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This bulletin provides practical approaches to improve soil using organic and ecologically based management. These practices depend on biological processes. Information is provided here on how to manage these processes and build your soil for a sustainable farm.

(Note: **boldface words** are defined at the end of the bulletin.)

Introduction

High quality soil is the backbone of a sustainable crop. Well-managed soil supports healthy, vigorous root growth, which improves plant resistance to soil diseases. Building soil requires a long-term management plan to improve soil **organic matter**, feed beneficial soil microbes and ensure nutrient supply to plants. This long-term plan requires growers to monitor their management practices over time and to evaluate how these practices affect **soil quality**.

Good soil management provides…

Short-term gains

- Adequate nutrients are available to meet crop requirements.
- Improved soil **"active" organic matter** supports the **soil food web**.
- Healthy root development can occur.
- Plant susceptibility to diseases and insect pests is reduced.

Long-term gains

- Soil organic matter is increased, supporting a resilient, healthy soil.
- **Soil porosity** is improved, enhancing water infiltration.
- **Soil water-holding capacity** is increased; this is particularly important in sandy soils.
- **Improved resistance to erosion** conserves organic matter in topsoil.
- **Improved soil carbon sequestration** contributes to the fight against climate change.

Building soil quality will increase its resilience. This is the ability to overcome stress or bounce back after being disturbed. Crops grown in resilient soil will be better able to withstand damage from drought, flood, extreme temperature or pest infestations.

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Questions to consider for a soil management plan:

· What is your soil texture?

· Does your soil quality measure up?

· What is a good reference/ benchmark site on your farm?

· How often should soil quality be measured?

Soil monitoring

Good record keeping is very important to document soil quality. Specific soil types and farmer goals vary tremendously and need to be taken into consideration when assessing soil quality. Soils are variable across Michigan and the Upper Midwest because of a complex history of soil formation. The environment and soil type are important influences on the rate of organic matter formation and the soil quality at any particular site. Crop management also profoundly influences soil properties including physical, biological and chemical characteristics. Thus selecting appropriate management practices is important to meeting set goals.

Soil plan

Designing a soil improvement plan requires developing a monitoring strategy. As part of that strategy, it's helpful to identify a benchmark site near a field in production. A benchmark site can be located along a fence row or in any nearby area of natural vegetation where soil is undisturbed and in a high quality state, an undisturbed site. The benchmark or reference site shows the optimum soil properties that are possible for a particular site given the parent soil type and environment.

A monitoring sheet is an integral part of a soil management plan. It provides a way to track soil quality and the progress made over time. An example of a soil monitoring sheet is shown on pages 3 and 4. Completing this form after each soil test will assist in tracking progress and documenting changes in soil quality. Evaluating the relationship of the soil quality properties of a given field site and a nearby reference site will provide important feedback. Note that the monitoring sheet provides a column to indicate the soil properties of the reference site along with those of the field site.

Over time, the general objective is for soil characteristics to improve relative to the reference site. For example, the soil organic matter percentage at many agricultural sites is about 50 percent lower than that in nearby natural sites. The goal is to improve the organic matter until it is close to the level in the natural site. Specific soil properties such as pH require careful consideration of the crop species to be grown. Some crop species require acidic soil; others favor a more alkaline soil. The grower seeking to improve soil pH needs to consider the pH value of organic inputs in addition to adjusting the pH with lime (raise pH) or sulfur (lower pH). (Visit this site for an overview of soil pH and the range favorable for production of many crops: "About Soil pH" at **http://soil.gsfc.nasa.gov/soil_pH/plant_pH.htm**.) USDA Natural Resources Conservation Service (NRCS) provides a useful overview of soil pH as well, at **http://soils.usda.gov/sqi/publications/files/indicate.pdf**. Detailed guides to monitor soil pH at field scales are also available (Lund, 2008).

Consistent Soil Sampling

Every 1-5 years (depending on purpose)

Take a sample that is:

· At the same time of year.

· At the same depth.

· From 12-15 subsamples/field.

Water infiltration device to test how quick water moves into soil in the field. This is a good indicator of soil biophysical quality.

Soil Monitoring Sheet

Date: __________________

Field location description (Farm location, field address or GPS coordinates):

History of management over last three years (crops grown, cover crops, soil amendments, tillage and/or livestock use):

Site Description (Field ID or name):

Reference Site Description (Nearby site in a natural state):

Soil Profile Description:

	Depth (inches):	Color & Shades	Texture: From lab analysis or observations	**Comments: (erosion, hardpan, other)**
Topsoil				
Subsoil				

Soil Properties:

Lab Analyses	**Analysis** **(list amount with units from lab)**	**Rate (1=low 2=moderate 3=mod. high 4=high)**	**Farmer Goal for Field**	**Reference Site Properties**
Soil Organic Matter				
pH				
Inorganic N				
Phosphorus				
Potassium				
Calcium				
Cation exchange capacity (CEC)				

Observations	Observation comments	Rate (1=low 2=moderate 3=mod. high 4=high)	Farmer Goal for Field	Reference Site Properties
Soil crusting *Rate based on observation*				
Soil biology *Observe number of earthworms and macropores, rate of residue decomposition*				
Ease of tillage *Observations*				
Plant stand *Observations*				
Plant health *Observations*				
Root health *Observations*				
Soil compaction *Observation or penetrometer*				
Other lab analysis: Micronutrients, List:				
Other (Add as needed):				

Soil sampling

When and how soil is sampled will influence the results of soil quality measurements. Information on soil sampling methods is available from resources such as the USDA NRCS National Soil Quality Team Web site (**www.soilquality.org**) and the MSU Web site **www.msue.msu.edu/objects/content_revision/download.cfm/revision_id.573341/workspace_id.72167/E-0498S.pdf/**. This site presents information on sampling soils for fertilizer and lime recommendations, including frequency of soil sampling.

A probe for sampling soil.

Soil sampling requires a sample that is representative of the field. In general, soil subsamples are taken from various random locations across a field and then systematically mixed together. It is recommended that soil be measured during "rest" periods in the agricultural calendar, such as in the fall after harvest or in the spring before planting a crop. Soil monitoring should be done at roughly the same time each year for consistency. Overall, refer to Tables 1 and 2 for more information on specific tests that can be used to monitor chemical, biological and physical properties that influence soil structure and nutrient supply. Some soil properties, such as inorganic nitrogen, should be monitored one or more times per year during the growing season. Checking properties such as soil organic matter about once every three years is adequate because it takes

Table 1. Managing soil chemical properties.

Chemical properties	Testing frequency	Function	Management to increase	Management to decrease
Inorganic nitrogen (N)	Once or twice per year: at planting, at first weeding or after harvest[1]	Promotes plant growth. Crops vary in N requirement.	• Add high N content manure, compost or organic product. • Grow legumes.	• Grow grasses or other non-legume cover crops. • Add straw or mature compost.
pH	Once per year	Regulates nutrient availability to crops.	• Add lime or wood ash and adjust pH according to soil test.	• Add elemental sulfur.
Potassium (K)	Once per year or every other year	Potassium influences water regulation in crops.	• Add poultry manure, compost or wood ash. • Grow deep-rooted crops.	• Removing hay or other high K crops from the soil could reduce K availability.
Phosphorus (P)	Once per year or every other year	Phosphorus influences energy supply and plant membrane integrity.	• Add poultry manure or compost. • Diversify with legumes.	• Add zinc (could reduce P availability; depends on soil pH).

[1] Presidedress nitrate test (PSNT) involves early summer soil monitoring in a nitrogen-demanding crop such as corn. Go to **http://ipmnews.msu.edu/fieldcrop/** and search "PSNT" for information on this important soil test.

Table 2. Managing soil biological and physical characteristics.

Biophysical characteristics	Testing frequency	Function	Management to increase	Management to decrease
Soil organic matter (closely related to soil organic carbon)	Once every 3-4 years Note: organic matter changes slowly.	Provides long-term support for soil organisms and improves soil **tilth**.	• Incorporate cover crops and rotations with pastures or hay. • Add compost or manure 120 days before crop harvest.	• Tillage that is too frequent or too deep. • Bare soil surface. • Planting down the slope.
Active organic matter. An example is earthworms in soil.	At the same time each year: early spring or late fall in between crops	Supports diversity and number of living organisms, and ability of soil to supply nutrients.	• Incorporate a cover crop that supplies green, vegetative material. • Diversify with a legume crop or cover crop.	• Repeatedly not incorporating crop residues or compost.
Soil aggregation	Every 2-3 years	• Improves soil tilth, **porosity** and structure. • Improves soil drainage and structure.	• Add compost or manure. • Grow deep rooted cover crops such as sweet clovers and sorghum-Sudangrass.	• Excessive cultivation or cultivating when soil is too wet or too dry. • Insufficient organic inputs.
Bulk density (Issues: shallow vs. deep, compacted soil and **hardpan**.)	Every 2-3 years at consistent soil moisture status OR Check using a penetrometer or metal flag stake*.	• Root growth • Provides nutrients and improves water drainage	Biological tillage to reduce: • Surface compaction: grow grass cover crops. • Deep compaction and hardpan: grow legumes.	• Excessive cultivation. • Cultivating when soil is wet or vulnerable to compaction.
Root health index (See root health test using bean plants as described in Snapp and Morrone, 2008.)	Upon demand (if grower notes a crop health problem or is evaluating a new site).	Promotes a healthy crop.	• Grow a **biofumigant** such as a mustard cover crop. • Rotate crops for 3 years to non-host plants.	Too frequent production of root-rot- susceptible crops such as bean or potato.

* Use a metal flag stake, push stake down until resistance is felt at several locations across the field. Note location and depth it becomes difficult. Manage soil to increase bulk density at these sites.

time for a detectable change in soil organic matter to occur. The reference site is generally sampled once and then on an infrequent basis — soil properties at the reference site are not expected to change rapidly, if at all.

Soil physical properties

Soil traits such as texture — the sizes of soil particles — greatly influence soil response to management. Texture is described on the basis of the percentages of sand, silt and clay. This soil characteristic cannot be changed. Coarse-textured soil has mostly large, sand-sized particles, and a fine-textured soil is dominated by small, clay-sized particles. The texture of the soil affects its ability to drain and to hold water during a drought, root development, susceptibility to form a **hardpan**, erodiblity, and ability to protect and build soil organic matter. Soil texture cannot be changed by farm management, so it's important to consider the soil texture when selecting a field site for crop production. **Aggregation** of soil particles is influenced by management. As aggregation increases the soil's biophysical characteristics improve, such as water infiltration and porosity. These traits together are termed **soil tilth**.

Soil physical properties and ways to measure them are shown in Table 2. Analyzing physical soil properties such as water infiltration, bulk density and aggregation will require extra effort and cost because they are not included in standard laboratory analyses. Information on simple field monitoring tests that can be conducted on the farm and a useful soil health monitoring guide are available at **http://soilhealth.cals.cornell.edu**. For soil monitoring tools that can be used at the field scale and more detailed tests, see Snapp and Morrone, 2008.

Improving soil structure

Building soil organic matter (SOM) is the primary means to improve soil physical structure. This takes time and a good management plan. The National Organic Program requires a farm management plan developed specifically for each certified farm. The plan should describe how soil is being managed to build soil organic matter, including stable, long-term organic matter called **humus**.

The amount of SOM needed to improve soil quality will depend on the texture of the soil. Sandy, coarse soils generally need more amendments and it is difficult to increase

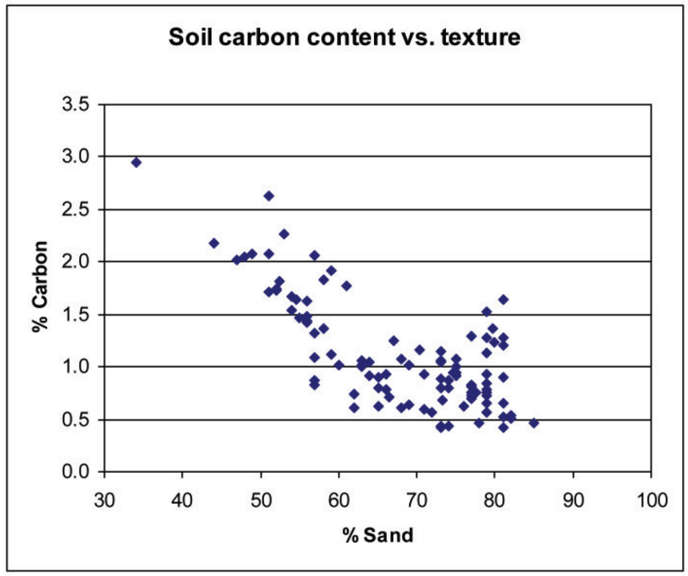

Figure 1. Soil carbon is the key component of organic matter. It tends to be much lower in soils with a high percentage of sand, as shown by these data from Michigan fields sampled in 2003. As the percent of sand increases, the percent of carbon goes down.

SOM on this soil type. These soils tend to be lower in organic matter content than clay or loamy, fine-textured soil (Figure 1). Two percent organic matter may be the maximum achievable level for sandy soil types. A fine-textured, high clay content soil, on the other hand, can be built up to more than 4 percent organic matter. A unique soil-type is muck soils, which have a very high organic matter content and require specific management practices. It can take five or more years to increase organic matter by a detectable amount in any soil type. How fast SOM accumulates will depend on management practices and on the climate. In cool, dry regions of the world, soil organic matter tends to accumulate faster than in wet, hot climates.

Soil nutrient status

Soil nutrient supply is determined by soil texture, soil organic matter and management practices. As discussed earlier, soil texture cannot be changed, but implementing good management practices can increase soil organic matter. Organic crop production greatly relies on building soils to supply crops with nutrients, an approach often referred to as "**feed the soil to feed the plant**". The nutrient supply is primarily provided by one component of soil organic matter, the **active organic matter pool**.

This pool of organic matter requires frequent replenishment. Active organic matter is broken down by microorganisms within a few months to a year, and it is the pool that supplies a wide range of nutrients to plants and provides a habitat and energy source for soil organisms.

Soil organisms act as decomposers – they provide a vital function by breaking down organic residue to release nutrients. In the process, soil organisms utilize the nutrients as well as release them. These two processes occur simultaneously. Soil nutrients are being released at the same time as they are being taken up, back and forth. The process of nutrient use by soil organisms is referred to as immobilization and is an underlying cause for pale green leaves. Addition of high-quality residues, such as the amendments listed in Table 3, reduces the potential for immobilization as they will speed up the process to release nutrients.

The bottom line is that organic production requires adequate lead time for change to occur. A soil management plan should be developed to provide sufficient nutrients for crop development. Applying a mixture of amendments a season or two before planting is an excellent strategy. This will replenish the active organic matter pool and supply macronutrients such as nitrogen, phosphorus and potassium, as well as micronutrients such as calcium, sulfur and zinc. You can augment soil nutrient supply with highly decomposable organic amendments (Table 3).

Table 3 provides information on how to supply and manage **soil nutrients** to assure good plant growth. Because plant nutrient supply is influenced by soil biophysical properties, it is important to also consider the methods described in Table 2. For example, if soil has good physical structure, it will support vigorous rooting and a healthy plant that can readily access needed nutrients.

Conventional soil testing laboratories typically provide a description of soil nutrient status based on chemical properties and recommend inputs in the form of inorganic fertilizers. Certified organic production permits only nutrients sourced from naturally occurring sources without chemical processing (such as rock phosphate). Nutrient deficiencies in organic production are addressed through long term planning and amendments that are approved by the Organic Material Review Institute (OMRI) (**www.omri.org/omri-lists**). Soil management plans should emphasize building and maintaining soil organic matter over the long-term.

Nutrient management

To develop a nutrient management plan, you need to consider the soil type, recent management practices and crop nutrient requirements. The two most important crop production nutrients to check are nitrogen (N) and phosphorus (P).

Table 3. Organic amendments that can be used to enhance soil nutrient supply.

Source	Carbon content	Comments
Poultry manure	Low	• Generally supplies large amounts of P, K and calcium, and moderate amounts of N. • Often pH is above 7.0 and amendment may act as a liming agent (raises soil pH).
Seaweed/fish emulsion & fishmeal	Very low	• Generally a good source of micronutrients. • Rapidly available N, P and K.
Soybean meal	Medium	• Rapidly available source of nutrients, especially N and P.
Compost	Medium-high	• Slowly available source of nutrients – such as N and P – and contributes to soil organic matter for enhanced soil fertility.
Compost tea	Low	• Nutrients supplied will depend on ingredients used to make compost tea.

Foot note: Nutrient release is relatively fast from these sources; about one-third to half of the nutrients applied will generally be available within 1 to 2 months. Apply amendments cautiously to seedlings and as dilute nutrient solutions to prevent burning plants from rapidly mineralized nutrients. Various soil organisms feed on different types of carbon, so it's useful to use a variety of types of carbon sources as soil amendments.

Predicting the amount of nutrients available from organic matter amendments can be challenging. Weather, soil type, management practices and quality of amendments all influence the speed of decomposition and the timing of nutrient release. Materials that are nutrient-rich and low in carbon are readily decomposable so nutrients will be released quickly — over a few weeks or months (Table 3). Seaweed, fish emulsions, and compost teas are examples of this type of amendment. Organic amendments that have medium to high carbon content tend to release nutrients more slowly — over several months or even years (Table 4). These types of inputs are good to build carbon in the soil.

Organic amendments generally release about one-third to half of their total nutrients in the first year after application. In contrast, inorganic fertilizer amendments release nearly 100 percent of their nutrients in the first year. The advantages of applying nutrients in an organic amendment form are that it adds to soil organic matter and reduces nutrient leaching. Soluble nutrients such as those in fertilizers are available quickly, but they are vulnerable to loss through leaching and denitrification to a gas (McSwiney, Snapp, & Gentry, 2010).

Leaving crop residues helps to protect soil from erosion. Note the mustard cover crop seedling emerging.

Nitrogen (N) is the nutrient required in the largest amount by plants. The available forms of nitrogen fluctuate in soil depending on the amount of biological activity and other soil properties. It is a challenge to measure and to predict how much N is needed. Soil organisms determine the rate of nitrogen supply. Because nitrogen occurs in a variety of forms, there are no chemical analytical

Table 4. Organic Amendments that are slow to release nutrients and are effective means to build soil organic matter.

Source	Management system used to produce	Carbon and nitrogen content	Comments
Cattle manure	Forage-fed, straw bedding	High carbon	• Builds soil organic matter.
Cattle and swine manure	Grain-fed	Low carbon	• Could burn plant tissues if applied to seedlings. • Supplies nutrients.
Poultry manure	Bedding material such as straw or sawdust	Medium to high carbon	• Builds active soil organic matter. • Supplies nutrients.
Compost	Straw or leaf mixture	Medium to high carbon	• Stable — builds soil organic matter.
Cereal cover crop, mature	Grow cover crop to maturity (past flowering, high straw).	Medium carbon Nitrogen 1% to 2%	• Builds active and stable soil organic matter. • Ties up nutrients for many months.
Cereal cover crop, immature	Young, vegetative cover crop	Medium carbon Nitrogen 1.5% to 2.8%	• May slowly release some nutrients, depending on soil conditions.
Legume cover crop, mature	Grow cover crop to maturity (past flowering, high straw).	Medium carbon Nitrogen 2.5% to 4.5%	• Rapidly releases nutrients and supports microbe growth. • Large root system will help build soil organic matter.

methods that can perfectly predict its availability to plants (Table 1). One measurement used by many soil laboratories as an approximate indicator of seasonal N supply is the presidedress nitrate test (PSNT). (Visit **www.css.msu.edu/SPNL/** or **www.css.msu.edu/PDF/Soil_Nitrate_Test_for_Corn.pdf** for a description of how to take a field sample.) This analysis can be done at any public or commercial soil analysis lab. This test should be taken about two weeks before applying N as a sidedress supplement for an N-demanding crop such as corn. For organic systems, a sidedress fertilizer might be fish emulsion, seaweed solution or any other rapidly available nutrient amendment allowed by NOP (Table 3).

Organic soil amendments commonly used to supply nutrients are described in Tables 3 and 4. Soil amendments are generally described as having high quality if they are nutrient-rich (Table 3) and low quality if they are low in nutrient content and contain large amounts of carbon (Table 4). If both nitrogen and phosphorus are required, manure from poultry or swine may be the most cost-effective sources. Growing legume species as a cover crop is also a cost-effective means of providing nitrogen and prevents nutrient loss. Legume-based organic amendments are particularly appropriate if a soil test shows that it is already high in phosphorus.

Diverse qualities of soil amendments will help supply nutrients over an extended period and simultaneously build soil organic matter. Aiming for a mixture of amendments and residues is a good strategy to increase soil organic matter. This will provide readily available nutrients and slowly degradable materials.

Building soil organic matter

Improving soil organic matter depends on enhancing the amount of carbon-containing inputs and reducing carbon outputs. Much of the carbon contained in soil amendments is lost into the atmosphere in the form of carbon dioxide as the organic matter decomposes. To reduce soil carbon loss, it is important to take steps to prevent erosion, keeping organic matter in place on the field. This is particularly important if the field site is vulnerable to wind or water erosion. Resources are available from soil conservation staff members (**www.macd.org/local-districts.html**) to help implement soil conservation practices such as growing cover crops and minimizing tillage. Core components of soil protection are minimizing soil disturbance and maintaining **ground cover** for most of the year. These practices include conservation tillage because this limits soil disturbance. Growing a perennial forage crop such as alfalfa reduces passes on the field. This crop provides an extended ground cover and deep root system, helping to hold soil in place. All of these practices contribute to better soil structure and improved water infiltration.

Organic matter amendments to the soil promote soil **aggregation** and provide residues that help build soil organic matter. Research has shown the value of roots in promoting soil aggregation — they contribute to improved soil tilth directly by keeping soil in place and indirectly by creating air spaces within the soil for the plants' roots to grow and access nutrients. Leafy, green materials are fast to decay; roots provide large amounts of tissue that are slow to degrade. On-going research investigates why roots are so beneficial to building soil organic matter, but known factors include the biochemical properties and tough tissues located belowground. Figure 2 shows the amount of

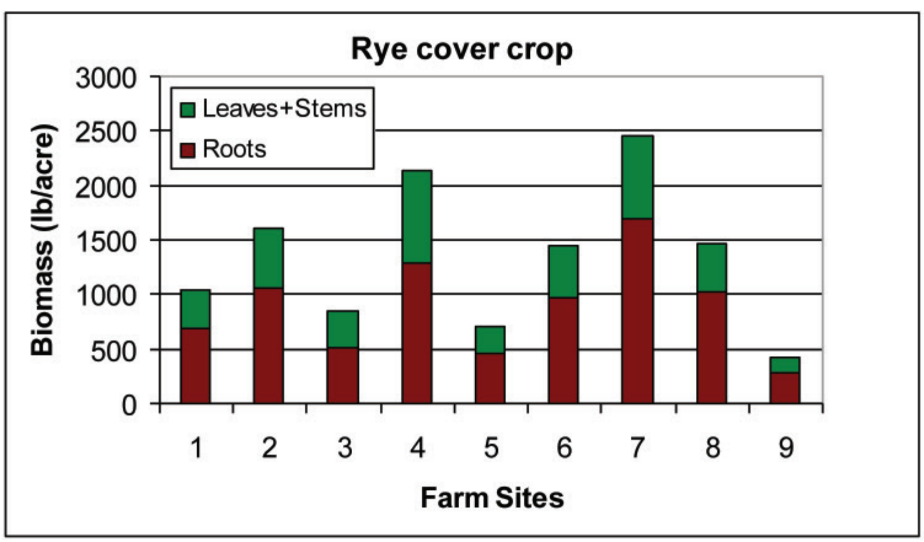

Figure 2. Amount of biomass from a young rye cover crop in the spring on fields across Michigan. Roots can be a hidden benefit. They provide a substantial proportion of the biomass inputs from cover crops.

root biomass measured in Michigan fields from rye cover crops. The take-home message is that growing a cover crop provides much more than soil cover. Roots feed soil organisms throughout the life of the cover crop. After the cover crop is killed, by frost or tillage, the roots slowly degrade and are a carbon source that contributes to building soil organic matter while the leaves decompose quickly and supply plant nutrients.

Overall, assuring a mixture of leaves, roots, compost and manure that provides diverse qualities of **active organic matter** and supports a wide range of soil microorganisms is a good strategy for building healthy soil.

Grow a variety of cover crops

- Legumes enhance soil nitrogen and organic matter.
- Deep roots break up hardpans.
- Winter-killed plants make for easier field preparation.
- Fibrous roots hold erodible soil in place.
- Large taproots build soil pores and organic matter.

Management options for improving soil quality

Cover crops. A wide variety of cover crops can be grown that contribute many soil-building attributes. Mixtures of cover crops may be the best way to maximize soil-building benefits. An ideal soil management plan should include various cover crop plant types grown over time to produce copious amounts of mixed qualities of residues. Consider the value of the roots as well as leaves (Figure 2). If feasible, allow the cover crop to grow long enough to produce large amounts of biomass, keeping in mind that growth is very rapid once the temperature warms in the spring. Be sure to cut or turn in the cover crop as the plant starts to flower to prevent seed formation. Three weeks of growth in May can almost double biomass produced by a cover crop. (Information on cover crops suited to Michigan farming systems is available at www.covercrops.msu.edu.) Sorghum-sudangrass is one of the most vigorously growing cover crops, but it requires warm growing conditions to produce abundant biomass. Cereal rye is the most effective cover crop to grow during the winter and can be planted in late fall. Alfalfa and clovers produce deep taproot systems; in contrast, grasses have largely fibrous root systems.

Use of manure in organic production

*Manure used in certified organic systems, regardless of its moisture and age, must be applied at least 90 days before harvest on organic trees or shrubs and at least 120 days before harvest on fruit and vegetable crops that have a harvested portion that may come in contact with the manure. Examples of crops that require adherence to the 120-day rule include greens, carrots and tomatoes. Unlike manure, compost made according to NOP protocol can be applied to crops at any time (*www.extension.org/article/18567*).*

Note: if crops are being sold to a buyer that requires third-party food safety certification, such as GAP-USDA, then manure must be applied 120 days before harvest, regardless of the type of crop.

Manure. Another important way to improve soil organic matter is to apply manure. The quality of manure depends on several factors — more than just the animal type. The method and length of manure storage, the bedding material and what the animals were fed all are important. For example, manure from cattle fed forage will generally be higher in carbon than manure from cattle that are fed grain (Table 4).

Manure should be managed carefully, following food safety and National Organic Program recommendations. (Information on manure management for certified organic production is available at www.michiganorganic.msu.edu [see soil amendments]). Manure can be applied alone or used in combination with cover crops to provide a diversity of residues that feed the **active organic matter pool**.

Information on the nutrient content of purchased soil amendments should be available from the supplier and are required to satisfy organic certification. Manure often varies in quality. Quality is affected by the duration of storage, how it has been stored, and the amount of moisture present. In the first year, manure from swine and poultry can

Compost produced on-farm in Michigan.

release 25 to 50 percent of the total nitrogen. Applying manure uniformly can be challenging, but it can be done sufficiently, even on smaller fields. Manure can be applied with a spreader, injector or as a slurry. Compost is often a more consistent product because it has completed an aging process, but it is generally lower in nutrient content than manure. It is recommended to have a sample of compost or manure analyzed before field application following procedures outlined at the Michigan Manure Resources Network (**http://web2.msue.msu.edu/manure**). (For more detailed information on use of manure, see "Managing Manure in Potato and Vegetable Systems" at **http://fieldcrop.msu.edu/documents/E2893.pdf**.)

Compost. Compost is one of the most stable forms of crop nutrient sources, and applying it is an effective means to help build soil organic matter. Manure-based compost is a good source of carbon, particularly if it is produced with a mixture that includes carbon-rich materials such as tree leaves or straw (Table 4). Compost should be produced using approximately three parts carbon-rich materials (such as straw) to one part nitrogen-rich materials (animal manure, leguminous vegetation, fresh hay).

Compost will not "burn" plants if added to the soil before seed germination or transplanting, and it can be applied at any time during the field season. Knowing the percent of nutrients contained in the compost and the approximate nutrient release rate will allow calculation of the appropriate amount to apply. See **http://smallfarms.oregonstate.edu/calculator**, a tool to calculate amount of nutrients in soil inputs. Purchased compost should include an analysis indicating the amounts of nutrients contained. For certified organic farms, documentation must be provided to show how the compost was produced, including that the core temperature reaches 120-140 F for three days and the pile is mixed when core temperature falls below 120 F to assure all parts are evenly heated. Following the NOP approved procedure reduces the risk of compost containing viable weed seeds and plant pathogens. If documentation of the process is not available, the compost must be used as manure in certified organic operations and applied no less than 120 days before harvest. If you make compost on your farm, grass clippings from a lawn that has been treated with herbicide should not be used because the carryover can affect your crops. Although NOP does not restrict the types of plant materials that go into compost, some certifiers require that they do not come from a lawn service or municipality because of the risk of herbicide con-

Differences between compost and manure. Compost is more than aged manure because it includes a combination of inputs that are high in carbon (such as leaves, straw, spent wood chips) and inputs high in nitrogen (such as manure, alfalfa, clover, soybean residue). The mixture becomes stabilized during the compost process. A "hot" compost is made by adding a volume ratio of about 3:1 (carbon:nitrogen) and turning it on a regular basis and aiming to assure that all of the ingredients are mixed and decompose evenly by heating and activating the soil microbes. Compost is a relatively complete nutrient source for crops. A typical nutrient analysis associated with mature compost is 2-4-3 (N-P-K), but this will vary depending on the ingredients used in compost preparation. Manure is a less stable nutrient source than compost, but it often provides larger amounts of nitrogen (compare Table 3 and Table 4). For this reason, manure should not be applied directly to young plants, which can be "burned" by nitrogen released from manure during the decomposition process. Applying manure or compost months before a crop is planted is the best strategy. This approach ensures that decomposition occurs well before young plants are present, and that application poses minimal risk to food safety.

tamination. Some certifying agencies will require a periodic analysis of the ingredients to assure that the compost is not contaminated with NOP non-allowable substances.

Conclusion

Each farmer has a unique approach to soil management and focus on aspects of soil building, depending on available resources and individual priorities. Environmental conditions and market demands will influence appropriate soil management practices. Frequency of applying organic inputs, crop diversity and rotations, tillage methods and intensity, and marketing strategies will all vary. Some farms are largely self-sufficient — they produce their own compost and grow cover crops to build soil fertility and organic matter. Other farms rely on bringing in manure and compost to apply in conjunction with soil amendments produced on-farm. Over time, soil management plans will require adjustment. Adjustments to the soil-building plan should be made to support the crops' needs, using practical farm management approaches.

Support is available as you develop a soil management plan for your farm, including the technical information provided in the resource list below. The U.S. Department of Agriculture NRCS offers cost-share assistance for actions that lead to improved soil quality and provides guidance to create a plan to manage nutrients and reduce runoff. (To learn about a conservation soil conversation plan, visit **www.nrcs.usda.gov/technical/afo/pdf/CNMP FactSheet.pdf**. For information on cost-share programs available in Michigan, go to **www.mi.nrcs.usda.gov/programs/**).

The bottom line is that the foundation to sustainable soil management is developing a plan that meets your goals. The approach to the plan will vary from farm to farm. Management plans should be based on the principles of applying a variety of organic materials and protecting soil through growing cover crops and perennial crops such as forages. Consistent soil monitoring will ensure that a management plan is effective by evaluating progress over time. Resources presented here are to help you develop a plan and achieve your goals for a healthy soil.

Resources

USDA NRCS National Soil Quality Team Web site — **www.soilquality.org**.

Cornell Soil Health Group (**http://soilhealth.cals.cornell.edu**). This resource focuses on soil quality in relationship to agriculture in New York and the Northeast. A useful manual to monitoring soil health can be downloaded from this site: B.K. Gugino et al., 2007 Cornell Soil Health Assessment Training Manual, Edition 1.2.1. Cornell University, Geneva, N.Y.

The Sustainable Agriculture Research and Education (SARE) Web site has synthesized information on soil quality and management in several key publications available at: **www.sare.org/publications**, including the following:

Steel in the Field: A Farmer's Guide to Weed Management Tools (128 pp.), published in 2001 (**www.sare.org/publications/steel/steel.pdf**).

Building Soils for Better Crops (3rd edition) (294 pp.), published in 2000 (**www.sare.org/publications/bsbc/bsbc.pdf**).

Crop Rotation on Organic Farms: A Planning Manual (154 pp.), published in 2009 (**www.sare.org/publications/croprotation/croprotation.pdf**).

Managing Cover Crops Profitably (3rd edition) (244 pp.), published in 2007 (**www.sare.org/publications/covercrops/covercrops.pdf**).

Michigan State University soil management information includes the presidedress nitrate test (PSNT), which involves early summer soil monitoring in a nitrogen-demanding crop such as corn. Go to **http://ipmnews.msu.edu/fieldcrop/** and search "PSNT".

MSU Web site on how to take a representative soil sample — **www.msue.msu.edu/objects/content_revision/download.cfm/revision_id.573341/workspace_id.72167/E-0498S.pdf/**.

Dr. Tim Harrigan shows how a slurry injector can be used to plant cover crop with manure slurry. Seeding Annual Ryegrass w/Manure Slurry 9/1/2010. Go to **www.youtube.com/annualryegrass**.

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Definitions

Active organic matter: This type of soil organic matter is also called the active pool. It consists mainly of recently added residues and is influenced greatly by management practices such as applying compost or reducing the amount of tillage. It is made up of partially decomposed residues of recently added materials plus associated microorganisms. Active organic matter provides a food supply and habitat (home) for soil organisms, which in turn consume it and release nutrients through this **mineralization** process.

Aggregation: How sand, silt and clay particles form larger granules (aggregates). Good aggregation is apparent in a crumbly soil with water-stable granules that do not easily disintegrate. The particles are held together by chemical, physical and biological processes. They are generally increased by clay and fine-textured soil, bacteria and fungal hyphal threads. A well- aggregated soil has good **tilth**, with pore space for air and water retention and exchange.

Erosion: The process of soil loss driven by forces such as water or wind.

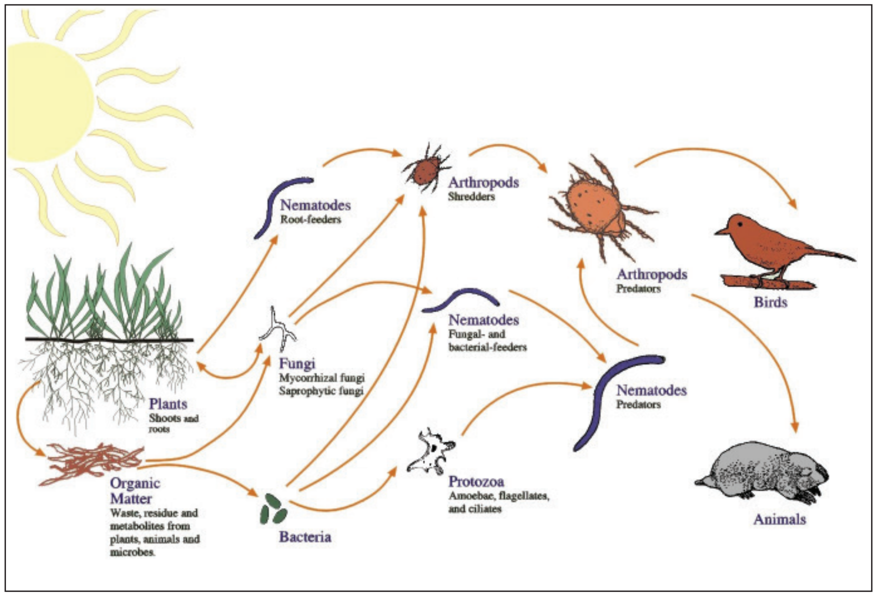
Feeding the soil: Adding a range of qualities and types of organic inputs to build a healthy soil and feed a wide range of beneficial microorganisms. The frequency and timing of tillage will also affect the extent to which organic inputs are available to microorganisms and how fast organic materials break down and make nutrients available.

Ground cover: A plant that is grown on the soil when a crop is not present to reduce erosion and loss of soil. It is important to maintain soil cover throughout the year to conserve soil. Surface ground cover and roots are both important to conserve topsoil and water.

Hardpan: This refers to a compacted layer in soil. It is commonly caused by tilling the soil repeatedly at the same depth, or by heavy equipment used to till excessively wet soil. It can occur naturally when a cemented layer of minerals fuse and form a layer that is impervious to water movement.

Humus: Completely decomposed, stable organic matter. This pool of organic materials resists further decomposition and is generally hundreds of years old. It has an important function in soil, particularly in terms of enhancing soil structure and water-holding capacity.

Organic matter: Soil organic matter can be conceptualized as three pools, living microorganisms, active organic matter (young), and stable humus (old). Ultimately, all pools of soil organic matter, whether thousands of years old or recent, come from once-living organisms such as plants, microbes and animals. Soil organic matter influences how soil functions at every level – including erodibility, agricultural productivity, water and air quality.



Source: http://soils.usda.gov/sqi/concepts/soil_biology/images/A-3.jpg.

Soil carbon sequestration: Soil organic matter consists primarily of carbon, and indeed is the largest terrestrial (land) pool of carbon. Soil carbon sequestration depends on carbon that is fixed through photosynthesis and then incorporated into the organic matter pool. The net gain of soil carbon depends on how much is lost as well as inputs, influenced by oxidation through disturbance (tillage). Biological activity is influenced by such factors as temperature and moisture, as well as residue quality.

Soil chemical properties: Chemicals in the soil include the pH and nutrients contained in the soil. There are three categories of chemicals important to crop production. The first is macronutrients, which are required in the greatest amount for plant growth and consist of nitrogen (N), potassium (K) and phosphorus (P). The secondary nutrients include magnesium (Mg), calcium (Ca) and sulfur (S). The micronutrients includes selenium (Se), boron (B), copper (Cu), iron (Fe), chloride (Cl), manganese (Mn), molybdenum (Mo) and zinc (Zn). Nutrients are derived from the soil and from amendments such as chemical fertilizers and organic matter such as manure, compost and growing legumes.

Soil food web: The community of organisms that live in the soil. A food web diagram shows a series of conversions (represented by arrows) of energy and nutrients as organisms eat and interact with one another (see food web diagram).

Soil porosity: This is the volume of soil that is not occupied by organic matter or particles. Pore space can be filled by air, gas or water. A fine-textured, clay soil that has many small particles that fit close together will have reduced porosity compared to a sandy soil. Soil porosity can be improved through aggregation of soil. Large pores allow the growth of roots and easy movement of air, water and nutrients.

Soil quality: This is an assessment or value judgment regarding a soil's ability to support a desired function, such as plant growth and development, and erosion management. Soil quality is sometimes referred to as soil health, and it depends on the interaction of biological, chemical and physical properties. Ultimately, soil quality depends on the function under consideration and who is making the assessment.

Soil water-holding capacity: The ability of a soil to hold water against the force of gravity. This is influenced by soil texture and aggregation A sandier soil has less capacity than a soil with a high percentage of clay.

Tilth: The soil's general suitability to support plant growth and, in particular, to support root growth. Tilth is defined as "the physical condition of soil as related to its ease of tillage, fitness of the seedbed, and how it impacts the ability of seedling emergence and root penetration" (Soil Conservation Society, 1982).

For more information

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