CENTER FOR ENVIRONMENTAL FARMING SYSTEMS

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Composting on Organic Farms

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One of the main goals of every organic farmer is to build long-term soil fertility and tilth by feeding the soil with a variety of natural amendments. The regular addition of compost is one of the best ways to enhance soil organic and humic content, which helps to build a fertile soil structure. Such a soil structure makes better use of water and nutrients. It is easier to till and, overall, is better able to achieve optimum yields on a long-term basis.

Figure 1. Compost can work wonders on farm soil. (Photo courtesy of USDA)

Populations of microorganisms that make soil come alive with productivity and enable plants to battle diseases and pests thrive in such an environment. Because compost has already decomposed, its impacts are much more long-lasting than crop residues and green or animal manures that rapidly degrade when added to the soil, especially in the humid Southeast. Composting also gives organic farmers a way to recycle manures and plant residues that otherwise might present some environmental problems. In many instances, a good composting program also allows farmers to save money by eliminating or trimming the need for farm fertilizers and other expensive inputs.

As we'll see in this publication, composting is not merely a matter of heaping up organic materials and allowing them to rot. Rather, it's a biological process that requires careful monitoring of air and moisture

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levels in compost piles or windrows to produce specific temperature ranges that promote the growth of beneficial microorganisms. These tiny hosts can turn farm manure, plant residues, and other organic materials into a valuable resource—finished compost.

In this publication, you will learn how the composting process works and why it is so beneficial to plants and soil:

- **How the composting process works.** Composting requires the right temperature, adequate moisture, and the proper feedstocks. The result is a product that makes a big impact on the soil.
- **Making compost that meets NOP standards.** We'll take a look at the three most widely used systems for on-farm composting: *passive pile*, *windrow*, and *aerated static pile*. You will learn about compost recipes, application rates, and some potential problems of the composting process.
- **Applying compost.** The nutrient content of compost must be considered, along with the presence of bioavailable trace metals.
- **Recommended reading.** We present some good resources for further reading and study.

HOW THE COMPOSTING PROCESS WORKS

Compost is the material that results when recycled plant wastes, *biosolid*s (solid materials like manure), fish, and other organic materials decompose *aerobically*—through the action of microorganisms that live in the presence of air. Depending on the organic matter being composted, it may take up to six months to produce a mature batch of compost. There are ways to speed up the process though, such as grinding woody materials so they decompose faster. After the materials decompose, many compost mixtures require a curing time that lasts up to 30 days. The final product should be dark brown to black in color, sweet smelling or at least neutral in aroma, soil-like in texture, and with particles reduced to ½-inch or less in diameter. None of the original *feedstocks*, the materials used to make the compost, should be recognizable.

Proper Conditions for Organic Composting

- An adequate supply of oxygen for microbial respiration (approximately 5 percent of the pore space in the starting material should contain air).
- A moisture content between 40 and 65 percent.
- Particle sizes of composting materials of approximately 1/8-inch to 2 inches in diameter.
- A carbon to nitrogen (C:N) ratio between 25:1 and 40:1. Later on in this publication, we'll more fully discuss the critical importance of the C:N ratio.

What distinguishes composting from natural rotting or decomposition is human involvement. A farmer arranges the materials to be composted into appropriate piles or windrows and then carefully monitors the amounts of oxygen and moisture that are introduced to those materials to produce optimum temperatures averaging from 120 to 140 degrees Fahrenheit (°F).

Populations of living microorganisms that work to decompose the materials flourish within this temperature range. The farmer uses a special thermometer with a 2- to 3-foot probe to take regular temperature readings of the composting materials. If temperatures fall below or climb above the optimum ranges due to various reasons that we'll discuss below, microorganisms begin to die off. The farmer then supplies more moisture or oxygen by wetting and turning the piles or sending streams of air through vented pipes into the composting materials.

Mesophilic and Thermophilic Stages

If the proper conditions exist, the pile begins to heat up almost right away. This first phase of composting, lasting one to two days, is called the *mesophilic stage*. In this stage, strains of microorganisms (the species that are most active at temperatures of 90° to 110°F) begin to break down the readily degradable compounds in the pile. As they rapidly consume sugars, fats, starches, and proteins, heat is given off, and the temperature of the substrate (materials base) rises. The pile becomes *active*, and a series of processes are set in motion.

The next phase in the composting process is the *thermophilic stage*, which can last for several weeks. As active composting takes place, temperatures in the center of the pile climb to about 120° to 150°F. At these temperatures, heat-loving (thermophilic) bacteria vigorously degrade the organic material. Temperatures will remain in this range as long as decomposable materials are available and oxygen is adequate for microbial activity (Chen and Inbar, 1993). Many important processes take place during the thermophilic stage. As the organic matter degrades, its particle size is reduced. Pathogens are destroyed as the heat in the pile climbs above a critical temperature of 131°F. Fly larvae and most weed seeds are destroyed at temperatures above 145°F.

Controlling Pathogens

Pathogens are organisms—such as bacteria, fungi, and nematodes—that incite disease. There are pathogens that are dangerous to humans, animals, and plants. The heat produced during composting helps to control all of these.

Temperature Is Critical

Decreasing temperatures in the composting pile indicate that more oxygen or moisture is needed. The pile may need to be *turned* to reintroduce oxygen for renewed microbial activity. In this operation, the pile or windrow is re-mixed by hand, with a front-end loader, or with other specialized equipment. Alternatively, perforated pipe can be placed under the pile during construction so oxygen can be delivered from blowers and fans into the pipe. Turning the pile also insures that materials are moved from its outer layers, where temperatures may be lower than 120°F, to its inner layers, where they will be subject to thermophilic temperatures. Several turnings also can ensure destruction of most pathogens, weed seeds, and insect larvae.

It is also possible for temperatures in the pile to become too hot. When temperatures reach the 150°F to 160°F range, thermophilic organisms begin to die and composting slows. Spontaneous combustion can occur in compost piles that become too hot and dry.

Moisture Is Critical

With normal temperatures in the composting pile rising as high as 160°F, evaporation is normal. As a result, it may be necessary to re-wet the pile frequently. If the moisture content falls below 40 percent, the pile may become too dry for microbial activity.

The Moisture Squeeze Test
A general rule of thumb is that the pile is too wet if water can be squeezed out of a handful of compost and too dry if the handful does not feel moist to the touch.

There's also a danger in making the pile too wet. When moisture content exceeds 65 to 70 percent, much of the *pore space*, the space between particles in the pile, will contain water rather than oxygen. Oxygen will then quickly become limited, and microbial activity will decrease, as reflected by the decreasing temperature. Without sufficient oxygen, the pile will become *anaerobic*. Anaerobes, an entirely different set of microorganisms that function effectively without oxygen, will assume primary responsibility for decomposition.

Unfortunately, anaerobes break down materials at a much slower rate than aerobic microorganisms. Slow decomposition produces many undesirable byproducts, among them noxious odors that have been compared to the rotten-egg smell of hydrogen sulfide gas. It also creates organic acids that can inhibit plant growth.

When active composting is finally completed, temperatures in the pile or windrow will gradually fall to about 100°F. Turning the compost or applying moisture will no longer cause temperatures to rise. The volume of the original materials will also be reduced by 25 to 50 percent. Decomposition continues beyond this point, but at a much slower rate, and little heat is generated. When the compost pile temperature falls to that of ambient air, the compost is ready for curing (Rynk et al., 1992). The curing stage, in which compost is allowed to rest undisturbed, takes about 30 days. Curing helps to ensure that the compost is fully matured, that any remaining weed seed and pathogens are destroyed, and that beneficial microorganisms re-colonize the compost.

Composting: The Scientific Explanation

The extent of organic matter decomposition at any particular time is related to the temperature at which composting takes place and to the chemical composition of the organic substrate undergoing composting (Levi-Minzi et al., 1990). Because of the presence of readily degradable carbon (C), most organic materials initially decompose rapidly. Thereafter, decomposition slows because the remaining carbon compounds, lignin and cellulose, resist decomposition when other environmental factors remain constant. Generally, the higher the lignin and polyphenolic content of organic materials, the slower their decomposition (Palm and Sanchez, 1991).

Readily available or *labile* organic nitrogen (N) is *mineralized,* which means that it is converted to nitrate-N, a form that plants use, by microbial activity during the first weeks of decomposition. As the more labile organic N disappears, the most *recalcitrant* organic N (the N that is resistant to microbial degradation) predominates in the organic N pool, and the mineralization rate slows (Iglesias-Jimenez and Alvarez, 1993). The predominance of recalcitrant organic C and N compounds in finished compost indicates a *stabilization* of the original organic material.

During the composting process, N is lost as gaseous ammonia heats up and vaporizes. This process is referred to as *volatilization*.

Losses can be substantial, as much as 50 percent of total N. The percentage of total N lost increases as the initial N concentration of the feedstock material increases (Douglas and Magdoff, 1991). This loss is somewhat offset by the loss in mass of the materials resulting from oxidation of organic C to carbon dioxide (CO_2) and by the loss of water. Nevertheless, composts made from materials that are high in ammonia, such as hog manure, can be expected to contain much less N than raw feedstock material.

Impacts on Soil Biological Properties

While heat exposure during composting kills or inactivates pathogens, it also kills off many "good guys," the biocontrol agents that help suppress plant disease organisms. Fortunately, these biocontrol agents recolonize compost during curing. With this in mind, it's easy to see how disease suppression can depend on the decomposition level of organic matter and the number of biocontrol agents and pathogens in the compost.

In simple terms, adding compost to the soil introduces a band of "good guys" (bacteria and fungi) that do battle with some of the "villains" (plant pathogens such as pythium and phytophthora) that may reside in the soil. The good guys can defeat the villains in three ways: by out-competing them for the necessities of life (water, air, and nutrients), by producing natural antibiotics,and by parasitizing them.

The good bacteria and fungi can also inoculate a host plant against disease by inducing what is called *systemic acquired resistance* in the plant. Systemic acquired resistance is a natural defense against disease infection. It is accomplished by tricking the plant into producing antibodies and other protective chemicals *before* infection actually occurs. It is comparable to the immunization process in humans and animals that a vaccination accomplishes.

Compost's Impact on Farm Soils

- Increases soil organic and humic matter, and overall fertility.
- Improves soil structure, aeration, and tillability so it better retains and uses water and nutrients.
- Reduces soil bulk density so plants have deeper root penetration.
- Improves the cation exchange capacity, which increases nutrient availability and reduces leaching
- Leads overall to soil aggregate stability, which allows the soil to function at optimum levels and produce the best yields.

MAKING COMPOST THAT MEETS NOP STANDARDS

The National Organic Program has developed composting standards that must be met if the compost is used to produce certified organic products. To meet these standards, the compost must be produced using an acceptable method. Allowable feedstocks must be used that meet the specified carbon-to-nitrogen ratio. And the compost must attain temperatures that minimize the risks of pathogens and weed seeds and stabilize the plant nutrients.

Composting Methods

• **Passive Pile Method.** This method is ***not*** approved for certified organic production. It has mixed or often poor results because organic materials are placed in a pile and left alone to decompose over an extended period of time. Manure is often composted with this method. Farmers who use this method may or may not use a compost recipe, and they usually make no attempt to adjust moisture content or the carbon to nitrogen (C:N) ratio. This is a critical issue that we will explain later in this publication. The piles are not aerated, and their temperatures, which are so critical to proper composting, are not monitored. Passive compost piles often turn anaerobic, when organisms that do not require oxygen take control of the decomposition process. Foul odors (and complaints from neighbors) often accompany passive compost piles, which decompose slowly at best.

BEWARE

Neighbors down-wind may start complaining about odors. Be sensitive to the concerns of neighbors about the composting operations on your farm. Noxious odors from improper processing (typically insufficient oxygen) and stockpiled feedstock materials, dust, noise from equipment, and fly or mosquito problems may strain neighborly relations.

• **Windrow Method.** This method is approved for certified organic production. In the windrow method, a mixture of feedstock materials is placed in a long, narrow pile. The pile is turned or mixed on a regular basis to provide oxygen throughout the pile. Turning the pile also helps to rebuild the pore space in the pile that is lost by settling and reductions in particle size. It is also important periodically to exchange outer layers of the pile, which will have cooler temperatures, with the warmer inner layers. As we'll see, maintaining the correct temperature in a compost pile is essential for fostering the microorganisms that decompose feedstocks and for killing off pathogenic organisms and weed seeds.

Farmers should size windrows in relation to the materials that will be composted and the turning equipment that will be used. For dense materials that allow less passive air movement in and out of the pile, piles might only be 3 feet high and 10 feet wide. For more porous materials like leaves, piles can be as much as 12 feet tall and 20 feet wide.

One should guard against making piles too large. Depending on the nature of the ingredients, a pile with a wide cross-section can have anaerobic pockets in the interior. Windrows are normally turned with front-end loaders or compost turning machines. Front-end loaders allow for tall piles, whereas turning machines normally produce low, wide piles.

How often a windrow pile is turned is determined by many factors, including the season and farm microclimate, and the temperature, moisture content, and porosity of the pile. Moreover, the National Organic Program final rule stipulates the number of times windrow compost piles must be turned when manure is included as a feedstock. Microbial decomposition, which is related to the age of the pile, decreases over time as organic materials in a windrow are fully composted.

Windrow temperature is critical and is the most commonly used turning indicator. As mentioned above, the microorganisms that drive the composting process thrive best when composting piles and windrows are kept between 120 to 140 °F. Generally, a pile should be turned when its interior temperature falls below 120°F. Thermometers with a special 2- to 3-foot stem are used to measure temperatures at 50-foot intervals along the windrow.

Maintaining the proper temperature is also critical for meeting what are called PFRP requirements. PFRP stands for *processes to further reduce pathogens*. These requirements stipulate the composting processes that must be used to maintain reduced levels of organisms that can be harmful to humans, referred to as *human pathogenic organisms*. PFRP requirements also apply to *vectors*, the carriers of those pathogens.

As composting proceeds, the volume of each windrow will decrease. If a pile becomes too small to maintain the correct temperature range, it should be combined with another pile.

Some USDA Target Ranges for Compost Piles

- temperature of 120 to 140°F
- moisture content of 50 to 60 percent.
- pH of 6.5 to 8.5
- bulk density of less than 1,100 pounds per cubic yard (40 lb per cubic foot)

•Aerated Static Pile Method. This method is approved for certified organic production. In the aerated static pile method, compost is not turned. Instead, air is supplied for microbial activity through perforated pipes that are placed along the bottom of the windrow or pile. Fans or blowers either blow air into the pile or suck air out of the pile. An insulating layer of finished compost or a bulking agent, such as wood chips or straw, normally covers the pile to retain heat. This layer also helps maintain the desired moisture content, discourages egg-laying by flies, and serves as a biofilter to scrub away noxious odors that may be generated by composting.

With this method, feedstocks are piled on top of a 6-inch base of a porous material, such as wood chips, chopped straw, or some other bulking agent. The perforated pipe is placed in this base material. Piles are 5 to 8 feet high, depending on feedstocks, climate, and equipment. Fans deliver air to the perforated pipe, and the porous base serves to distribute the air throughout the pile. Conversely, suction in the perforated pipe draws air through the pile.

When constructing an aerated pile, it is important to extend the walls of the pile beyond the width of the 6-inch porous base. Otherwise, air will flow solely through the base itself and not through the pile. A good rule of thumb is that the width of the porous base should be only 1/4 to 1/3 of the width of the pile of feedstock materials. The base should stop short of the end of the pile by a distance approximately equal to the pile height. To ensure that air is distributed evenly throughout the perforated pipe, the length of the pile should normally be less than 70 to 90 feet.

Composting is faster with the aerated static pile method, typically taking from three to five weeks. For a detailed description of the engineering, construction, and management of aerated static systems, refer to the *On-Farm Composting Handbook*, which is cited in the recommended reading list at the end of this publication.

Compost Recipes

Many farmers base the construction of a pile or windrow on their personal judgment of moisture, texture, and feedstock materials. From past experience, they make a rough calculation of a mixture's carbon to nitrogen (C:N) ratio. However, these trial-and-error methods may not always produce the best results. More often, developing an appropriate compost recipe based on some definite calculations is a better way to consistently obtain a high quality, finished product in a timely manner.

Proper proportions of feedstock ingredients can be calculated using procedures that are described in such books as the *On-Farm Composting Handbook*. Calculations in the handbook predict the moisture content and C:N ratio of a mixture of feedstocks based on the characteristics of the individual raw materials. First, the moisture content of each feedstock must be determined. Appropriate proportions of each feedstock are based on moisture content. Then, if necessary, the proportions are adjusted to bring the C:N ratio in line without excessively changing moisture content.

Compost Recipe Software
Computer software is available that simplifies compost recipe calculations when three or more ingredients are used. The Cornell University Web site provides user-friendly spreadsheets at www.cfe.cornell.edu/compost/science.html (Cornell University, 1995).

The *On-Farm Composting Handbook* also provides an example of a composting recipe calculation based on the moisture content, the percent of nitrogen in a feedstock, and either the percent of carbon or the C:N ratio for each ingredient. From Klickitat County, Washington, a "Compost Mix Calculator" is also available on the Web at **www.klickitatcounty.org/solidwaste/files html/organics/compostcalc.htm**

Compost Feedstocks and the NOP Rule

Farmers intending to compost feedstocks for organic production should first read the composting explanations contained in the Soil Fertility and Crop Nutrient Management Practice Standard (Section 205.203) of the final rule. A complete version of the final rule can be viewed or downloaded at the NOP's Web site: **www.ams.usda.gov/nop.**

Producers should also study the *Compost Task Force Final Report*, which was prepared by the National Organic Standards Board (NOSB). A copy of that report appears later in this publication.

The NOP Rule will assist producers in managing plant and animal materials to maintain or improve soil organic matter in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances. The Rule stipulates that any plant and animal material can be composted for organic production, provided that it does not contain any synthetic substances prohibited by the National List or any incidental residues that would lead to contamination. Of course, it's the responsibility of the organic producer—assisted by his or her organic certifying organization—to make sure that any amendment added to the soil has been approved for organic production.

Identifying Feedstock Sources. The first step in producing high quality compost for organic production is to identify the source of *all* feedstocks used to make the compost. This will help ensure that only allowable plant and animal materials are included in the compost, that feedstocks are not contaminated with prohibited materials, and that materials are mixed in quantities suitable to the composting system design.

Certifying agents who visit a farm will evaluate the appropriateness of potential feedstock materials and may require testing for prohibited substances before allowing a material's use. For example, a certifying agent could require a laboratory analysis of off-farm materials, such as leaves collected through a municipal curbside program or organic wastes from a food processing facility. These types of feedstocks have been known to contain such contaminants as motor oil, heavy metals, and gross inert materials (such as glass shards).

Examples of NOP Approved Feedstocks (materials that can be composted)

- animal bedding
- crop residues
- yard wastes
- fish and food processing wastes and byproducts
- seaweed and many byproducts of the plant industry
- manures

Meeting Carbon:Nitrogen (C:N) Ratios. When composting mixed plant and animal feedstocks, organic producers must meet what is called the *C:N 25:1 to 40.1 ratio*. This ratio refers to the carbon and nitrogen content of feedstocks. It has been developed to help farmers produce high quality compost that is fully mature, so that any pathogens and their vectors (such as fly larvae), weed seeds, and other contaminants have been rendered harmless.

The ratio allows for very diverse combinations of feedstock materials. It is also meant to help producers establish conditions that favor the time and temperature criteria required by the Compost Practice Standards. C:N ratios that are outside this range generally result in immature, incompletely digested compost. Farmers should note that there are *no* specific regulations for composting when feedstocks are made up of *only* plant materials.

Other Feedstock Characteristics To Consider

- resistance to decomposition
- ease of handling
- potential for odor
- presence of pathogens and other nuisances

(Rynk et al., 1992)

Determining C:N Ratios. How do organic producers determine the carbon and nitrogen content and ratios of various feedstocks? For the most part, they consult available sources that estimate these values and ratios for approved feedstocks. Values of the carbon and nitrogen content in common manures and plant materials are generally available. Other feedstocks may be tested once and, given consistent quality, assumed to approximate that value for later use. Fortunately, the range of C:N ratios permitted by the National Rule allows for considerable flexibility in constructing a pile that composts properly.

Table 1. Characteristics of Compost Feedstocks [1]

Material	% N (dry wt)[2,3]	C:N (wt/wt)[4]	Moisture % (wet wt)	Bulk Density (lb/cu yd, wet wt)
Plant Residues				
Apple filter cake	1.2	13	60	1,197
Apple pomace	1.1	48	88	1,559
Corn stalks	0.6 - 0.8	60-73	12	32
Cottonseed meal	7.7	7	-	-
Cull potatoes	-	18	78	1,540
Fruit wastes	0.9-2.6	20-49	62-88	-
Potato processing sludge	-	28	75	1,570
Rice hulls	0.3	121	14	202
Soybean meal	7.4	4-6	-	-
Vegetable produce	2.7		87	1,585
Animal Residues				
Blood wastes	13-14	3-3.5	-	
Crab wastes	6.1	5	47	240
Fish wastes	10.6	4	76	-
Poultry carcasses	2.4	5	65	-
Shrimp wastes	9.5	3	78	-
Manures				
Broiler litter	1.6-3.9	12-15	22-46	756-1,026
Beef	1.5-4.2	11-30	67-87	1,323-1,674
Dairy	3.7	13	83	775
Horse	1.4-2.3	22-50	59-79	1,215-1,620
Layers	4.0-10.0	3-10	62-75	1,377-1,620
Sheep	1.3-3.9	13-20	60-75	-
Swine	1.9-4.3	9-19	65-91	918
Turkey litter	2.6	16	26	783

Table 1. (continued)

Material	% N (dry wt)[2,3]	C:N (wt/wt)[4]	Moisture % (wet wt)	Bulk Density (lb/cu yd, wet wt)
Municipal Wastes				
Food waste	1.9-2.9	14-16	69	-
Paper	0.2-0.25	127-178	18-20	-
Refuse (mixed)	0.6-1.3	34-80	-	-
Sludge	2.0-6.9	5-16	72-84	1,075-1,750
Straw, Hay, Silage				
Corn silage	1.2-1.4	38-43	65-68	-
Hay (legume)	1.8-3.6	15-19	-	-
Hay (non-legume)	0.7-2.5	32	-	-
Straw (wheat)	0.3-0.5	100-150	-	-
Wood and Paper				
Bark (hardwood)	0.1-0.4	116-436	59	471
Bark (softwood)	0.04-0.39	131-1,285	40-50	225-370
Corrugated cardboard	0.1	563	-	259
Newsprint	0.06-0.14	398-852	-	195-242
Sawdust	0.06-0.8	200-750	-	350-450
Wood chips/shavings (hardwood)	0.06-0.11	451-819	-	445-620
Wood chips/shavings (softwood)	0.04-0.23	212-1,313	-	445-620
Yard Wastes				
Grass clippings	2.0-6.0	9-25	82	300-400
Leaves	0.5-1.3	40-80	38	100-300
Seaweed	1.2-3.0	5-27	53	-
Shrub trimmings	1	53	15	429
Tree trimmings	3.1	16	70	1,300

1. Source: *On-Farm Composting Handbook*, NRAES 54
2. Where a range is not given, data indicate an average value.
3. A dash indicates that information is not available.
4. All ratios are expressed relative to 1; e.g., the C:N of apple filter cake is 13:1

Labs Will Analyze Feedstock Materials
Many private and public laboratories will analyze feedstock materials and provide composters with carbon to nitrogen (C:N) ratios, concentrations of nitrogen (N), phosphorus (P), potassium (K), and carbon (C), percent dry matter, and other useful information.

For example, the Waste Advisory Section of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) Agronomic Division will analyze manures and other organic materials, issue an analytical report, and provide interpretation of the results.

A good analytical service should also determine the concentrations of calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B). If carbon concentration is not determined, a rough estimate can be calculated from the following equation: *% Carbon = (100 - % Ash) / 1.8.*

Determining Compost Biomaturity

How can a producer tell when the compost pile is mature and ready for curing? The answer is that most producers rely on physical tests and past experience. Two other common tests—chemical and biological—require operator training and a substantial investment in laboratory equipment. Because of the diversity in origin and type of feedstocks in the compost, it may be impossible to use a single method to evaluate the maturity of a given compost. Therefore, a combination of indicators is often used to determine the maturity of specific composts in specific instances.

Warning

Applying immature compost to land can produce problems in the soil:

- Organic acids that are produced as organic matter begin to degrade in compost piles. These organic acids can have adverse effects on seed germination and plant growth.
- Ammonia and ethylene oxide are generated when immature composts are added to soils. These inhibit plant root growth.
- The rapid decomposition of immature compost may cause a decrease in the oxygen concentration of a soil. In addition to inhibiting root respiration, this situation may cause an increase in the solubility of heavy metals. When soil metal concentrations are high, phytotoxicity can occur.

A physical examination can tell a farmer a lot about compost maturity. Does the compost pile smell bad? If so, it may need oxygen. Temperature and time are other indicators. For example, has the compost in the windrow reached the thermophilic temperature range and remained there for 15 days and five turnings?

Various scientific methods for evaluating compost maturity are being developed. In these evaluations, chemical and biological tests are taken on compost samples to show amounts of mineralization (m), humification (h), plant bioassays (pb), respiration indices, and nitrogen parameters. These test results are compared to stock index values.

Other promising tests of compost biomaturity under development include optical density of water extracts of a compost, relatively simple respiration tests (for example, using a dissolved oxygen meter to measure changes in oxygen concentration of an aqueous compost suspension), and other spectroscopic methods (such as nuclear magnetic resonance and gel chromatography). We cannot review all of these methods here.

APPLYING COMPOST ON THE ORGANIC FARM

Calculating application rates for compost is similar to figuring the application rates for manure on cropland. First, estimate the nitrogen (N), phosphate (P) and potassium (K) requirement for the crop (based on realistic yield expectations for a particular soil or field). A chemical analysis will show the N-P-K content of the compost. Then calculate a compost rate based on N, P, or K as the critical or priority nutrient. The amount of compost to apply is calculated from the recommended rate of the priority nutrient and the plant-available nutrient content of the compost.

Compost Application Rate Formula
The amount of compost to apply equals the *Recommended Amount of Priority Nutrient* divided by the *Plant Available Priority Nutrient* (the total priority nutrient concentration of the compost times the availability coefficient).

For example, if compost contains 56 lb total N/ton (wet weight basis) and the availability coefficient is 0.25 (for incorporated material), then the plant available N is 56 times 0.25,or 14 lb/ton. If the priority nutrient is N and the recommended amount of N for the crop is 140 lb/acre, then the appropriate application rate is 140 (recommended amount) divided by 14 (plant available N), or 10 tons of compost per acre.

As we stated in the introduction to this publication, some organic growers prefer to base nutrient management strategies on a *feed the soil* approach, building up an available soil nutrient pool. Adding organic matter to the soil provides energy for soil microbes, increasing microbial activity. Increased microbial activity increases the nutrient cycling rate, thus increasing available nutrients for plant uptake. This strategy also attempts to build the soil to a high fertility level and then to maintain that level by replacing nutrients removed in harvested crops. Many organic growers reduce the standard N recommendation for a particular crop to reflect the higher fertility and increased nutrient cycling in organically managed soil.

Calculating Nitrogen Content

Determining an accurate nitrogen (N) content for a particular compost when trying to calculate application rates for a crop can be tricky. By the time compost has reached maturity, it has undergone extensive microbial degradation and stabilization. It will take longer than one cropping year to further mineralize (break down) the remaining recalcitrant organic N in the compost. Therefore, if application rates are based on the total amount of nitrogen in the compost (which includes this recalcitrant organic N), crops may experience nitrogen deficiency and yields may be poor. So, we must calculate the agronomic rate of compost application by the compost's *plant-available N* (PAN), which is a fraction of the its total N.

Another consideration to keep in mind is that soil temperature and moisture influence the availability to plants of recalcitrant organic nitrogen. Cool or wet weather, or a combination of these, slows microbial activity and thus inhibits mineralization processes (Aoyama and Nozawa, 1993).

Consequently, the organic nitrogen in compost may not become mineralized by the time crop demand is greatest. For example, compost may not be able to supply nutrients at crop emergence in a wet, cool spring (Dick and McCoy, 1993).

N Content: Compost Versus Manures
The concentration of available N in finished compost is generally lower than that in manures. As a consequence, application rates are generally higher, allowing for greater organic matter additions to soil. Thus, use of compost as a nutrient source instead of manure alone provides a greater opportunity to improve the soil's physical properties.

Composts with high carbon to nitrogen (C:N) ratios (20:1 and above) are relatively more resistant to further degradation. So, nitrogen is slower to mineralize and to become available for plant use in these composts. The C:N ratio of mature compost is commonly in the range of 8 to 14:1. Predicting how much and when nitrogen will be mineralized can be difficult, albeit critical to crop performance. Rough guidelines for availability coefficients at various C:N ratios are given in Table 2.

Table 2. Nutrient Availability Coefficient Guidelines for Composts

C:N Ratio	Nutrient Availability Coefficient		
	N	P	K
< 10:1	0.50	.8	.8
10 to 15:1	0.25	.6	.6
16 to 20:1	0.10	.4	.4
21 to 30:1	0.05	.25	.25
> 30:1	0.00	.10	.10

The availability of residual compost N to crop plants in the second year after addition is not well-documented. As a general rule, 10 percent of the remaining organic N (after one cropping season) is available for the next crop. Consistent, annual applications of organic matter increase the amount of available nitrogen from compost in the soil.

Bioavailability of Trace Metals in Compost

Some composts contain relatively high concentrations of heavy metals, toxic organic compounds, or both. When applied to soils, they can be directly phytotoxic to crops. In some cases, metals can accumulate in forages. Livestock that consume these forages may accumulate unhealthy concentrations of metals in their tissues. Organic growers are advised to carefully monitor soil chemical properties when using composts that are shown to contain or suspected of containing high concentrations of trace metals such as copper or zinc.

Little is known about the long-term availability of metals applied as constituents of composted organic materials, or whether use of these composts is sustainable over time. Little, if any, research is available from studies lasting decades and longer.

Southeastern soils are typically very acidic. When pH values decrease below 6.0 in these soils, the possibility of copper and zinc uptake increases dramatically. However, in soils with a pH value of 6.5 to 7.0, zinc and copper trace metals become very tightly adsorbed and relatively unavailable for plant uptake (Gupta et al., 1971; Locascio, 1978; Adriano, 1986).

Acidic clay soils may contain large amounts of iron (Fe), aluminum (Al), or manganese (Mn) compounds, all of which coat clay particles, alone or in combination with each other. These compounds also provide adsorption sites for trace metal ions, including zinc, copper, and other metals. Unfortunately, the relatively sandy surface soils of the coastal plain offer few adsorptive surfaces for binding trace metals. That is, they contain very little organic or humic matter and do not contain the negative surface charge of clay soils. In these soils, organic amendments decompose quickly. Carbon compounds are oxidized to CO_2, reducing binding sites for trace metals and increasing metal availability to crops.

As composts containing trace metals are added to soils over time, total concentrations of metals necessarily increase in the soil. In some cases, trace metal concentration increases in plant tissue as well (Petruzelli, 1989). There are two scientific theories about the impact of this.

Some researchers argue that increasing levels of trace metals in the soil may produce a *plateau response*. They argue that the metal uptake by crop plants reaches some upper limit with increasing compost application, and then levels off (Corey et al., 1987). Evidence from experiments with biosolids suggests that the metal adsorption capacity added with an organic substrate persists as long as the heavy metals of concern persist in the soil (Corey et al., 1987).

In contrast, other researchers have argued that the *sludge time bomb* hypothesis is a more likely scenario for trace metal behavior in sludge and, therefore, compost-amended soils (Chang et al., 1997). The sludge time bomb hypothesis postulates that organic matter added along with the sludge augments a soil's metal adsorption capacity. It is believed that this capacity, however, will revert back to its original background level, with time, after sludge application stops. Mineralization of added organic matter will take place with a concomitant release of metals into more soluble forms: thus, a time-bomb effect.

In addition to compost, organic farmers may amend soil with

- A mined substance of low solubility, such as lime or rock phosphate.
- A mined substance of high solubility, such as potassium sulfate or guano, if the substance is used in compliance with the NOP National List of nonsynthetic materials.
- Ashes of untreated plant or animal materials that have not been combined with a prohibited substance.
- A plant or animal material that has been chemically altered by a manufacturing process if it is listed as approved on the NOP National List of synthetic substances.

Note: The producer MAY NOT use sewage sludge or other biosolids generated from industrial processing.

Compost Teas

The National Organic Program Final Rule does not contain specific provisions for the use of materials commonly referred to as *compost teas*. A compost tea is produced by combining composted plant and animal materials with water and a concentrated nutrient source, such as molasses. Normally this concoction is aerated; that is, air is bubbled into it. The moisture and nutrient source contribute to a bloom in the compost's microbial population. The compost is then applied in liquid form as an agent for pest or disease control in crops.

The microbial composition of compost tea is difficult to ascertain and control. Growers should check the National Organic Program Web site for more information on application of compost teas to organic crops. It appears that compost teas made from properly produced compost will be accorded the same flexibility of use as compost itself. Manure teas or teas made from improperly prepared compost should be handled according to the 90- and 120-day manure rulings.

The National Organic Program Web site is www.ams.usda.gov/nop

COMPOST TASK FORCE FINAL REPORT

NOTE: This is a recommendation by a task force of the National Organic Standards Board. This final report provides guidance to producers and certifying agents. As guidance, this report does not constitute a federal regulation and is subject to change as needed by the USDA based on pending or new information and comments received from interested parties.

Producers of any agricultural commodity or product certified as organic under the National Organic Program (NOP) must meet the fundamental requirements for processing and applying plant and animal materials for soil fertility and crop nutrient management practices as described in Section 205.203(c) of the final regulations. This section states the following:

The producer must manage plant and animal materials to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances.

Examples of plant and animal materials are described in 205.203 (c) 1-5. This policy statement is being distributed to denote other materials that would be acceptable under 205.203 (c) (2), which applies to plant and animal material mixes. There are no specific regulations for composting when feedstock is made up of only plant material.

1. Compost, in addition to that described in section 205.203 (c) (2), is acceptable if (i) made from only allowed feedstock materials, except for incidental residues that will not lead to contamination; (ii) the compost undergoes an increase in temperature to at least 131°F (55°C) and remains there for a minimum of three days; and (iii) the compost pile is mixed or managed to ensure that all of the feedstock heats to the minimum temperature.

The monitoring of the above three parameters must be documented in the Organic System Plan (plan) submitted by the producer and verified during the site visit. An explanation of compliance with section 205.203 (c) should also be presented in the plan.

2. Vermicompost is acceptable if (i) made from only allowed feedstock materials, except for incidental residues that will not lead to contamination; (ii) aerobicity is maintained by regular additions of thin layers of organic matter at 1-3 day intervals; (iii) moisture is maintained at 70 to 90 percent; and (iv) duration of vermicomposting is at least 12 months for outdoor windrows, 4 months for indoor container systems, 4 months for angled wedge systems, or 60 days for continuous flow reactors.

3. Compost and vermicompost teas are still under review and are, therefore, not eligible to satisfy section 205.203 (c) at this time.

4. Processed manure materials must be made from manure that has been heated to a temperature in excess of 150° F (65°C) for one hour or more and dried to a moisture level of 12 percent or less, or an equivalent heating and drying process that produces a product that is negative for pathogenic contamination by salmonella and fecal coliform material.

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