Building Soil Organic Matter with Organic Amendments

A resource for urban and rural gardeners, small farmers, turfgrass managers and large-scale producers

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"Soil is a living entity: the crucible of life, a seething foundry in which matter and energy are in constant flux and life is continually created and destroyed." — Daniel Hillel, *Out of Earth*, 1991.

My intention with this bulletin is to give you an appreciation for soil organic matter and what it does for the health of your soil and crops. Soil organic matter is a **dynamic** property of soil, not a static one. Building soil organic matter is something you can do for your soil, and the benefits to your soil and the health of your plants can't be overstated! If you follow practices that build and maintain soil organic matter, especially through the addition of organic amendments, you will improve the quality of your soil, reducing compaction and crusting, and increasing drainage and water-holding capacity. Plants will be healthier, may yield more, and will be more tolerant of drought, insects and diseases. You may also need less fertilizer because soil organic matter serves as a reservoir for plant nutrients. Some gardeners and farmers incorporate organic amendments into the soil as a way to recycle organic materials—thereby turning a "waste" product into a valuable soil resource. In this bulletin, you will learn what soil organic matter is, how it functions in the soil and how organic amendments can be used to build soil organic matter.

What is soil organic matter?

Soil is three-dimensional and highly dynamic. It contains abundant plant and animal life. There are four main components of soil: mineral matter, organic matter, air and water (Fig. 1).

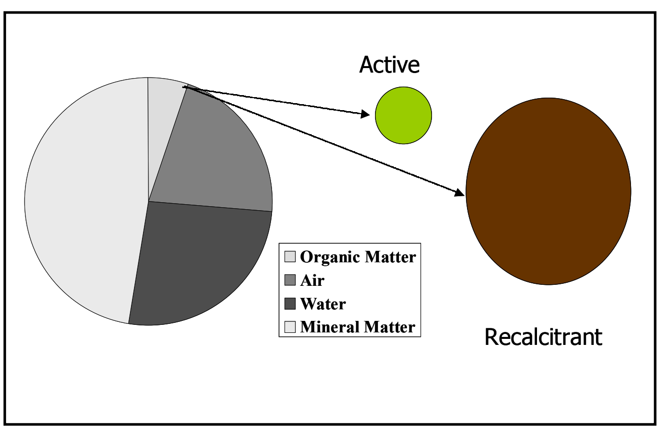


Figure 1. There are four main components of soil.

The *mineral matter* is made of sand, silt and clay size particles—the basic texture of the soil. The *soil water* contains dissolved minerals and is the main source of water and nutrients for plants. The *air* in the soil is needed for plant roots and soil microorganisms to obtain oxygen. *Organic matter* includes plant and animal materials in various stages of decomposition. Some soil scientists think of living plant roots and soil microorganisms as part of the soil organic matter.

Dead animal and plant matter begin to decompose as soon as they are added to the soil. Eathworms, beetles, springtails, and collembola, the macro (large) to meso (medium) fauna, begin to break large pieces of debris into smaller pieces. At the same time, the microbial population increases rapidly. The microorganisms consume the animal and plant remains and then die, adding themselves to the organic matter. Some organic matter is more readily decomposed than others. The end product of decomposition is **humus**—dark brown or black organic matter that is highly resistant to further decomposition.

Most soil organic matter is present near the soil surface, rather than deeper in the soil. Plant roots become organic matter as their cells slough off or as they die. Aboveground parts of the plant that are not harvested are left on the soil surface when it dies. Earthworms and insects incorporate the surface residues deeper into the soil, but the greatest concentration of organic matter still remains in the top six inches of soil.

Small component, big impact!

Most Wisconsin soils contain about 1 to 6 percent organic matter. Despite its small percentage, soil organic matter is the foundation of a healthy and productive soil. Fertility, water availability, susceptibility to erosion, soil compaction and even resistance to insects and disease *all depend on soil organic matter*!

Soils will have inherent differences in organic matter contents depending on the vegetation history and mineral parent materials. For example, the Central Sands Plainfield loamy sand typically contains less than 1% organic matter, while a bog soil can have close to

90% organic matter. The Wisconsin state soil, the Antigo silt loam, contains 1 to 4% organic matter. Crop cultivation, harvesting, erosion, and natural decomposition gradually reduce the amount of organic matter in soils. However, you can maintain and even increase your soil's current organic matter level through proper management.

Pools of soil organic matter based on decomposition level

Not all soil organic matter is created equal. Fruit and vegetable wastes are easily degraded because they contain mostly simple carbohydrates (sugars and starches). In contrast, leaves, stems, nutshells, bark and trees decompose more slowly because they contain cellulose, hemicellulose and lignin. The ease with which compounds degrade is determined by the complexity of the carbon compounds and generally follows the order: carbohydrates > hemicellulose > cellulose = chitin > lignin.

In contrast to fresh plant residues, composted organic materials decompose slowly when added to soil because they have already undergone a significant amount of decomposition during the composting process (Fig. 2).

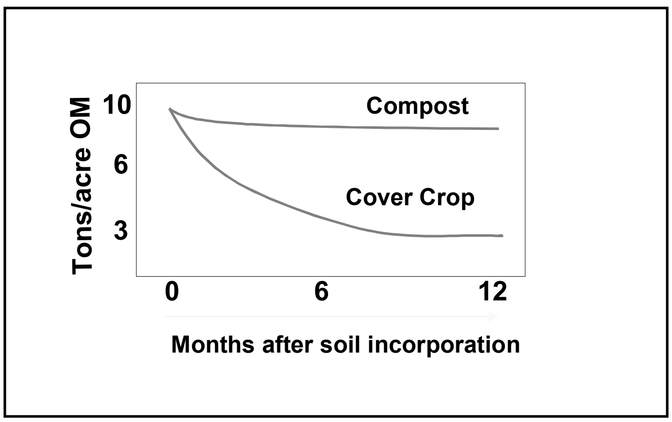


Figure 2. Composted organic materials decompose more slowly than fresh organic matter because they have already undergone a significant amount of decomposition.

Thus soil organic matter can be differentiated into **pools** or **fractions** based on their availability for microbial breakdown. The active fraction has the highest turnover rate: 1 to 2 years. The intermediate pool turns over in two to five years. The recalcitrant or stable pool is well-decomposed organic matter that is chemically or physically resistant to breakdown, taking more than 10 years (Fig. 3).

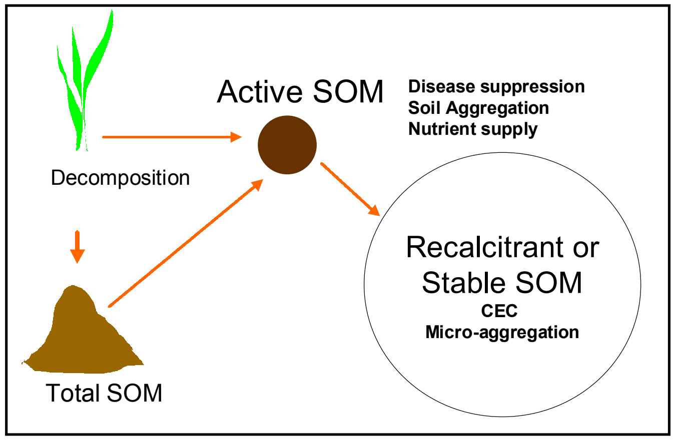


Figure 3. The different pools of soil organic matter (active and recalcitrant) play different roles in soil function.

Well-decomposed organic matter no longer provides as many nutrients for plants and soil microbes as the active pool, but it does play important roles in the soil, such as promoting water and nutrient retention, and prevent soil compaction and crusting.

How does soil organic matter improve soil properties and functions?

Soil organic matter is often viewed as the thread that links the biological, chemical and physical properties of a soil. It has been associated with numerous soil functions like nutrient cycling, water retention and drainage, erosion control, disease suppression and pollution remediation (Table 1).

Table 1. How soil organic matter affects soil quality.

1. Stores and supplies plant nutrients (N P K and micronutrients; increases cation exchange capacity.
2. Stabilizes and holds soil particles together as aggregates.
3. Helps soil to resist compaction, promotes water infiltration, and reduces runoff.
4. Aids growth of crops by improving the soil's ability to store and transmit air and water, as measured by improved porosity; water holding capacity, and drought resistance.
5. Makes soil more friable and easier to work so that plant roots can penetrate the soil profile better.
6. Provides a source of carbon and energy for soil microbes which cycle nutrients and fight plant diseases.
7. Reduces the negative environmental effects of pesticides, heavy metals and other pollutants by binding contaminants.

Soil fertility and nutrient supply

Plants obtain essential nutrients from fresh organic residues as they decompose in soil. The nutrient value of soil amendments and plant residues can be assessed by analyzing the amount of nitrogen, phosphorus and potassium (N-P-K) they provide. However, knowing the total amounts of N, P and K doesn't tell you how much will become available for crop uptake during the growing season. Plant available amounts of N, P and K are often estimated as some percentage of the total N-P-K in the amendment or residue. For example, available N from manure is estimated at 25-40% of the total N content (depending on manure type, age and manure storage practices). Available N from compost is estimated at less than 10% of total N, because the composting process stabilizes organic N.

The active fraction of SOM has been most closely associated with nutrient supply. However, the stable, recalcitrant soil organic matter pool also improves soil fertility by holding plant nutrients and preventing them from leaching into the subsoil out of reach of plant roots. The SOM has a net negative charge and nutrients such as calcium, magnesium, potassium and ammonium (called cations) have a positive charge. The capacity of a soil to hold plant nutrients so that they are easily released or "exchanged" into the soil solution is measured by the *cation exchange capacity* or CEC. Soil CEC is estimated from the sum of exchangeable cations in the soil.

Soil organic matter also binds plant micronutrients like iron, aluminum, zinc, copper and manganese by chelation—a chemical association of organic matter and micronutrients that keeps the micronutrients in a form available for plant uptake.

Soil pH buffering capacity

Organic matter has the ability to moderate major changes in the soil pH. Soil pH is a measure of acidity or alkalinity as determined by the amount of positively charged hydrogen (H^+) ions in the soil solution. Organic matter buffers the soil against major swings in pH by either taking up or releasing H^+ into the soil solution, making the concentration of soil solution H^+ more constant. The result is a stable pH close to neutral or suitable for the specific crop to be grown.

The blue color in hydrangea flowers is a classic example of buffering pH with organic matter. The blue color results from plants taking up available aluminum from the soil under low pH or acid conditions. High pH or alkaline soils don't have enough available aluminum to turn the hydrangea flowers blue, and their resultant color is either pink or white. When organic matter is added to alkaline soil, it grabs or **chelates** the aluminum and pulls it into the soil solution in a form that hydrangea plants can take it up. And then their flowers turn blue!

Soil structure and tilth

Many people often use soil texture and structure interchangeably. There is a difference, however. **Soil texture** is defined as the proportion of sand, silt and clay size particles. The *arrangement* of these primary soil particles into **aggregates** is the **soil structure**. The aggregates are held together chemically and biologically by the "glue" of organic matter. (Fig. 4)

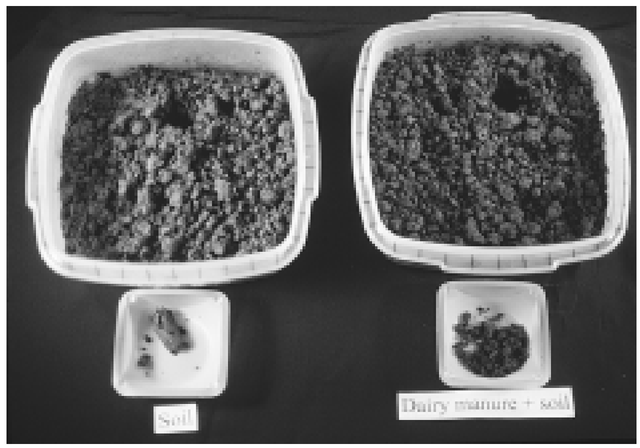


Figure 4. Dairy manure added to a silt loam soil improves soil structure, especially the formation of macro-aggregates.

When fresh organic matter is added to the soil, soil microbes release long-chain sugars or polysaccharides relatively quickly. These polysaccharides promote formation of large or **macro-aggregates**. As the organic matter decomposes over the longer term, different sizes of aggregates are formed that are resistant to physical disruption. The number and diversity of stable soil aggregates are what give a soil an excellent physical structure.

A soil with a good physical structure will have pores and channels of many sizes, from the tiniest channel to large spaces that will allow rainfall to penetrate without running off and taking soil with it. Soil organic matter helps to form and maintain the air passages and channels, protecting the soil from compaction.

When a soil has plenty of spaces for air passage, holds water well without becoming too wet, is not compacted, and has a good physical structure for plant roots to grow and explore, we say it has good **soil tilth**. Organic matter is one of the key components to good tilth.

Soil organic matter reduces erosion

The degree of surface soil aggregation will determine how tightly the soil particles are held during rain or wind storms. Stable soil aggregates resist movement by wind or water because they are larger than primary particles of silt or clay. Soil pores created by aggregation also promote water infiltration, thereby reducing runoff and the likelihood that soil particles will be transported with the water.

Crop residues, vegetative cover or mulches on the soil surface will also slow down water as it impacts the soil during a rainstorm, giving it a better chance to seep into the soil.

Preventing soil erosion conserves soil fertility because the most fertile soil is the top few inches.

SOM supplies carbon and energy to soil microbes

A soil rich in organic matter and regularly supplied with different kinds of soil organic matter will support a rich and varied population of soil organisms. There is a complex food web below ground similar to the food web above ground.

Organic matter provides a carbon source for **primary producers** like cyanobacteria that can convert atmospheric nitrogen to plant available N forms. Organic matter is the principle food source for **secondary consumers**. The most predominant functional group of secondary consumers are the decomposers: bacteria, fungi and actinomycetes. Decomposers quickly colonize newly-added organic materials and begin the decomposition process. It is during this decomposition process that nutrients become available to plants, humus is created, and soil-building aggregation and channels are formed.

A soil populated by a diverse, active microbial population is less likely to support uncontrolled spread of plant pathogens (Cook and Baker, 1983). Interactions between beneficial soil organisms and plant pathogens create situations in which pathogens are suppressed or inhibited, especially soil-borne pathogens. Some soil microorganisms are antagonistic to plant pathogens, creating an unfavorable environment for them to grow. Others compete against pathogens, effectively keeping the pathogen population in check. There is also evidence that soil microorganisms can induce the plant itself to fight disease. This phenomenon is called systemic acquired resistance (SAR) (Fig. 5).

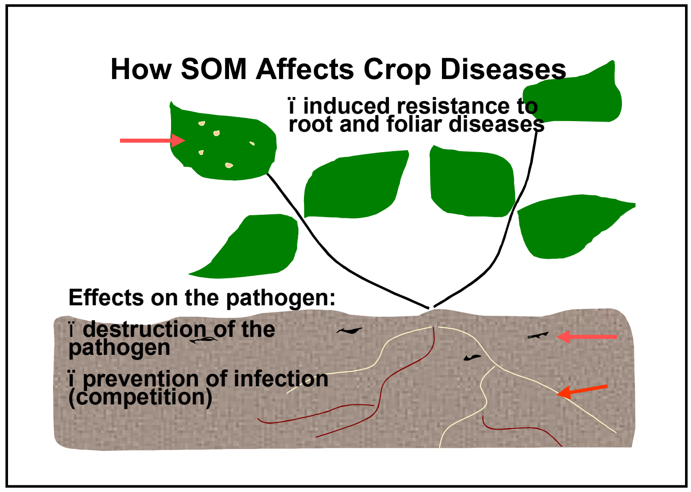


Figure 5. How soil microorganisms help prevent plant disease. (Figure courtesy of Dr. Alex Stone, Assistant Professor, Horticulture, Oregon State University, Corvallis, OR)

We are only beginning to appreciate the numerous roles soil organic matter and the associated microorganisms play in the productivity and health of soils. For example, research studies show that moderate application rates (5-10 tons/acre) of organic amendments (both raw and composted) can reduce the incidence and severity of root rot diseases like Pythium.

SOM buffers environmental pollutants

Just as soil organic matter buffers the soil from rapid changes in soil pH, it also binds organic pollutants, keeping them out of the soil solution where they would be taken up by plants or leached into ground water. Organic matter also provides sites for microbes to colonize and decompose organic pollutants.

Soil organic matter has been shown to protect plant roots from potentially harmful levels of aluminum, which occur in some acid soils, and also from certain herbicides that are potentially toxic to plants.

SOM sequesters carbon and can mitigate greenhouse gas emissions

There is an emerging awareness of global warming and its connection to human activities that promote greenhouse gas emissions (carbon dioxide or CO_2, methane or CH_4, nitrous oxide or N_2O). **Carbon sequestration** or storage in soil is considered a means to reduce greenhouse gas (CO_2 or CH_4) emissions. Building and maintain higher soil organic matter levels should translate to lower levels of CO_2 being given off to the atmosphere. Research is underway to quantify the effects of different cropping systems and tillage practices on carbon sequestration.

Building soil organic matter

The first step in effective management of soil organic matter is to determine your management goals (Figure 6). Do you want to build the amount of soil organic matter quickly? Do you want to supply nutrients in the first year of amendment application? Or is your main goal to improve the structure of the soil, gradually over time?

Choose those practices that are most effective in promoting the goal(s) you have in mind for your soil. Building and maintaining soil organic matter requires a sustained effort. But it can be done.

Building soil organic matter with cover crops and green manures

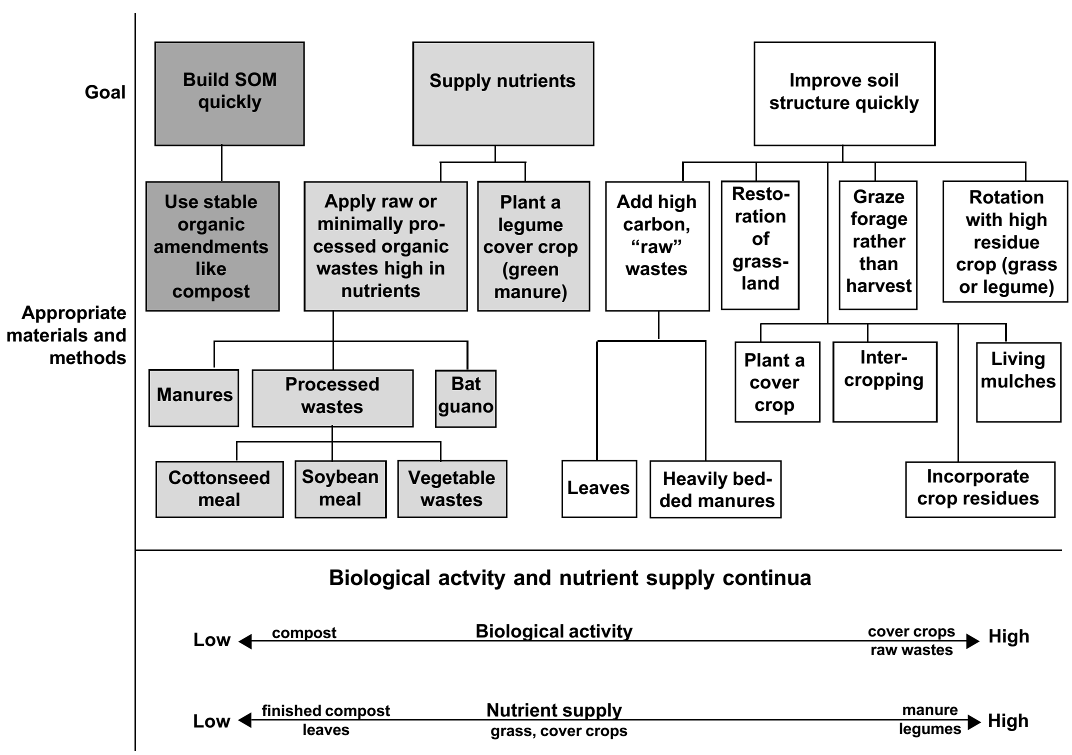
Cover crops are those crops planted after the main (cash) crop is harvested. Some cover crops are seeded over the standing cash crop so they can get a head start on growth while the cash crop is still in the field. Cover crops are usually killed the following spring, prior to planting the next season's cash crop.

Planting cover crops or green manures build soil organic matter in several ways. Both protect the topsoil completely and greatly decrease soil erosion by reducing raindrop impact. Cover crops reduce leaching losses by utilizing excess nutrients, especially nitrogen, after the main crops are harvested (Table 2). Green manures are cover crops that are managed to provide

Table 2. Ability of cover crops to scavenge nitrogen (N) in the fall.
(Staver and Brinsfield, 1997)

Cover crop	N uptake by December (lb/acre) following corn
Cereal rye	71
Wheat	40
Ryegrass	38
Brassica (mustard)	35
Oats	28
Barley	32
Legumes (various)	10

Figure 6. What is your management goal?



nutrients to the next season's cash crop by killing them while they are still green. Usually legumes and other nitrogen-fixing plants such as clover and vetch are used as green manures for their nitrogen supply (Table 3). Decomposition is rapid and nitrogen is released. Grasses can also make good green manure crops if they are killed early.

Table 3. Relative N value of certain cover crops
(Source: Sarrantonio, 1994.)

Legume	N-fixation capacity
Alfalfa	High
Hairy vetch	High
Crimson clover	Moderate
Field peas	Moderate
White or red clover	Moderate
Common bean	Low

High = greater than 150 lbs. N/acre
Moderate = 50 to 150 lbs. N/acre
Low = less than 50 lbs. N/acre

The extensive root systems of cover crops contribute to the soil organic matter while the crop is still alive. Some cover crops won't survive a hard frost and don't overwinter, such as oats and vetch in Wisconsin. If the cover crop survives the winter, most farmers kill the crop several weeks before the next crop is planted and till the residues into the soil. As the residues decompose, they build SOM.

Building soil organic matter with organic amendments

There is no end to the number of possible organic amendments available for your soil. Many are currently considered "waste" products or by-products from farm enterprises, food processors, municipalities or industry. They can be applied raw or following some kind of processing like anaerobic digestion, composting or drying/pelletizing. Common organic amendments available in Wisconsin include:

1. On-farm wastes: manure, crop residues, spoiled straw, hay and silage.
2. Municipal wastes: yard debris and biosolids (sewage sludge).
3. Organic wastes from food processors: vegetable, meat, fish, dairy.
4. Organic wastes from paper mills and the timber industry.
5. Post consumer food wastes (restaurants, institutional cafeterias).
6. Pre-consumer food wastes from grocery stores and supermarkets
7. Composts

Amendment or fertilizer?

Whether an organic soil amendment can be considered a "fertilizer" or general soil conditioner depends on its effect on plant nutrition.

Fertilizers are a source of readily available nutrients and have a direct, short-term effect on plant growth. Soil conditioners affect plant growth indirectly by improving the physical and biological properties of the soil, such as water retention, aeration and microbial activity and diversity.

Animal manures and biosolids (sewage sludge) are good examples of organic amendments with fertilizer value. Both can supply N, P and K needs of many crops because greater than 25% of their total N, P and K contents are in forms readily available for crop uptake. Amendments like municipal yard waste, bark and composts are examples of soil conditioners. They are not considered fertilizer substitutes, but mainly they improve soil properties by building soil organic matter.

C:N ratio

All organic matter contains some carbon and some nitrogen. The relative amount of each present (the carbon to nitrogen ratio) will determine whether nitrogen, and sometimes other nutrients, will be tied up in the decomposition process. Decomposition of materials with a low C:N ratio like animal manures (less than about 20:1) will release nitrogen, while the decomposition of high C:N materials such as straw or sawdust, will require that soil microbes use the amendment N for their own metabolic needs.

Table 4 lists some average ratios for common organic by-products. Green materials usually have lower C:N ratios than woody materials or dead leaves. Animal wastes are more N rich than plant wastes.

Characteristics of specific organic soil amendments, their production in Wisconsin, and guidelines for use

Animal Manures

In general, raw manures are a good source of N, P and K as well as organic matter. There are major differences in nutrient contents among livestock species

Table 4. Common organic amendments and their C:N ratios
(Adapted from various sources, including Rynk, 1992, to illustrate representative values.)

Organic amendment	C:N
High in carbon	
Corn stalks	60-70
Straw	40-150
Corn silage	40
Fall leaves	30-80
Sawdust	200-700
Brush, wood chips	100-500
Bark (paper mill waste)	100-130
Newspaper	400-800
Cardboard	500
Mixed paper	150-200
High in Nitrogen	
Hay	15-30
Dairy manure	5-25
Poultry manure	5-15
Hog manure	10-20
Cull potatoes	18
Vegetable wastes	10-20
Coffee grounds	20
Grass clippings	15-25
Municipal biosolids	9-25

(Table 5). For example, poultry litter typically has higher concentrations of N and P compared to dairy manure. Wisconsin is home to close to 2 million dairy cows. Each full-grown dairy cow produces approximately 80 lbs manure/day; statewide this translates to over 30 million tons of manure produced annually. Most of this manure is spread directly on croplands associated with the dairy operations.

Table 5. Rule of thumb average nutrient content from various solid and liquid manures (not composted)

Type of Manure	lbs. per ton (solid) lbs. per 1000 gallons (liquid) N	P_2O_5	K_2O
Dairy, solid	10	5	9
Beef, solid	14	9	11
Swine, solid	14	10	9
Duck, solid	17	21	30
Chicken, solid	40	50	30
Turkey, solid	40	40	30
Sheep, solid	26	18	40
Horse, solid	10	6	10
Dairy, liquid	24	9	20
Veal calf, liquid	15	10	25
Beef, liquid	20	9	20
Swine, liquid indoor pit	50	42	30
Swine, liquid outdoor pit	34	16	20
Swine, liquid, farrow-nursery indoor pit	25	23	22
Poultry, liquid	16	10	12

These data are taken from a combination of Midwest Plan Service (2000), manure analysis from Wisconsin certified soil testing laboratories (2002), and University of Wisconsin-Extension publications.

Guidelines for use

Since manures are most commonly applied to soils based on their N contents, application rates can vary from 3-5 tons/acre for poultry litter to 25-40 tons/acre for dairy manure. Till fresh manure into the soil in the late fall or early spring.

Manure can be applied raw or composted. Composting changes the qualities of the manure. For example, nutrient availability will be lower after composting. But the composted manure is much more biologically stable. This means that the effects of the organic matter will be longer lasting. Composted manure is odor, weed and pathogen-free and can be stored for a longer time (Table 6). See *The Art and Science of Composting* in **Resources** for details on how to compost manure.

Table 6. Qualities of raw and composted manure

Raw manure	Composted manure
High available nutrients: N,P, K	Low available nutrients, esp. N
Heterogeneousóhigh volume	Homogeneousólow volume
Very biologically active	Biologically stable
Strong odor	Non-offensive odor
Wet	Moist-dry
May contain weed seeds and pathogens	Weed seeds and pathogens killed

Precautions in using manure

Salts, especially sodium, in raw animal manures can be high enough to cause problems for plant growth. If raw manure is land-applied, it is important to incorporate the manure into the soil to dilute salt concentrations. Also, it is best to allow rain or precipitation to leach out some of the salts before you plant. Potassium (K) can build up in surface soils from long-term applications of manure. This can lead to increased concentrations of K in livestock feed, which has been associated with some cattle health problems.

Raw manures often contain weed seeds and pathogens. Pathogens found in the animal digestive system will usually not survive in soils, especially if the manure is applied several months prior to crop planting or harvesting. If fresh manure is applied to vegetables, apply at least three months before crops are harvested. Weed seeds can survive in manure-amended soils long after the manure is applied. The types and amount of weed seeds will depend partly on animal feed sources and where manure is stored prior to land spreading.

Farmers applying manures to supply nitrogen (N) are often applying too much phosphorus (P), because manures contain similar amounts of N and P, yet crops need about six times more N than P. A long-term consequence of fertilizing soils with manure is that P builds up in the soil and may be lost in runoff. One way to minimize P loss in runoff is to reduce manure application rates to supply only the P needs of the crop. The tradeoff in this approach is the need for supplemental N from other sources and reduced additions of organic matter.

Crop residues, spoiled hay and straw

The parts of the plants remaining after you have harvested the usable portion are called crop residues. They are an important source of organic matter. It requires no extra time or labor to grow the material or to leave it in place. Beneath the soil surface, decaying roots are also adding to the soil organic matter. Although crop residues add organic matter, diseased plant parts left in the field can serve as inoculum that could infect the next year's crops. So it is important to remove diseased plant residues and compost them before you return this organic matter to the field. Rotating crops also reduces the transmission of many soil-borne diseases.

Leave crop residues on the surface to increase soil aggregation and protect the soil surface from crusting. Soil crusts are caused by raindrop impact and freeze-thaw processes that break soil aggregates into fine particles, creating a seal over the soil surface.

Spoiled hay, straw and silage can be applied to soils as organic amendments. However, these materials are high in carbon and very biologically active. As such, they should be applied in the fall or at least two months prior to crop planting to avoid nutrient tie up during the active phase of their decomposition.

Municipal yard waste

Municipal yard waste includes leaves, brush and grass clippings that are collected curbside in most municipalities. Fresh yard trimmings can contain 1.2-2.3 % N, 0.2-0.3% P, 0.5-1.0 % K, 50-60% organic matter and pH values between 5-6 (Cogger et al., 2002). Nutrient contents increase in relation to the proportion of grass clippings in the mix. Wisconsin, like most states in the U.S., has a ban on sending these materials to the landfill. In 2000, Wisconsin recovered and recycled approximately 225,000 tons of yard waste (Goldstein and Madtes, 2001).

Yard wastes are either composted or applied directly to farmland. Composting municipal yard waste varies from intensive, well-managed operations that sell the finished compost to facilities that occasionally turn piles and give away the finished product. Low-intensity management of yard waste composts frequently leads to variable, low quality finished products that often contain woody debris, trash and weed seeds ("buyer" beware!).

Guidelines for Use

Composted municipal yard waste can used in home gardens, landscape plantings, establishment of turf grasses and green spaces and for erosion control on steep hillsides. For most of these applications, it is important to use biologically stable, screened finished compost. Application rates vary from 1/2 to 3 inches applied to the surface of the soil. In most cases, it should be incorporated into the top 6 inches of the soil. It can also be used as a mulch for trees and shrubs.

Fresh yard trimmings can be applied to agricultural fields to build soil organic matter. However, it is best to apply leaves in the fall to give them ample opportunity to break down before the next year's crop is planted. In one study (Peterson, 1991) 20-40 tons/acre of leaves were applied to a corn field each fall. The leaves decomposed in fall and early the next spring, increasing soil organic matter. The high application rate of leaves received supplemental N to lower the C:N ratio of the leaves. All leaf-amended plots and controls (no leaves) produced similar corn yields the following year, demonstrating that fall leaf applications minimize the chances of decomposing leaves robbing N from the corn crop.

Experiences with on-farm "leaf mulching" in New Jersey showed that a 3-inch layer of leaves chisel-plowed into the soil surface improved soil aggregation and increased soil water holding capacity (Kluchinski et al., 2002). Crops grown the spring following leaf application showed reduced drought stress. However, increased soil moisture in the spring prolonged germination of some broadleaf and grass weeds. A 6- inch layer of leaves proved to hold too much moisture and tie up too much N, reducing crop yields.

Precautions
In general, fresh yard trimmings are more difficult to land spread than composted yard trimmings. Leaves and chipped brush can be difficult to till into the soil. Yard trimmings need to be spread as soon as they are delivered to minimize odor generation.

Biosolids (sewage sludge)

Biosolids are by-products of municipal wastewater and sewage treatment. There are several technologies in use that separate and de-water solids following aerobic (with oxygen) or anaerobic (in the absence of oxygen) digestion of municipal sewage. Some wastewater treatment facilities use lime or organic polymers to precipitate and coagulate the solids. Some use wood or coal ashes to chemically stabilize and separate the solids. Others use belts and presses to squeeze excess water out of the solids. Digested, dewatered biosolids commonly contain 3-6%N, 1-4%P, 0.2-1%K and 50-60% organic matter. Biosolids also contain Ca, Mg and trace metals. Water contents can range from 70-95% by weight, depending on the process.

Guidelines for use
At present, there are two classes of biosolids that can be used in agriculture: class A and class B. The major difference between the two classes is the acceptable pathogen load. Class A biosolids have lower pathogen loads than class B; as such, class A are considered "exceptional quality" and can be distributed to the general public for higher value crops like turf, home gardens and vegetable crops.

Direct land application of class B biosolids is regulated by the federal government. All municipalities with land spreading programs follow strict guidelines about which crop fields can receive biosolids and what application rates can be used. Typically, biosolids are applied to meet the nitrogen requirements of the crops grown (application rates can range from 10-25 wet tons/acre). They are most commonly applied to field crops like corn and soybeans. Municipalities apply biosolids either in the fall (after crop harvest) or in spring (prior to crop planting). In Wisconsin, they are not allowed to winter spread. Biosolids are either injected below the soil surface as a semisolid or surface applied and tilled into the top 6" of soil.

There are a growing number of municipalities that are seeking to diversify their land spreading programs to produce class A biosolids. Heat drying and pelletizing and composting are two accepted technologies used to produce class A biosolids products.

For example, the city of Milwaukee has been marketing a fertilizer product called Milorganite for several decades. Milorganite is 100% organic activated sewage sludge in a fine granular form. It is heat-treated for sterilization and is inoffensive and easy to handle. Milorganite is high in nitrogen (6-2-0) and a good source of iron and trace elements that are slowly released. Milorganite is easy to apply to lawns, planting beds or as a soil mix. The turf industry (golf courses, city green spaces) has long recognized the fertilizer value of this product. Cities in other states have been producing biosolids composts for use in potting mixes.

Precautions
Most of the concerns about biosolids are with class B materials. Potential concerns include the presence of pathogenic organisms such as bacteria, protozoa and viruses, excess salts, the presence of heavy metals such as copper, lead, cadmium and the presence of organic contaminants such as polychlorinated biphenyls (PCBs or dioxins) and "endocrine disrupter" type compounds. It is important to note that the concentrations of heavy metal and organic toxins in biosolids have been declining over the past 20 years because the discharge of sewage contaminated with metals or organic toxins from industrial sources is no longer allowed.

Alkaline (high) soil pH conditions can result from biosolids treated with lime, especially in soils with low pH buffering capacity. As with livestock manures, applications of biosolids to meet N crop needs have led to buildup of soil P over time. Accordingly, biosolids and manures share similar concerns related to non-point source pollution of water bodies.

Wastes from dairy, vegetable, fish, meat and poultry processing industries

The state of Wisconsin is a leading cheese producer in the U.S. For every one pound of cheese produced, approximately 9 pounds of liquid whey result. The Food and Drug Administration defines whey as "the liquid substance obtained by separating the coagulum from milk, cream, or skim milk in cheese making."

Wisconsin dairy facilities deal with approximately 19 billion pounds of liquid whey by-product every year. Whey by-products are either reused to make other food products or spread on land as wastes. In the past, raw whey (containing approx. 93% water and 12 lbs. N per 1000 gallons) was separated from waste water and land-applied to crops as a fertilizer. Today, most of the material that is land spread is whey permeate (the by-product left after the protein has been removed). Whey permeate contains 0.4% solids, 6.5% sodium, 25% potassium and 21% chloride.

Wisconsin is also home to a large fruit and vegetable processing industry. All food processing facilities have waste water discharge permits, and land spreading of their solid wastes is part of their strategy to minimize point-source pollution of surface waters. Both solid wastes and liquid effluent from canneries and fruit processors (e.g. cranberry processors) can be applied to cropland. Most fruit and vegetable wastes have a low C:N value and will decompose rapidly. This will result in intense microbial activity and short-term improvement in soil structure and nutrient levels. However, these wastes have high water contents, and composting the vegetable wastes simplifies handling and spreading of the organic material Composting will also produce an amendment that will release nutrients more slowly and provide organic matter that is more stable and longer-lasting.

Meat packers and processors, also numerous in Wisconsin, produce wastewater treatment residuals (sludges), paunch manure (manure left in the animal gut after slaughter) and manure collected from the barns used to house the livestock before storage. Poultry processors produce offal (intestines, unwanted animal parts), feathers, wastewater sludge and some manure. Fish processors produce similar waste products like wastewater treatment residuals and unwanted fish parts. Most of these wastes are direct land-spread under strict state permit guidelines.

Precautions

Whey contains milk sugars that are easily degraded, resulting in a very high biological oxygen demand (BOD) when applied to the soil. This can be toxic to crops if applied shortly before crop planting. If whey runs off crop fields into streams, the high BOD can deprive oxygen to fish and kill them. Salt accumulation from land spreading is a major concern in addition to the high BOD.

The greatest concern about organic amendments from the fish, meat and poultry industries are with odors, excess nutrients and high BOD. Some meat processors sell their wastes to other processors who convert these materials into fertilizer products or organic soil amendments such as feather meal and fish emulsion. There has been some composting of these types of wastes in Wisconsin.

Wastes from paper mills, timber and paper products

Paper mill sludge is one of the largest under-utilized organic by-products in Wisconsin. Paper mill residuals are either land filled or land spread, but over 60% (740,000 dry tons) are still land filled.

Historically, paper mill wastes contained high levels of organic contaminants (PCBs, dioxins) and heavy metals. The presence of these contaminants prevented land spreading. However, most paper companies have changed the way they make paper so that less contaminated residuals are produced. As land fill options decline for both economic and environmental reasons, the paper industry is shifting focus to beneficial reuse. There are a growing number of paper companies in Wisconsin with permitted land spreading programs.

Paper mills that combine primary residuals from the paper making process itself with the secondary wastewater treatment sludges create sludges with a C:N ratio less than 20:1. This makes them quite suitable for crop production. The residuals are mostly organic matter, but also contain calcium carbonate (lime) or clay used as binders and fillers in paper making. Farmers can contact local mills to see if they have a program.

Guidelines for use

Typical application rates are based on N supply and range from 5-20 dry tons/acre. Residuals from deinking (recycling) mills have much higher C:N ratios (>50:1) and their use for crop production is limited. Paper mill residuals with high C:N ratios should be applied in fall to allow time for decomposition.

A mill in Northwest Wisconsin has conducted farm trials using high C:N residuals to control weeds in alfalfa stands. Since alfalfa makes its own nitrogen, it can grow and out-compete grass and broad-leaved weeds that are deprived of N from the high C:N residuals.

Paper mill residuals contain approximately 30% solids and can be composted with bark, a by-product from pulping, to make a high value soil amendment.
Use of paper mill sludge, either raw or composted, holds promise from a soil quality perspective. In coarse-textured sandy soils, increases in organic matter

content can quickly improve soil chemical, biological and physical properties. Our research has shown that that paper mill residuals applied to vegetable fields in the Central Sands region of Wisconsin increased the water holding capacity and plant-available water by 33%-80% (Foley and Cooperband, 2002). Paper mill residuals also reduced incidence of root rot diseases in snap bean.

Wisconsin supports a strong timber industry, which generates a substantial amount of sawdust throughout the state. A survey by the USDA Forest Service reported sawdust production in Wisconsin of more than 409,000 and 46,000 fresh tons for hardwood and softwood species, respectively. Presently, many of the by-products of the timber industry are used to produce animal bedding, mulches or biofuels.

Wood ash is another by-product of the timber industry. Many mills landfill ash generated from burning wood as a biofuel. However many ashes possess liming value and some fertilizer (P, K, Ca, Mg) value. Application rates from 5-20 dry tons per acre were shown to increase alfalfa yields (Meyers and Kopecky, 1998).

Precautions

Concerns about use of paper mill residuals in crop production relate mostly to the C:N ratio of the material and potential presence of organic toxins. There are also concerns about increasing soil pH with lime-containing residuals, especially if fields receive repeated applications of paper mill residuals. High soil pH has been related to potato scab disease in potatoes grown on sandy soils.

The greatest concern about direct land spreading of wood by-products like sawdust and wood chips and incorporation with soil is their very high C:N ratio (often greater than 100:1). This property can result in severe and long-lasting N tie-up in the soil. However, the physical properties and high carbon contents make wood by-products ideally suited to be composted with other organic wastes generated in Wisconsin. These include livestock manures and food processing wastes.

Peat

Peat is a partly-decomposed plant material that slowly accumulates in pond and lake bottoms and swamp areas. Sphagnum peat moss is younger and coarser than muck or sedge peat, which is a fine-textured, more decomposed type of peat.

Peat mosses can hold water and nutrients ten to fifteen times their own weight when fully saturated, yet still can hold 40% air. They have little nutrient value themselves, but are excellent at holding nutrients to prevent them from leaching from the soil or container mix. Peat moss is the predominant component of commercial potting mixes.

Issues of concern include the low pH (3.7-4.5) and the fact that peat is a non-renewable resource. Commercial nurseries that depend on peat as a growing medium are finding that high-quality sources are harder to obtain. Fortunately, composts are being developed to serve as peat substitutes.

Compost

Composting transforms raw organic waste materials into biologically stable, humic substances that make excellent soil amendments. Compost is easier to handle than manure and other raw organic materials, stores well and is odor-free.

Compost has a unique ability to improve the chemical, physical, and biological characteristics of soils. It improves water retention in sandy soils and promotes soil structure by increasing the stability of soil aggregates. Soil becomes microbially active and more suppressive to root pathogens. Enhanced microbial activity also accelerates the breakdown of pesticides.

Compost can be purchased or made at home or on-farm. Common composting materials (called *feedstocks*) are poultry, hog and cattle manures; food processing wastes; biosolids; leaves, brush and grass clippings collected by municipalities; and sawdust, wood chips and bark from wood processing.

Ideally, at least two raw materials should be mixed together. Highly biodegradable ingredients such as biosolids, manure, and yard waste should be incorporated into blends at rates under 15-20%. Blended mixes should have a C:N ratio between 25-40:1 and moisture content around 50%.

See *The Art and Science of Composting* (**Resources**) for a detailed discussion about how to compost.

Spent mushroom compost

Spent mushroom compost is the organic material that remains after the mushrooms have been harvested. It is usually a composted mixture of manures and straw. The concerns about use of spent mushroom compost either as a soil amendment or as a component in container mixes are quality inconsistency and high soluble salts.

Guidelines for using composts

Compost makes an excellent medium for growing plants, provided it is a mature compost with characteristics that promote plant growth (Table 7). Nutrient content, water holding capacity, bulk density and organic matter content should all be measured.

Table 7. Preferred compost characteristics for growing media

(From U.S. Composting Councilís Field Guide to Compost Use.)

Parameter	Value Range
pH	5.5-8.0
Moisture content	35-55%
Particle size	1/2î screen or smaller
Stability	Stable to highly stable; provide nutrients for plant growth; no substantial shrinkage
Maturity/growth screening	Demonstrated ability to enhance seed germination and plant growth
Soluble salt concentration	3 dS (mmhos/cm) or less

- **Turf establishment and renovation**. Soils low in organic matter, nutrients and water holding capacity will benefit greatly from compost addition. Recent research has shown that use of high quality compost can degrade some turf pesticides over time reducing risks of water contamination. Fine particle size is usually recommended to ensure good seed-to-soil contact.

- **Flower and vegetable beds.** Successful recipes for annual and perennial beds include 20-40% compost by volume incorporated into native soil or included in commercial topsoil mixes. Compost quality parallels that for container media, soluble salts should be 2.5 dS or less.

- **Field nursery production.** Growing nursery plants can result in a tremendous mining of topsoil in just a few years. The conventional practice for building organic matter is planting cover crops. However, this practice does not build enough organic matter over the short-term and should be supplemented with annual compost applications. Characteristics of compost for field nursery production are similar to those described for container media, except that particle size can be larger (up to 1 inch) and the compost can be less mature or stable if applied the fall before planting. Recommended application rates are 1-3 inches tilled into the top 6 inches of soil.

- **Backfill mix.** Amending backfill with compost encourages plant establishment and survivability. It may also reduce damage from soil-borne diseases. Highly stable composts rich in nitrogen are best.

Precautions for compost use

Low application rates are recommended for salt sensitive crops including dogwoods, narrow-leaf evergreens and ericaceous crops. Salt damage is more likely to occur in sandy soils with low organic matter contents and low cation exchange capacity. You can delay planting until amended soil has received rainfall or irrigation water to leach salts from soil. Soluble salts should not exceed 1.25 dS for seeds, young seedlings or salt-sensitive crops (e.g. geraniums).

Unfinished composts can contain high ammonium, salts or other phytotoxic compounds. It could suppress weeds but also kill desired plants. Some unfinished composts have high C:N ratios, resulting in N tie-up in the soil. Many of these problems can be avoided if unfinished compost is applied to soil at least one month prior to crop planting.

Summary

Now you know what soil organic matter is, how it benefits your soil and how you can build it using an array of organic amendments. Remember to identify your goals for building soil organic matter before you choose a soil amendment. Do you want to build the amount of soil organic matter quickly? Do you want to supply nutrients in the first year of amendment application? Or is your main goal to improve the structure of the soil, gradually over time?

Also, test any new soil amendment you plan to use for its chemical, physical and biological properties so you know how it will affect your soil and crops. Lastly, remember that soil organic matter is a dynamic property, and you have the ability to manage it to improve soil properties and grow healthier plants.

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