eliminated it is difficult for roots to grow properly and for microbes to survive. Compaction also keeps the soils water logged, resulting in anaerobic losses of nutrients. Essentially, nutrient cycling is severely limited without proper pore space.

There are three types of compaction that we observe on farms: surface, plow layer, and subsoil compaction. Surface compaction is common in annually cropped fields. Surface crusting occurs when soil is unprotected by surface residue, and raindrops disperse the aggregates by smearing them together into a thin layer of soil. Surface compaction can inhibit the germination of crops and increase the chance of erosion runoff.

Plow layer compaction is also common in our fields. The causes of plow layer compaction are erosion, reduced SOM levels, and heavy field equipment. Fields that are too wet for tillage are prone to this type of compaction.

Subsoil compaction occurs below the normally tilled surface layer. Subsoil is easily compacted because it is commonly wetter and more dense than the topsoil. This compaction occurs when a tillage implement applies pressure to the subsoil or when heavy equipment with poor weight distribution is run over the surface of the soil. Compaction is always most severe on wet soils.

Certainly the goal of a farmer should be to implement practices that maintain and improve soil tilth. Maintaining soil tilth first requires the addition of various types of organic matter to the soil. This organic matter increases the biological activity of the soil, resulting in the glues that form aggregates. These aggregates create ample pore space to allow for root, air, and water movement in the soil. Organic matter additions can help reduce the chance of surface and plow layer compaction. It is also important to maintain soil tilth through tillage. Tillage can be a detriment to soil tilth but also can be beneficial in alleviating soil compaction. Reduced tillage can increase SOM and reduce traffic on the fields. It is important to work the soil when it is at proper moisture. One rule of thumb is to roll some soil into a ball and drop it on the ground. If it breaks apart when dropped it is a signal that the soil is dry enough to be worked.

Fertility Principle 4 — Preventing Erosion

When managing fertility it is important to reduce nutrient losses to the environment. Erosion is a principle mechanism by which valuable topsoil is lost from agricultural fields. Eroding soil generally
has nutrients attached to it. As this soil is moved and deposited, valuable nutrients and organic matter are removed from crop fields. It is important to reduce or eliminate erosion to keep nutrients and organic matter on the field. Ways to reduce erosion from agricultural fields include reducing the speed of water or wind and keeping the soil in a condition that will resist the impact of rain and wind.

There are many practices that can be implemented to control erosion that will not hinder plant productivity. First, keep the soil covered with plant material as much as possible. For example, there is a greater chance of losing soil from a row crop than from a perennial grass crop. The grass crop holds the soil in place and the leaves can provide more coverage of the bare soil. In row crop systems, cover crops can be grown to protect the soil from erosion during the fall and winter months. Reduced tillage can also reduce erosion. When the soil is turned with a moldboard plow more bare soil is exposed, making it susceptible to erosion. Reduced or no-tillage options will leave more plant residue on the soil surface. However, in the case of corn silage, where the whole plant is removed, there is minimal residue, even with no-tillage. Cover cropping will need to be implemented in order to have enough residue to protect against erosion. The residue can absorb the impact of rain droplets and improve soil infiltration. In general, soils with higher levels of organic matter and good structure are less prone to erosion. The organic matter helps to create good soil tilth. These soils are better able to absorb rainfall because they have more pore spaces to allow for water flow through the soil.

![Legumes such as this red clover are an important part of a crop rotation.](image)

Fertility Principle 5 —
Maintaining a Proper Soil pH

Next we must remember to maintain the soil pH. It remains true that spending money on lime is probably the biggest bang for your fertilizer buck. A neutral soil is at a pH of 7. An acidic soil would fall below 7 and an alkaline pH would rise above 7. The pH can highly influence the nutrient availability in the soil. Most crops prefer a pH between 6.0 and 6.8. Some crops such as alfalfa prefer a pH of 6.8. This crop will perform poorly when the pH falls below 6. Some of this sensitivity is due to the fact that legumes generally form an association with a special type of bacteria. The bacteria have the ability to fix atmospheric N into plant-available N. These bacteria require a soil pH of 6.0 to survive. Molybdenum, which is necessary for nitrogen fixation in legumes, is more available at a more basic pH.
Fertility Principle 6 — Maintaining a Balance of Nutrients

The last principle of soil fertility is to balance the nutrients needed by plants while reducing their impact on the environment. This probably sounds familiar, as it is the primary goal of nutrient management. The goal is to provide what the crops require while being careful not to over-apply various nutrients. This is difficult to achieve, especially when manure is used as a nutrient source. We want to make sure that nutrients added to the soil do not become environmental hazards.

Hopefully from this session you have learned that there are many factors that affect soil fertility. It is not as easy as just maintaining N-P-K. Careful management of the soil’s biological, physical, and chemical properties will provide optimum crop production.

Creating Biodiversity

It is important to increase biodiversity above and below ground. Above-ground biodiversity can both enhance soil characteristics and help control pest populations. When crops are grown in monoculture there is a better chance of significant pest outbreaks. The living organisms above ground can play an important role in pest management. To encourage beneficial insects above ground we must provide them with a diversity of food and a proper home. Generally these requirements can be met by making sure that there is more than one crop growing in an area. This can be done by planting biological or ecological islands; habitat and food for beneficial organisms; biostrips, flower strips, beetle banks, strip insectary intercropping, vegetative corridors, or hedge rows. It can also be accomplished by planting a diversity of crops on the farm. Lastly, the judicious and careful use of pesticides is important to minimize harm to beneficial organisms.

Hedgerows provide habitat for many beneficial insects that help control pests.
While traditional soil tests measure the chemical properties of soil such as pH and nutrient levels, it is well accepted that biological and physical properties also play an important role in soil's ability to grow crops. This more holistic approach to looking at soil has been called "soil health." Soil health (or soil quality) can be defined as the capacity of a soil to function within an ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994).

Since 2001, Cornell University has been developing a test to measure soil health. Twelve indicators of biological, physical, and chemical soil properties are used to make a comprehensive assessment. Some of these indicators include: available water capacity (a measure of the ability of crops to store water between rains), aggregate stability (a measure of how well soil aggregates hold together in rain and resist surface crusting), and active carbon (a measure of the soil organic matter fraction that is available as a food source for microorganisms). The test results show how your soil compares with more than a thousand soil samples that have been submitted from the northeastern United States.

The procedure for submitting a soil sample for the Cornell soil health test is somewhat different than for traditional soil tests. First of all, the sample should be taken in the spring before the ground is tilled. If you are interested in submitting a sample from your farm, you will need to borrow a special piece of equipment called a penetrometer (or soil compaction meter) as measuring field compaction is part of the test. Biological properties are very sensitive to changes in temperature, thus, the sample must be kept refrigerated until it is submitted. It is important to follow the sampling instructions carefully or to get help from someone with experience taking soil health samples in order to obtain meaningful results.

Because of the wide array of tests that are performed on each sample, the soil health test is more expensive than a standard chemical soil test. The current cost of a soil health test is $45 per sample (2008 price). Because of the cost, it is most economical to target specific "problem areas" on the farm for sampling and compare them with "good areas." The test will identify constraints on plant growth that exist for a particular soil, but will require interpretation to determine the best management strategies for dealing with constraints.

For more information on the Cornell soil health test, visit the following website: www.hort.cornell.edu/soil-health.