



Steve Culman

introduction to soils

## Managing Soils

**T**he goal of good soil management is to meet essential plant needs for water, nutrients, oxygen, and a medium to hold their roots with as little management as possible.

Plants need water, nutrients, carbon, oxygen, and a medium to hold them up. All our actions managing soils will affect these components. For example, when we add compost, plant residue, or cover crops to the soil we are feeding the soil microbes. These microbes exude sticky substances that hold the soil structure together and protect soil organic matter. When we till, we integrate organic material into the soil where it can break down and burn off organic matter by stimulating microbes that breathe out carbon. This fact sheet briefly outlines some considerations for new soil managers.

### MANAGING FOR OPTIMAL OXYGEN AND WATER IN SOIL

Plants need oxygen and water to grow. By forming and maintaining soils with good soil tilth—i.e., containing many large soil aggregates and high organic matter content—we maintain the correct balance of pore space in the soil filled with air and water to soil particles (see *Start Farming—Introduction to Soils: Soil Quality*).

“The plow is one of the most valuable of human inventions. But long before it existed, the land was, in fact, regularly plowed, and continues to be thus plowed, by earthworms.”

—Charles Darwin, 1881

#### Excessive tillage:

- Decreases organic matter
- Reduces biological activity
- Destroys aggregates
- Reduces nutrient holding capacity
- Restricts drainage
- Diminishes pore space

“Whatever the cause of soil unthriftiness, there is no dispute as to the remedial measures. Doctors may disagree as to what causes the disease, but agree as to the medicine. Crop rotation! The use of barnyard and green manuring! Humus maintenance! These are the fundamental needs.”

—Hills, Jones, and Cutler 1908 (cited in Magdoff and van Es 2009)

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One goal of soil cultivation is to maintain good soil structure and tilth. The first time you go through a field each season with a plow or disk is called primary tillage. This cultivation loosens and opens the soil, aiding root penetration and aerating the soil. Remember, a good loam soil has about 50 percent soil and 50 percent pore space. Tillage increases air/gas exchange with the atmosphere. Plants, as well as soil organisms, need this oxygen. When you till and integrate both oxygen and organic matter, you stimulate biological activity, causing microbes to decompose the plant material into the nutrients plants need (Miles and Brown 2007).

Primary tillage allows you to integrate cover crops, compost, other organic material, and mineral amendments into the soil. Without tillage, cover crops and residue form a thin layer of highly organic material on the surface of the soil instead of being distributed throughout the soil profile.

Cultivation can also break up compaction layers. Deep tillage physically fractures the soil. Of course, one of the most important reasons for tillage is weed control. Primary cultivation buries weeds that may have grown up during the winter. This is especially important in organic systems. Organic row crop producers in Pennsylvania found that when they used tillage that was less aggressive, such as the chisel plow, weeds in soybeans and corn were difficult to control. In contrast, when they used a moldboard plow, they did not have as much weed pressure.

### POSSIBLE IMPACTS OF EXCESSIVE TILLAGE

Like most things, tillage can be good in moderation. However, it is essential that you think about when you till, how often you till, and how well you balance your tillage with organic matter inputs.

Tillage reduces soil organic matter content by a process called oxidation. Usually, the amount of oxygen in the soil limits the activity and number of soil microbes. When we till, we mix in oxygen, and bacteria and fungi multiply. When you consider that some bacteria can double their population in ten minutes, their populations increase quickly. This “bloom” of bacteria and the slightly slower increase in fungi and other organisms results in the oxidation or release of carbon (the primary component of organic matter) into the atmosphere. Microbes act like tiny soil cows, grazing on organic matter and breathing out carbon dioxide (CO<sub>2</sub>). They convert the carbon from sugars, carbohydrates, and amino acids in organic matter to energy and CO<sub>2</sub>, a by-product of the metabolic reaction called oxidation.

Although in the short term tillage increases the numbers of microbes by giving them more oxygen, in the long term excessive tillage can reduce biological

### National Organic Standards for Compost and Manure

According to the *Pennsylvania Certified Organic Guide*, raw animal manure must be composted unless it is:

- Applied to land used for crops not intended for human consumption
- Incorporated into soil not less than 120 days prior to the harvest of a product whose edible portion has direct contact with the soil
- Incorporated not less than 90 days prior to the harvest of a product whose edible portion does not have direct contact with the soil

activity and diversity. Soil organic matter is the food source, the fuel for the soil food web. Continually oxidizing soil organic matter diminishes the food source if it is not replaced.

Burning off soil organic matter creates a domino effect: less food for soil organisms, which then do not produce the sticky substances and long hairlike strands of fungal hyphae that knit the soil together into clumps called aggregates. Soil with fewer aggregates has less pore space with less water-holding capacity, oxygen, and ability to drain. All these components affect plant growth.

### BALANCING TILLAGE WITH ORGANIC MATTER INPUTS

While no-tillage agriculture is increasingly popular and has many advantages, it's not realistic for all situations, especially for new vegetable growers. Remember, tillage is not all bad. Good tillage regimes provide aeration and a good seedbed and, most important for organic producers, knock back weed pressure.

Many growers like to think of soil organic matter as their savings account. As they build up their soils, they are putting money into their savings account. When they till the soil or grow a crop, they may draw down the account. It is important to keep putting money (organic matter) back in; otherwise, the soil and the grower might go broke.

### ADDING ORGANIC MATTER WITH COMPOST AND MANURE

Adding compost and manure to soil can increase your organic matter content. For example, in an eleven-year study in Vermont, 20 tons per acre per year of dairy manure (14 percent dry matter) were able to maintain organic matter levels at 5.3 percent in a conventionally tilled corn silage field. When they added 30 tons per acre per year, soil organic matter levels increased to 5.5

### National Organic Standards for Compost

According to the *Pennsylvania Certified Organic Guide*, composted plant and animal material must be produced through a process that:

- Established an initial C:N ratio of between 25:1 and 40:1 and maintained a temperature between 131°F and 170°F for three days using an in-vessel or static aerated pile system

~or~

- Maintained a temperature between 131°F and 170°F for 15 days using a windrow composting system, during which period the materials must be turned a minimum of five times

percent. In another study, adding 5,200 pounds of dry matter per year maintained soil organic matter (SOM) levels in conventional corn. With no manure additions, SOM decreased by almost 20 percent in eleven years (Magdoff and Weil 2005).

### PLANTING COVER CROPS TO INCREASE SOIL ORGANIC MATTER

Cover crops are planted to provide a cover for the soil grown between orchard rows, or in fields between cropping seasons, but they are not harvested. They are grown as a cover, primarily as a biological soil conservation tool, to prevent soil erosion by wind and/or water, and they foster multiple benefits. They are planted before and after the main designated cash crop in a rotation. Cover crops are used as a ground cover or mulch, green manure, nurse crop, or a smother crop.

Some of the commonly used nonlegume cover crops are listed below. Most of these are grasses, which are good for scavenging nitrogen (recovering residual nitrogen), preventing erosion, building up soil organic matter, and suppressing weeds. Classified as winter annuals, perennials, biennials, and summer annuals, grasses typically have dense masses of fibrous roots that improve the soil structure and stimulate soil microorganisms, which aggregate soil particles. The fine roots of grasses also bind soil crumbs directly.

**Annual ryegrass**, a reliable performer, can be grown all over the United States where there is moisture, grows quickly, holds soils well, and is a good scavenger of nitrogen. Cutting the ryegrass will increase dry matter and can improve overwintering, if there has been significant fall growth.

**Cereal rye**, a winter annual, is the hardiest of the cereals and may be seeded later in the fall than the other covers and still gives good soil protection, dry matter, and nitrogen scavenging. It grows all over the United States and is a good weed suppressor, by both



Cereal rye, or “rye,” is a winter-hardy cover crop and prolific producer of organic matter. Drawing: Marianne Sarrantonio.

shading weeds and releasing allelopathic compounds, which discourage seeds from germinating. It is a favorite for rolling down or mowing in spring to seed soybean into the mulch. The advantages of grasses such as rye as cover crops include low seed costs and quick fall groundcover establishment, vigorous growth, and good winter survivability. The cultivated variety ‘Aroostook’ rye does well in the Northeast; it is winter hardy, produces significant biomass, and will flower earlier than other varieties. In most places “bin run” rye without a specific variety stated is available and less expensive.

**Triticale**, a winter annual, is a cross between wheat and rye that is planted and established like wheat or rye. Often grown as a forage, it provides fall and winter cover like rye. Its biomass production and growth rate in spring are less than rye and greater than wheat.

**Winter barley**, also a winter annual, grows well in dry or light soils and in poor soils that need to be rebuilt. Barley will tolerate moderately alkaline conditions but does poorly in acidic soils with pH below 6.0. It outcompetes many weeds for soil moisture.

**Oats** are summer annuals that are low in cost and perform reliably. They can be planted as a nurse crop as a biculture in combination with hairy vetch or other winter annual legumes or perennial legumes. Oats will establish quickly in the fall and then winter-kill in Zones 6–7 and colder. They like cool, wet weather and produce prodigious biomass. They also compete well with weeds. If planted as a companion crop with legumes, oats may outcompete the legumes if planted too early (August). Wait until September to use oats as a companion crop with legumes such as Austrian winter peas and hairy vetch or other legumes. Oats can also be planted in the spring before a late summer crop. Oats may be prone to lodging in nitrogen-rich soil.

**Wheat** has nearly all the benefits of the other cereal cover crops, yet it can double as a cash crop. It has less potential to become a weed than other cereals. It is slower than barley to mature in spring. Wheat is a heavy nitrogen and water user in the spring.

See *Managing Cover Crops Profitably* (Clark 2007) for more details. See Table 1 for seeding dates and rates.

**MANAGING SOILS FOR NUTRIENTS**

Of the eighteen elements needed by plants, only four—nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg)—are commonly deficient in Pennsylvania soils when soil is maintained at the optimum pH level for crops. Of those, N is the most frequently deficient. Deficiencies of other nutrients such as sulfur (S), zinc (Zn), boron (B), and manganese (Mn) can occur, but they most often occur in regions with highly weathered soils, such as the southern states or the African subcontinent, and areas with very high rainfall, such as the Pacific Northwest (Magdoff and van Es 2009).

It is critical that we manage soils for levels that meet, but do not exceed, crop needs. The law of limiting factors was first described by Justus von Liebig (1803–1873), who analyzed plant samples that led him to propose the law. This law states that plant growth is proportional to the amount available of the most limiting nutrient. For example, if I provide nitrogen sufficient to produce 70 bushels of wheat, but only enough phosphorus for 50 bushels of wheat, I will only get 50 bushels of wheat (Miles and Brown 2007). However, also beware of applying excessive nutrients. Too many nutrients not only make an environmental hazard but can also create negative interactions with insect pests, plant diseases, and weeds, or even become toxic to plants at very high levels.

**FIRST STEP: SOIL TEST!**

Soil testing is important. Underapplying nutrients retards plant growth and will reduce your production. Overapplication of nutrients is not only expensive, it's also an environmental hazard. This holds true for organic nutrient sources as well as synthetic fertilizers. Just because you are using organic sources such as compost and manure does not mean that you should

merely apply as much compost or manure as is readily available. On a farm in southeastern Pennsylvania where mushroom compost is plentiful, one new farmer raised his soil phosphorus from low to highly excessive levels in just one year by applying a load of mushroom compost to 2 acres. Excess phosphorus and nitrogen can move into water sources, causing algal blooms that reduce water oxygen to toxic anoxic levels.

Nitrogen, a very important nutrient and one that is frequently deficient, is not included directly in most soil tests. Nearly all the nitrogen in soil is not in forms that are available to plants, and the N that is in forms that are available to plants—nitrate, ammonium, and certain free amino acids—fluctuates rapidly and widely throughout the season. A heavy rain can leach the nitrate out in a matter of hours or cause large quantities of N to escape to the atmosphere as nitrous oxide, an important greenhouse gas. Since N is so leaky and levels of available N forms can change so quickly, it is not included directly in most soil tests.

Soil organic matter content is an indirect assessment of soil N. Most labs include organic matter automatically or at least as an option on soil tests. Soil organic matter levels can be interpreted into a rough estimate of the amount of plant-available N. The amount of nitrogen that will be available within a given season can be estimated from the soil organic matter. Depending on the season's temperature and moisture, microbes can be expected to release between 20 and 60 pounds of plant-available N from each percentage of organic matter in the soil (Gaskell et al. 2006). Microbes will make more N available in warm, moist soils and less in cooler or drier soils.

If you don't know whether organic matter is automatically included in your soil test, ask. If organic matter is an optional test, be sure to check the box and pay the extra fee to find out what your soil's organic matter levels are.

**TABLE 1. COVER CROP RATES AND SEEDING DATES.**

Species	Seeding rate/A	Date	Winter hardiness
Annual ryegrass	5–10 lbs (mix)	Aug. to Sept.	Depends on variety and planting date
Annual ryegrass	10–15 lbs (alone)	Aug. to Sept.	Depends on variety and planting date
Oats	1.5–2 bu (mix)	July to late Sept.	No
Oats	3–4 bu (alone)	July to late Sept.	No
Rye	1–1.5 bu (mix)	Early Aug. to early Nov.	Very
Rye	2–3 bu (alone)	Early Aug. to early Nov.	Very
Triticale	1–1.5 bu (mix)	Early Aug. to Oct.	Most are very
Triticale	2–3 bu (alone)	Early Aug. to Oct.	Most are very
Wheat	1–1.5 bu (mix)	Sept. to Oct.	Most are very
Wheat	2–3 bu (alone)	Sept. to Oct.	Most are very

Source: Penn State Extension Crop Management Group.

**SAMPLE SOIL TEST REPORT ILLUSTRATING "DEFICIENT," "OPTIMUM," AND "EXCEEDS CROP NEEDS" CATEGORIES FOR NUTRIENT LEVELS.**

SOIL TEST REPORT FOR:				ADDITIONAL COPY TO:		
DATE	LAB #	SERIAL #	COUNTY	ACRES	FIELD ID	SOIL
11/12/2004	S00-02986		0		2122	

SOIL NUTRIENT LEVELS				Deficient	Optimum	Exceeds Crop Needs
Soil pH		6.5				
Phosphate	(P <sub>2</sub> O <sub>5</sub> )	321.0	lb/A			
Potash	(K <sub>2</sub> O)	336.0	lb/A			
Magnesium	(MgO)	1813.0	lb/A			
Calcium	(CaO)	6088.0	lb/A			

**Recommendations for:** SWEET CORN (FRESH MARKET)

### How to Read a Soil Test

Every soil test looks a little different, but in general there will be a graph that gives you a quick summary of how your soil is doing. Start there.

Soil tests provide the levels of P, K, Mg, and pH in soil. If a Penn State soil test has bars that reach all the way across into "Exceeds Crop Needs" (vegetables) or "Above Optimum" (agronomic crops), the soil has too many nutrients, which will encourage weed growth and contaminate the water supply. If bars are in the below optimum zone, there are not enough nutrients to support the next crop.

A series of recommendations will also be included. For phosphorus and potassium the recommendations are based on the amount of soluble nutrients available in the soil. For nitrogen (not tested directly because it is continually changing from one form to another in the soil) recommendations are based on the amount of nitrogen needed to attain optimal production in average soil. If your soil has high levels of organic matter, less will be needed. If this is your first soil test, follow the recommendations as a best guess. Over time, as you build your soils, the trends in the soil tests from year to year rather than the exact recommendation become more important. Are you maintaining, increasing, or decreasing your phosphorus and potassium? Are you increasing your organic matter?

Many soil testing labs have a home gardener as well as commercial vegetable, fruit, or agronomic soil testing options. Make sure you use the commercial option. Recommendations for home gardeners often do not include more detailed information and can be hard to interpret for organic growers.

### SOIL pH AND LIME

Although, strictly speaking, soil pH is not a plant nutrient, maintaining soil at the optimum pH for your crop is essential to ensuring the crop can access sufficient quantities of soil nutrients. For example, iron deficiency is a common problem in blueberries; however, the soil is rarely deficient in iron. Most often, the pH is simply too high for the blueberries to access enough iron.

Soils in Pennsylvania tend toward being too acidic for producing most crops. The carbonates in lime neutralize acidity and the calcium and magnesium in lime are essential plant nutrients. Different types of lime are available. The most commonly used are calcitic and dolomitic lime. Other forms, such as hydrated lime or quick lime, can be caustic or expensive.

Not all limes neutralize soil equally. Look at the CCE (calcium carbonate equivalent) to find out how much neutralizing capacity a given lime might have. The law requires that all limes have their CCE on their labels. For example, lime with a CCE of 50 only has 50 percent of the liming capability of calcitic lime (the baseline). So, you have to use twice as much. Dolomitic lime can actually have more than 100 percent of the CCE, so you would have to use less than the recommendation. The fineness of lime is also important. The smaller the particles, the more surface area there is to react with the soil. Fall is an excellent time to apply lime for it to react with the soil and neutralize acidity before the next crop is grown.

See Penn State Extension's *Soil Acidity and Aglime* fact sheet for more details (Beegle and Lingenfelter 1995).

## YOUR ORGANIC NUTRIENT CHOICES: Cover Crops, Manures, Composts, and Fertilizers

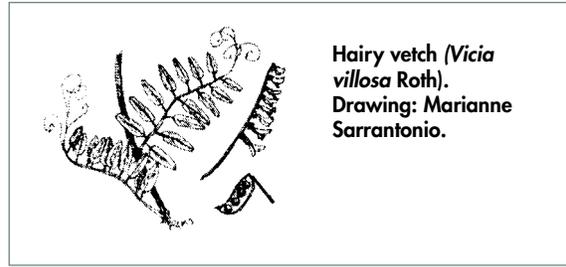
When it comes to building and maintaining soil fertility, farmers have many choices, which fall into three broad categories: cover crops, manure and manure-based composts, and commercial fertilizers. Organic nutrient sources vary in their cost, which nutrients they contain, the relative concentrations of those nutrients, and the availability of those nutrients to subsequent crops. Check your production guide for herbicide options.

### Legume Cover Crops for Nitrogen

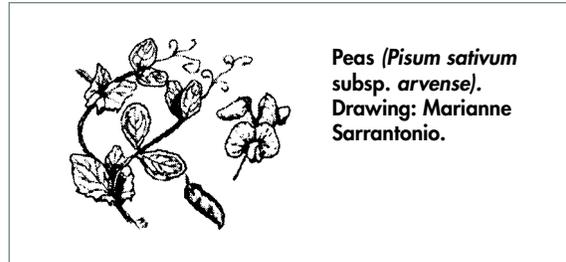
Legumes, like peas, beans, and clovers, are great organic nitrogen sources. Legumes have a symbiotic relationship with soil bacteria called rhizobia. The rhizobia use the carbohydrate energy they receive from the plant to split the bonds of atmospheric N and convert it into nitrate and ammonium, forms of N that plants can use. There are several legume cover crop options available to farmers in the Northeast. Pick one that meets the N needs of the cash crop to follow and the niche available in the rotation.

**Red clover** is a common, perennial leguminous cover crop. It is known for being winter hardy in Pennsylvania as well as easy and economical to plant. It can be broadcast and then disked in or broadcast in the early spring or late fall before a frost. The freeze thaw of a frost cycle will work the seed into the ground and it will sprout later. Red clover is slow to establish. Plant clover at 10 pounds per acre to receive 50–170 pounds of N per acre. Don't plant it in fields that have heavy weed pressure or for early season nitrogen in an annual rotation. Since red clover is a perennial, plow it in to terminate it—mowing or rolling/crimping does not kill red clover.

**Hairy vetch** is a winter annual nitrogen-fixing powerhouse. It generally produces the most biomass, fixes the most N, and has the lowest C:N ratio of legume cover crops grown in Pennsylvania (10:1). However, if it is large, it may smother out under heavy snow. The low C:N ratio and high N production means vetch commonly supplies up to 200 pounds of N to the next crop. (Remember that 200 pounds is based on how much plant material there is. If it does not grow well, the N will be little.) Hairy vetch must be established at 20–30 pounds of seed per acre in late summer the year prior to cash crop establishment. In Pennsylvania this is usually August 1 to September 15, or 6 weeks prior to the first expected frost. Planting too early or too late often results in the vetch dying over the winter. Vetch puts on the most biomass and fixes the most N between mid-April and late May. Because it is a winter annual, vetch may be terminated by plowing at any time in the spring or by rolling or mowing when the vetch is in full flower.



**Hairy vetch (*Vicia villosa* Roth).**  
Drawing: Marianne Sarrantonio.



**Peas (*Pisum sativum* subsp. *arvense*).**  
Drawing: Marianne Sarrantonio.

**Peas** are a good choice for a spring cover crop or a winter annual cover crop in Zone 6 south. Peas planted at 60–65 pounds per acre early in the season (end of March) produce up to 2.8 tons of dry matter and 166 pounds of nitrogen. Assuming 40 percent availability, 66 pounds per acre of the peas' N is available—enough for many crops.

**Crimson clover**, like hairy vetch, is another winter annual option. A moderate N producer, if planted at 18–20 pounds per acre in August or September, crimson clover will produce 70–130 pounds per acre, with 50 pounds available (Sarrantonio 1994). To terminate crimson clover in the spring, it can be mowed or rolled/crimped at full bloom (usually early to mid-May) or plowed in.

**Cowpeas** are a summer annual legume that can provide a good quick green manure for farmers who have an available summer niche. Overseeded in broccoli or other spring crops at 70 pounds per acre, they will grow quickly after spring crop harvest, contributing up to 300 pounds of nitrogen per acre to the system by late summer, although 130 pounds per acre of available N is more typical (Sarrantonio 1994). Cowpeas break down quickly and allow for establishment of a fine seedbed in time for establishing many fall or overwintering crops.

### Manure for Soil Fertility

Manure is a highly variable nutrient source. The amounts of nutrients in manure vary by the animal it came from, what the animal ate, how the manure has been stored, and how long it's been stored. For example, poultry manure generally has more N than dairy manure and fresh manure has more N than stored manure. Further, the way the manure is applied

**TABLE 2. LEGUME COVER CROP RATES AND SEEDING DATES.**

Crop	Seeding rate	Seeding date
Austrian winter pea	40–80 lbs	Aug. to Sept.
Hairy vetch	15–20 lbs	Aug. to Sept.
Crimson clover	10–15 lbs	Aug. to mid-Sept.
Red clover	8–12 lbs	July to mid-Sept.

Source: Penn State Extension Crop Management Group.

(broadcast, injected, plowed in) impacts the proportion of nutrients that are lost and the amount left for the crop. If you plan to use manure, have it tested to find out what nutrients it contains and in which proportions.

Manure does not provide nutrients in the proportions in which plants use them. In general, if you apply manure to meet plant N needs, you're applying excessive P and K. To avoid building up excessive levels of P and K in your soils, use manure to meet your P and K needs and balance out your N needs with a legume cover crop. To calculate how much manure to apply to meet your P and K needs, see *Using Organic Nutrient Sources* (Sanchez and Richard 2009) and the *Penn State Agronomy Guide*.

### Composts for Phosphorus and Slow-release Fertility

Compost is humified organic matter produced by controlled, accelerated decomposition. During the composting process, microorganisms convert raw materials such as manure, straw, leaves, and food waste into stable organic matter. To foster this accelerated decomposition process, farmers must monitor and maintain the moisture and temperature of the pile, often covering the pile to conserve moisture or turning the pile to mix the raw materials and add air. There is even more variability among composts in the amounts of nutrients they provide than there is among legumes and the amounts of nitrogen they provide. In general, composts are good sources of phosphorus and potassium, especially if they're manure based. Conversely, composts contain very little available nitrogen. Most of the nitrogen in composts is in stable organic forms.

To use compost as a fertility source, have the compost tested by an agricultural or environmental lab to find out what nutrients (and in which proportions) your compost contains. When applying compost for soil fertility, apply only as much compost as you need to meet your soil's P or K needs. Do not apply enough to meet the next crop's N needs, as that much compost would contain levels of P that far exceed plant needs and could pollute nearby surface waters. To calculate how much compost to apply to meet your P and K needs, see *Using Organic Nutrient Sources* (Sanchez and Richard 2009).

### Commercial Fertilizers

For certified organic growers, commercial fertilizers are usually the most expensive option for meeting the crop's fertility needs. The number of commercially available organic fertilizers has increased dramatically in recent decades. Many, like fish emulsion, blood meal, feather meal, and bone meal, are by-products of the meat-packing industry. Others, like alfalfa meal and soybean meal, are by-products of the feed industry. Commercial fertilizers are a good option to meet a specific nutrient deficiency quickly. These short-term benefits come at a cost. Unlike cover crops, compost, and manure, they generally do not come with the added benefits of a large organic matter input that provides longer-term slow-release soil fertility. To find a commercial organic fertilizer that could meet your short-term soil fertility needs and calculate how much you'll need to apply, see *Using Organic Nutrient Sources* (Sanchez and Richard 2009).

Conventional growers can more easily attain commercial fertilizers. See your state's commercial vegetable or agronomy guide for additional details.

### BUILDING FERTILE BIOLOGICALLY ACTIVE SOILS

As a new grower, you not only want to supply the nutrients your crop needs this year but also to slowly build your soils and enhance your soil health. Soils with high organic matter not only increase the structure of your soil but also store more nutrients and maintain large, diverse biological communities. For example, soil scientists assume about 20 pounds of plant-available nitrogen per acre per year for each percent of organic matter in the soil. A soil with 6 percent organic matter would likely provide sufficient nitrogen for most vegetable crops.

Soil biota not only enhance the physical structure of the soil, they also play critical roles in nutrient availability and cycling. For example, a type of mutualistic fungus called mycorrhizae colonize plant roots and grow networks of thin strands, acting like extensions of the plant roots. In exchange for sugars and carbohydrates from the plants, the mycorrhizae scavenge nutrients, like phosphorus from deep in the soil, and provide them to plants. Other types of biota, such as microscopic worms called nematodes and tiny soil insects, feed on soil bacteria and fungi. As they graze the soil flora they release nitrogen in forms more available to plants, acting like tiny soil cows whose "manure" is fertilizing the soil.

All the subtleties of building and maintaining diverse, active biological communities are not yet understood, but two principles generally hold true: provide abundant, diverse food sources for soil biota and enhance their habitat (less tillage/better soil structure). Including perennials and cover crops in your

rotation is a good way to provide stable food sources for soil biota. Reducing tillage, including long rotations with perennials, and increasing soil organic matter and structure tend to enhance biological diversity.

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