
The Art and Science of Composting

A resource for farmers and compost producers



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What is composting?

Composting is controlled decomposition, the natural breakdown process of organic residues. 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.

Composting is an ancient technology, practiced today at every scale from the backyard compost pile to large commercial operations. There are Roman and biblical references to composting. The nation's first president, George Washington, was also the nation's first recognized composter. Washington recognized the degradative effects of farming on soil and he built a "dung repository" to make compost from the animal manures so he could replenish the soil's organic matter.

Uses and markets for compost

As landfills reach their capacity and ban acceptance of organic wastes, composting is an increasingly viable means of organic waste management. Composting animal manures can also be a solution to manure management on the farm. Most importantly, the final product is a **valuable soil resource**. Compost can replace materials like peat and topsoil as seed starters, container mixes, soil amendments, mulches and natural fertilizers in commercial greenhouse production, farms, landscaping, turf and land remediation (Table 1).

There is a big potential demand for compost in plant production-related industries—close to 900 million cubic yards of compost could be used in agricultural

Table 1. Compost Markets and Use

Market	Compost Use
Agronomic	Soil amendment
Horticultural	Seed starter, soil amendment, mulch, container mix, natural fertilizer
Urban/suburban landscaping	Soil amendment, mulch
Turf	Seed starter, soil amendment, topsoil, natural fertilizer, mulch
Forestry	Seed starter, soil amendment, topsoil, mulch
Land reclamation Bioremediation Land fill cover	Soil amendment, mulch

and horticultural applications and 0.6 million cubic yards for land fill covers and surface mine remediation (U.S. EPA, 1998).

Benefits of adding compost to soils

Compost is an organic matter source with a unique ability to improve the chemical, physical, and biological characteristics of soils. It improves water retention in sandy soils and promotes soil structure in clayey soils by increasing the stability of soil aggregates. Adding compost to soil increases soil fertility and cation exchange capacity and can reduce fertilizer requirements up to 50%. Soil becomes microbially active and more suppressive to soil-borne and foliar pathogens. Enhanced microbial activity also accelerates the breakdown of pesticides and other synthetic organic compounds. Compost amendments reduce the bioavailability of heavy metals—an important quality in the remediation of contaminated soils.

The Composting Process

Composting occurs through the activity of microorganisms naturally found in soils. Under natural conditions, earthworms, nematodes and soil insects such as mites, sowbugs, springtails, ants, and beetles do most of the initial mechanical breakdown of organic materials into smaller particles. Under controlled

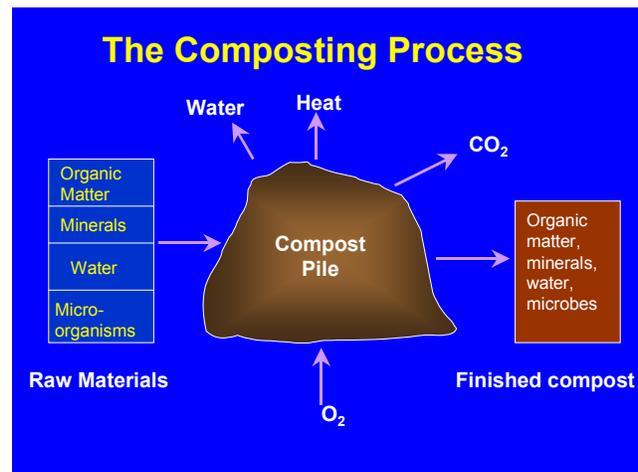


Figure 1. The Composting Process. Adapted from Rynk, 1992.

conditions, composters break down large particles through grinding or chopping. Once optimal physical conditions are established, soil bacteria, fungi, actinomycetes and protozoa colonize the organic material and initiate the composting process (Figure

1.) These mesophilic organisms function best at warm temperatures (50-113°F).

The active phase of composting

As temperatures in the compost pile increase, *thermophiles* (microorganisms that function at temperatures above 113°F) take over. The temperature in the compost pile typically increases rapidly to 130-150 °F within 24-72 hours of pile formation, which is maintained for several weeks. This is called the *active phase* of composting (**Figure 2, 3**).

In the active “thermophilic” phase, temperatures are high enough to kill pathogens and weed seeds and to break down phytotoxic compounds (organic compounds toxic to plants). Common pathogens killed in this phase are *Escherichia coli*, *Staphylococcus aureus*, *Bacillus subtilis*, and *Clostridium botulinum*. During this phase, oxygen must be replenished through passive or forced aeration, or turning the compost pile.

The curing phase

As the active composting phase subsides, temperatures gradually decline to around 100°F. The mesophilic microorganisms recolonize the pile, and the compost

amended to container mixes or the soil.

There is no clearly defined time for curing. Common practices in commercial composting operations range from one to four months. Homeowner compost piles can cure for as long as six to twelve months.

When is the compost finished?

There is no fixed time to produce finished compost. Duration depends on feedstocks, composting method used and management. It can take as little as three months and as long as two years. Compost is considered finished when the raw feedstocks are no longer actively decomposing and are biologically and chemically stable. Some practitioners refer to finished compost as stable; referring to the state of biological activity. Maturity is usually defined as the degree of humification (conversion of organic compounds to humic substances, which are most resistant to microbial breakdown). It is easier to measure compost stability than maturity, so most composters measure temperature or compost respiration (oxygen consumption). When the temperature at the center of the pile returns to near-ambient levels and oxygen concentrations in the middle of the pile remain greater than 10-15% for several days, compost is considered stable or finished. These measurements should be taken when the compost pile has at least 50% moisture content by weight.

It is important to learn how to assess the maturity or stability of the compost because stability will affect many of the chemical and biological properties of the compost, and ultimately how the compost can be used. “Stability indices” and maturity/stability testing are available from compost research and education organizations (**see Resources**). Immature or biologically unstable composts can be used on farms as

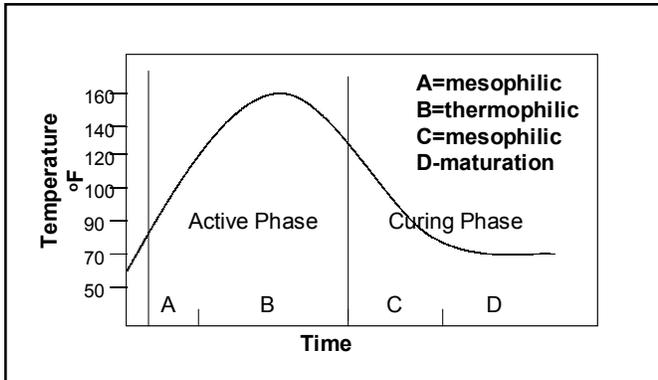


Figure 2. Temperature changes in an average compost pile.

enters the *curing phase*. The rate of oxygen consumption declines to the point where compost can be stockpiled without turning. During curing, organic materials continue to decompose and are converted to biologically stable humic substances—the mature or finished compost. Curing is a critical and often neglected stage of composting. A long curing phase is needed if the compost is unfinished or immature. This can happen if the pile has received too little oxygen or too little or too much moisture. Immature composts can contain high levels of organic acids, high C:N ratios, extreme pH values or high salt contents, all of which can damage or kill plants if the compost is



Figure 3. Steaming compost pile during active, thermophilic phase of composting, when compost temperatures can reach as high as 150° F

a soil amendment **ONLY IF** applied several months prior to planting. Immature composts can also be used in site remediation, and as land fill covers.

Setting Up the Composting Environment

Since composting is a microbial process, providing the right environment for microbes is crucial for successful composting. In other words, feed the microbes and let them do the work for you! Three factors interact in the

Table 2. Optimal conditions for rapid, aerobic composting (Adapted from Rynk, 1992)

Condition	Acceptable	Ideal
C:N ratios of combined feedstocks	20:1 to 40:1	25-35:1
Moisture content	40-65%	45-60% by weight
Available oxygen concentration	>5%	>10% or more
Feedstock particle size	< 1 inch	Variable
Bulk density	1000 lbs./cu yd	1000 lbs./cu yd
pH	5.5-9.0	6.5-8.0
Temperature	110-150 ^o F (43-66 ^o C.)	130-140 ^o F (54-60 ^o C)

making of good compost:

- the chemical makeup of the raw organic ingredients, called *feedstocks*
- the physical size and shape of the feedstocks (porosity of the pile)
- the population of organisms involved in the composting process.

Aerobic vs. anaerobic composting

Compost “happens” either aerobically (with oxygen) or anaerobically (without oxygen) when organic materials are mixed and piled together. Aerobic composting is the most efficient form of decomposition, and produces finished compost in the shortest time. If the proper amounts of food (carbon), nutrients, water and air are provided, aerobic organisms will dominate the compost pile and decompose the raw organic materials most efficiently. Pile “heat” is a by-product of biological “burning”—the aerobic oxidation of organic matter to carbon dioxide so that microbes can generate energy. Optimal conditions for rapid, aerobic

composting are listed in **Table 2**.

Feedstocks: the quality of the microbial “food”

Composts can be made from most organic by-products. Common feedstocks are poultry, hog and cattle manures, food processing wastes, sewage sludge, municipal leaves, brush and grass clippings, sawdust, and other by-products of wood processing.

Ideally, several raw materials should be mixed together to create the “ideal” range of conditions listed in Table 2. However, in the real world this can’t always happen. Fortunately composting is a forgiving process that can occur over a wide range of conditions, and if you mix materials with an eye to an acceptable *moisture content* and *carbon-to-nitrogen ratio* (**Table 3**), you can produce acceptable compost with good management practices. In general, the combination of feedstock quality and compost management will determine the quality of the finished product.

The supply of carbon (C) relative to nitrogen (N) is an important quality of compost feedstocks. It is designated as the **C:N ratio**. The ideal starting range is C:N 25:1 to 35:1. As a general rule, if the C:N ratio is greater than 20:1, microbes will use all the N for their own metabolic needs. If the C:N ratio is lower than 20:1, they have surplus N and it can be lost to the atmosphere as ammonia gas and cause odor problems.

Table 3. Common feedstocks and their characteristics (Adapted from Rynk, 1992, and other sources to illustrate representative values)

Feedstock	Moisture content	C:N	Bulk Density
High in Carbon			
Hay	8-10	15-30	-
Corn stalks	12	60-70	32
Straw	5-20	40-150	50-400
Corn silage	65-68	40	-
Fall leaves	-	30-80	100-300
Sawdust	20-60	200-700	350-450
Brush, wood chips	-	100-500	-
Bark (paper mill waste)	-	100-130	-
Newspaper	3-8	400-800	200-250
Cardboard	8	500	250
Mixed paper	-	150-200	-
High in Nitrogen			
Dairy manure	80	5-25	1400
Poultry manure	20-40	5-15	1500
Hog manure	65-80	10-20	-
Cull potatoes	70-80	18	1500
Vegetable wastes	-	10-20	-
Coffee grounds	-	20	-
Grass clippings	-	15-25	-
Sewage sludge	-	9-25	-

Green materials usually have lower C:N ratios than woody materials or dead leaves. Animal wastes are more N rich than plant wastes (Table 3).

The complexity of the carbon compounds also affects the rate at which organic wastes are broken down. The

Estimating the carbon content of feedstocks

$$\% \text{ carbon} = \frac{\% \text{volatile solids}}{1.8}$$

where %volatile solids = 100 - %ash (material incinerated at 500° C.)

ease with which compounds degrade generally follows the order: carbohydrates > hemicellulose > cellulose = chitin > lignin. 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.

Water Requirements

The ideal moisture content of the compost pile is between 45-60% by weight. This should feel moist to the touch when you squeeze a handful of blended feedstocks. The material should hold together but not exude excess water.

Low moisture content will slow the composting process. Moisture also regulates temperature. Drier piles tend to heat up and cool down more rapidly than wetter piles, and excessive dryness makes piles susceptible to spontaneous combustion. Moisture content in excess of 60% means pore spaces in the compost pile will be filled with water rather than air, leading to anaerobic conditions.

Feedstocks with different moisture contents can be blended to achieve ideal moisture content.

Carbonaceous materials like newspaper, and wood by-products like sawdust can be used as bulking (drying) agents. Chipped brush, wood chips, and bark can be added to fine particle feedstocks to create large pore spaces. If you can't achieve the ideal moisture content by blending feedstocks alone, you can add water to materials as you blend them. Take samples and measure

moisture content by drying and weighing.

A common and effective feedstock combination on farms is manure (high in N, high in moisture), combined with straw bedding (high in C, low in moisture). Be sure there is enough straw or other dry material in the mixture.

pH and temperature

The acidity or alkalinity of the organic materials, measured by the pH value, affects the growth of microorganisms. Bacterial decomposers prefer a pH range 6.0-7.5 while fungal decomposers prefer pH range 5.5-8.0. If the compost pH exceeds 7.5, gaseous losses of ammonia are more likely to occur. Certain materials such as dairy manure, paper processing

How to calculate the moisture content of compost or feedstock

Materials needed: small container, scale, samples of compost or feedstocks

1. Weigh the empty container.
2. Add 10 g of the material into the container (this is the *wet weight*).
3. Dry the sample for 24 hours in a 110°C oven.
4. Reweigh the sample and subtract the weight of the container. This is the *dry weight*. Determine the moisture content using the following equation:

$$\text{Moisture content} = 100 \times \left(\frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \right)$$

wastes and cement kiln dust can raise pH, while food processing wastes or pine needles can lower pH.

Measure pH at the beginning and end of composting. Send samples to a soil lab for saturated paste pH and EC measurements (electrical conductivity or soluble salts). You can also monitor pH using the soil pH kits from farm and garden catalogs.

Ambient air temperatures affect microbial growth and activity in the compost pile, and hence the rate at which the raw materials decompose. In temperate climates, composting is fastest in spring, summer and fall months and is likely to come to a complete stand still in winter months. However, if pile size is increased in winter to 8-12 feet tall and 10-12 feet wide, piles can

retain heat and remain active.

Determining compost mixes

Many composters determine their feedstock mix by the look and feel of the mix. With an eye to optimizing C:N ratio and moisture content, and some experience with the raw materials, this trial and error approach can often work. For composters trying out new materials, for larger operations, or when composting needs to be efficient, more precise compost recipes can be calculated using formulas and computer spreadsheet programs that are based on the characteristics of the raw materials (see **Resources**).

General Guidelines for Pile Management

Managing compost piles for good aeration

A well-aerated compost pile has at least 5% oxygen content during the active phase of composting (ideally closer to 10%). Composts must be aerated either passively or actively as aeration is key to successful composting. As microbial activity increases in the compost pile, more oxygen will be consumed. If the oxygen supply is not replenished, composting can shift to anaerobic decomposition, slowing of the composting process and foul odors.

Oxygen monitoring equipment is available, but is expensive. Temperature, odors and moisture are easy to measure and provide a good indication of active decomposition and adequate aeration. Monitor temperature at least weekly, using a thermometer with a three-foot stem and a range from 0 to 200 degrees F. Check the moisture content and odor. A compost pile is not odor-free, but a distinct foul odor usually means anaerobic conditions have developed. An ammonia smell can mean too

much nitrogen is present, which can be corrected by mixing in carbon-rich materials. A putrid odor can mean too much water—correct by mixing in bulking materials (see Table 3).

Good aeration can also be achieved by managing pile porosity. Porosity is defined as the volume of pores divided by the total volume of compost. Some of those pores will be filled with water and the rest with air. The initial pile mix should have between 45-60% air-filled porosity and during the active phase of composting, it shouldn't drop below 35% (see sidebar: How to measure bulk density and porosity).

Managing Pile Moisture

Water will be given off as vapor during the active phase of composting, when temperatures are high. If

How to measure pile bulk density and air-filled porosity

First determine **bulk density** (the weight per unit volume of your combined feedstocks). Weigh the container (5 gallon bucket) empty. Add material 1/3 full, tap the bucket five times on a flat hard surface, add another 1/3 of material, tap five times again, then fill to top without tapping. Weigh filled bucket and record. Determine bulk density using the calculations below.

Material measured	Example
1. Weight of bucket with material (lb)	20.5
2. Weight of empty bucket	2.0
3. Weight of material (line 1- line 2)	18.5
4. Bulk density (lbs/cubic yards)= (line 3 X 40).	740

Note: this conversion factor only works for a 5-gallon bucket.

Take the full bucket with material and fill with water. Use the spreadsheet below to calculate **air-filled porosity (%)**.

Material measured	Example
1. Weight of bucket with material + water (lb)	46.5
2. Weight of bucket with material (from line 1 in bulk density table)	20.5
3. Weight of water (line 1- line 2)	26
4. % air-filled porosity = (line 3 X 2.4)	62%

Taking the temperature of your compost pile

- Σ Use a probe with a 3 foot stem.
- Σ Leave in place long enough for the reading to stabilize.
- Σ Take readings in several locations ñ at different depths from the top and sides.
- Σ Find the hottest pockets.
- Σ Graph your findings as in Figure 2.

you are turning piles, you can add water as you turn.

If you are using static aeration, it is much more difficult to add water to the compost pile. It is best to make initial feedstock blends on the wet side (65-70%) by weight, so that when they lose moisture vapor, they will still be wet enough to keep microbes active. Some commercial composters using forced aeration systems add moisture by introducing humidified air into pipes

that blow air into the piles.

Pile size

The ideal height and width of the piles will depend on the porosity and moisture content of the raw materials, composting method and your specific equipment (Table 4). For example, a light, dry pile can be stacked higher than a wet, dense pile, without the risk of

Table 4. Pile size guidelines

Composting method	Height (feet)	Width (feet)
Static Piles	3-6	12
PAWS	3-6	10
Windrow Composting -		
Tractor pulled	6-8	10
Self-propelled turner	3-9	9-20
Bucket loader	6-12	10-20
Aerated Static Piles	6-12	10-20
In-vessel	NA	NA

developing anaerobic conditions within the pile. Small piles will be able to maintain higher internal oxygen concentrations than large piles, but large piles will retain the higher temperatures better than small piles. For a pile to heat and stay hot, the minimum size should be one cubic yard.

The *particle size* of the feedstock will affect porosity, airflow, and the amount of microbial activity. Smaller particles have more surface area per unit volume and, therefore, microbes have more surface to colonize. However, if particles are too small, porosity will

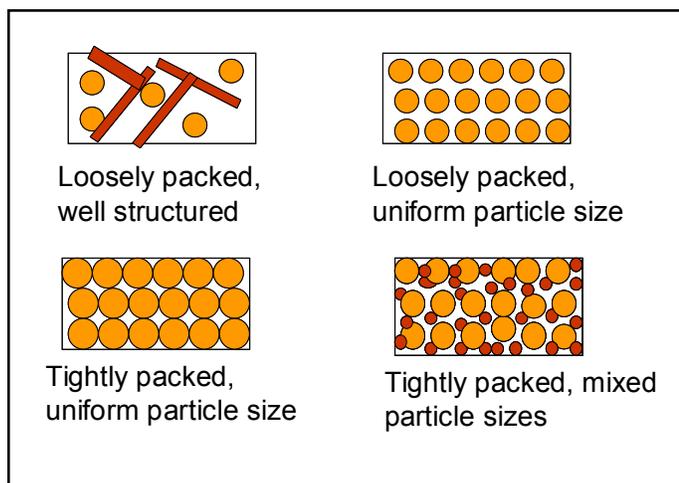


Figure 4. How porosity affects aeration. From T. Richard, Cornell Waste Management Institute.

To get aerobic bacteria breathing again

- Σ Mix wet feedstocks with coarse, dry bulking agents as soon as they come on site.
- Σ Create adequate porosity in compost piles by increasing the number and sizes of pores, such as adding wood chips.
- Σ Build piles to maximize temperature-driven convective air flow

decrease and airflow within the compost pile will be restricted. A mix of particle sizes creates the most porous pile (Figure 4).

Managing Foul Odors

Good aeration promotes active aerobic decomposition. When piles are too wet, too large, not porous enough, or are degrading too quickly, aerobic bacteria can't get enough oxygen and anaerobic bacteria take over. Sulfur compounds and other by-products of anaerobic respiration form and odors build. Odors can originate from specific incoming or stockpiled feedstocks (such as sewage sludge, liquid manure or fish by-products) or poorly aerated compost piles. Anaerobic respiration, and resulting odors, can also occur in standing pools of water around compost windrows and in water retention ponds. You can minimize odors by proper pile management. Once aerobic conditions are reestablished, the bacteria will "eat" the odorous compounds.

Ammonia

Ammonia odors can form independent of the aeration of the feedstocks or piles. Nitrogen-rich feedstocks usually have low C:N ratios. If N is in excess, nitrogen is metabolized in a way that gaseous N compounds (ammonia and nitrous oxide) are released. To minimize this, set pile C:N well above 10:1 (25-35:1 ideal) and try to blend feedstocks to keep the pile pH below 7.5.

Siting Considerations, Technology Options and Management Intensity Levels

Siting Considerations

In choosing a site, consider

- Management operations: access to roads and ease of handling materials
- Water quality protection: siting is the first step in preventing leaching and run-off into

- surface or groundwater
- Neighborhood relations: odor, noise, dust, debris and appearance of your operation

Leaching of nitrates and other soluble nutrients is most likely to occur during curing phase and compost storage. Highly permeable soils are most at risk. Try to find a soil of intermediate permeability. Ideally, the site should be several feet above the seasonally high water table, and several hundred feet away from wells or surface water. Consider the slope of the site, especially the potential for water to run *into* the compost piles during storms or snowmelt. Plant grass buffer strips to slow run-off. Consider providing roofs over some of the composting area to divert precipitation and keep stored compost dry.

Site visibility and appearance can go a long way in maintaining a good perception of your operation. Use some of your compost to landscape the site, plant and maintain trees and grassy areas—these will also help control and filter run-off from the composting site. Choose a site with some consideration of the homes of neighbors and the direction of prevailing winds during warm weather. Plan grinding and turning for hours during the day in which neighbors are less likely to be affected by the odors and noise.

Composting Technologies

The most common composting technologies or methods are

- Static piles
- windrow composting
- passively aerated windrows
- forced aeration, static piles
- enclosed, or in-vessel, composting
- vermicomposting.

Within these methods are ranges of technology options.

Static Piles

Static piles are the simplest form of composting and require little management and equipment. Once established, it is very difficult to adjust moisture, and static piles tend to go anaerobic in the center. Aerobic conditions can be achieved if the initial pile porosity is high (>60%) and there is a high proportion of bulking materials to keep pores open for air exchange. While simple, this method takes the longest to produce finished compost, and the composted material can be



Figure 5. Although windrow composting uses more land than other methods, it can be put in the field where the compost is to be applied

quite heterogeneous.

Windrow Composting

Windrow is the general term for an elongated pile of stacked raw materials. (Figure 5). Piles need to be small (3-6') and porous enough for air to pass through them over a long period of time.

A *turned windrow* is one that is mechanically turned using a bucket loader, manure spreader or a windrow turner (Figure 6A,B). Turning the windrow remixes the materials, allowing all the raw materials to be colonized by microorganisms in the warmer, more active internal part of the compost pile. Oxygen is reintroduced, heat, water vapor and gases escape. The most important part of turning the pile is the reestablishment of porosity and the ability of air to get into the pile.

Passively aerated windrow system (PAWS)

PAWS includes perforated pipes placed at the base of each windrow to promote convective airflow throughout the pile. The key to this system is thorough premixing of feedstocks before placing on the perforated pipes. Also, windrows need to be insulated with finished compost to ensure thermophilic temperatures reach the outer edges of the windrow (Figure 6C).

Forced Aerated Static Piles

Forced aerated static piles are similar to PAWS piles, but blowers are installed at the ends of perforated pipes or air ducts as shown in Figure 7. Air flow can be adjusted by changing the frequency and duration of the blower. Usually, blowers are set to turn on when the compost reaches a maximum temperature (e.g., 150°F).

Enclosed Composting

Enclosed, or in-vessel, composting is mainly for the commercial compost producer who needs more



Figure 6a. Mixing poultry litter and agricultural byproducts in a feed mixer for passive aeration composting



Figure 6b. Using a tractor-pulled windrow turner to mix cannery wastes with sawdust and municipal leaves



Figure 6c. Turning poultry litter using a self-propelled windrow turner

environmental control during the composting process. Some large scale composting operations use completely enclosed in-vessel equipment to achieve maximum control of temperature, oxygen and moisture. Some farms have also successfully used the smaller, less expensive bin equipment. Equipment ranges from a simple enclosed bin, an agitated bin or reactor, to an entire building devoted to composting.

Vermicomposting

Vermicomposting is worm composting; in which red worms transform decaying organic matter into worm



Figure 7. Pipes are inserted into static aerated compost piles.

castings. The castings contain high concentrations of readily available nutrients for plants. Vermicomposting does not achieve the high (thermophilic) temperatures in windrow and aerated static pile composting because the worms can't survive the high temperatures.

However, research has shown that both pathogens and weed seeds can be destroyed in vermicomposting.

Vermicomposting is usually done in containers and can be done indoors and outdoors, allowing year round composting. The two types of worms best suited to worm composting are the red worms: *Eisenia foetida* (commonly known as red wiggler, brandling, or manure worm) and *Lumbricus rubellus*. They are often found in the litter layers of forests, manure piles and backyard compost heaps. For more information see **Resources**.

Choosing a composting method

Choose an approach that best suits your reasons for making compost, the location of the compost site and the amount of specialized equipment you have available to produce compost (**Figure 8**). Where you are located is important from environmental impact and potential nuisance perspectives. For example, composters located in rural areas need to be concerned that composting activities don't adversely affect surface and ground waters, but they usually are

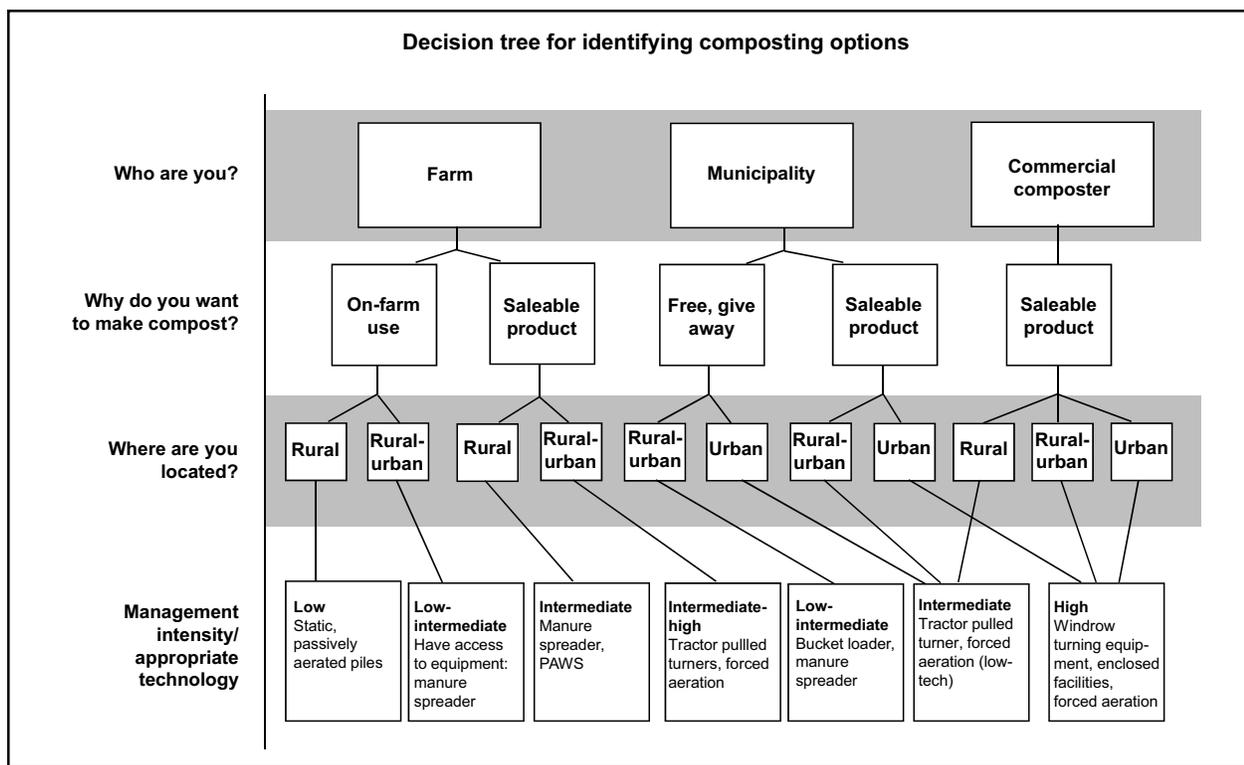


Figure 8. Choose an approach that best suits your reasons for making compost, the location of the compost site and the amount of specialized equipment you have available to produce compost.

less concerned about neighbor complaints related to odors, noise and dust. Composting sites located in rural-urban and urban areas often are forced to use high technology options to minimize nuisance complaints.

The decisions about technology options and management intensity can be viewed as a continuum (Figure 8). If you are new to composting and want to make compost exclusively for your own use, you might start out at the low to intermediate scale. Later if you decide to make a saleable product or expand your site, you might decide that you can justify the costs of higher technologies and more intensive management.

“Low technology” composting

Low technology options usually go hand-in-hand with minimal management. Examples include static, passively aerated piles where you would use dry and large-particle size feedstocks to give the compost pile sufficient porosity. Use of a bucket loader to turn piles infrequently (every two weeks) would also be considered a low-technology option for on-farm composting. These options make the most sense for individuals in rural areas making compost largely for their own use.

“Intermediate” technology options

Intermediate technology - moderate management intensity includes turned windrow composting using

non-specialized equipment. The most common example is building and turning piles using a manure spreader. These windrows would likely be turned once per week during the active phase of composting and then monthly during the curing phase. The passively aerated windrow system (PAWS) would also be considered an intermediate technology option because the composter will need some kind of equipment to premix feedstocks and will need to purchase perforated pipe for placement underneath the compost pile. Management of the PAWS system is intensive in the pile establishment phase, but minimal thereafter. Both of these intermediate technology options are suited to rural or rural-urban fringe locations. Composts produced using these methods would be best suited to internal use, unless the composter can demonstrate product consistency over time.

“High technology” composting

High technology options usually include specialized composting equipment: tractor-pulled or self-propelled windrow turners, forced aeration systems with perforated pipes and blowers and enclosed (or in-vessel) systems. These require serious financial and labor commitments. Use of these technologies are justified when the composter intends to make a saleable product and when the compost site is located either on the rural-urban boundary or within an urban setting. Management intensity of these systems is

usually high. For turned windrow systems, windrows are usually turned 2-3x/week during the active phase of composting (minimum of 1x/week) and then 1-2x/month during curing. For the forced-aerated and enclosed technologies, you will need to monitor the equipment to make sure that air flow and moisture are optimized to produce the desired temperature range.

Studies comparing technology-management effects on compost quality.

There are several studies evaluating the effects of different composting technologies and management intensities on compost “process variables” (measurements used to assess how the process is progressing) and finished compost. Lopez Real and Baptista (1996) evaluated three composting methods to determine their effects on composting process variables and methane emissions. The methods

Table 5. Percent change in compost total volume and volatile solids for three manure composting methods over a 36 day period. Average methane emissions over the same period.

Process variable	Minimal intervention	Windrow	Forced Aeration
	% change over time		
Volume reduction	55	73	55
Volatile solids	12	22	15
Average methane emission (ppmv)	28,744	223	3

ppmv = parts per million per volume

included 1) minimal intervention or passively aerated stacked manure; 2) windrowing or turned mechanically with a manure spreader and 3) forced aeration using perforated pipes and a blower. They evaluated changes in the first 36 days of composting and found that windrowing produced the greatest change in total volume and volatile solids compared to minimal intervention and forced aeration (Table 5). Methane emissions from the passively aerated piles were over 100 times greater than the windrow turned piles and 1000 times greater than the forced aeration piles. Results showed that introducing air mechanically speeds up the composting process and greatly reduces emissions of a greenhouse gas (methane).

Woods End Research Labs in Maine presented findings from two manure compost studies using a

Table 6. Technology and management effects on total losses of organic matter and nitrogen during composting.

Treatment	Organic Matter loss (%)	Total Nitrogen loss (%)
Cow manure compost at 120 days		
No turn	70	51
Bucket loader-turned	78	60
Turned 1x/2 weeks	73	53
Turned 2x/week	80	64
Poultry manure compost at 150 days		
No turn	75	72
Bucket loader-turned	79	76
Turned 1x/2 weeks	79	78
Turned 2x/week	88	86

Source: Brinton, 1998

range of composting technologies from no turning to highly specialized self-propelled windrow turners (Brinton, 1998). The evaluated compost pile temperature and oxygen, organic matter and nitrogen loss and operations & maintenance costs. Results showed that use of a turning machine reduced the time to finished compost by a few weeks compared to no turning or use of a manure spreader. When temperature profiles were compared, intensification of the composting process either through turning or adding bulking material to increase porosity decreased the time to “stable” compost by approximately 20 days. As management intensification increased, so did loss of organic matter and nitrogen (Table 6). However, the costs associated with technology and management also increased with intensification (Table 7). They concluded that if the goal for composting is nutrient management and on-farm use of compost, intensive technologies and management are not necessary.

Cost Considerations

These can be grouped into six general categories: 1) business and site development (most applicable to larger scale operations or permitted facilities), 2) feedstock costs, 3) equipment, 4) labor; 5) management (for large facilities) and 6) marketing and/

Table 7. Costs associated with varying technology and management intensities.

Treatment	Cost/wet ton (\$)
No turn	3.05
Bucket loader-turned	6.74
Turned 1x/2 weeks	14.34
Turned 2x/week	41.23

Source: Brinton, 1998

or compost use. For most feedstocks they will either be “free” or you will receive a “tipping fee.” However, in some cases, you will need to purchase bulking agents like wood chips or sawdust. Equipment costs include ownership, fuel and maintenance. Labor costs can be divided into operations and maintenance. It is wise to estimate these costs before starting a new composting operation to determine feasibility and pricing of saleable compost products.

Composting regulations and permits

If you are composting on farm or compost small volumes of material (<20,000 cubic yards per year), you can compost without a special permit from the Wisconsin Department of Natural Resources (DNR). However, most states regulate large-scale composting. Many composting facilities must obtain composting permits to ensure minimal negative environmental impacts. For more information, contact your state Department of Natural Resources. In Wisconsin, on-farm composting of crop residues, manure and animal carcasses at the location where they are produced are exempt from regulations, IF

- The facility is operated in a nuisance-free, environmentally sound manner.
- The compost is land-spread in compliance with NR 518.04(1).
- Composting of animal carcasses complies with s. 95-50(1).
- Yard wastes and wood chips accepted from off-site are only used to increase C:N ratio of manure and the porosity of the pile, and meet minimum operation and design standards

Qualities of the Finished Compost

Not all composts are created equal. What goes in as feedstocks partly determines what comes out. Compost quality depends on the composting process used, the state of biological activity, and, most importantly, the intended use of the compost. Just as beauty is in the eye of the beholder, the end use defines compost quality.

There are some specific chemical, physical and biological parameters that can be used to evaluate compost quality. For on-farm use as a soil amendment, a moisture content, organic matter content, C:N ratio

Table 8. Qualities of compost for on-farm use and how to test.

Quality	Optimum	How to test
Source of organic matter	Should have a good organic matter content	Have organic matter tested by a soil lab
Source of nitrogen	10-15:1 C:N ratio	Have C:N ratio checked by soil lab
Neutral pH	6-8	Use soil pH kit at home or soil lab
Low soluble salts	If compost will be spread in the fall, no test necessary. If compost will be spread before planting, have soil lab check that levels are below 10 dS	
No phytotoxic compounds	Good seed germination	Plant 10 seeds in a small pot.
Weed-free	No or few weed seeds	Moisten compost and watch for weed seedling growth.

and pH should be determined before compost application (**Table 8**). High value markets like nurseries, landscaping, and turf require a high quality compost with specific qualities and characteristics suitable for plant growth.

Compost Quality Standards

Aside from temperature requirements to kill pathogens (55°C for at least 72 hrs.) and general acceptance of US EPA 503 Biosolids rules for trace metal concentrations, there are no federal standards for finished compost. Some states are in the process of developing standards to minimize negative environment effects (pathogens, heavy metals and organic pollutants). Other states require tests for biological stability and compost-use related properties (salt content, pH, C:N ratio).

However, there are excellent programs dedicated to establishing market-driven standards for the benefit of composters and compost users: Two of these programs are the *Seal of Testing Assurance* (STA) by the United States Composting Council and the *Solvita Quality Seal of Approval* by the Woods End Research Group.

How the STA Program works

Compost producers regularly sample and test their product, using STA Program approved labs, for chemical, physical and biological properties. All of these labs must use the same standardized testing methodologies. Testing frequency is based on the each production facility’s volume and can be as frequent as monthly for the largest producers, to quarterly for the

smaller composter. Compost use directions are provided with the test results. The goal of the program is to provide a standard STA label to allow end users to compare compost products and make an informed purchasing decision. See their web site under Resources for more detail.

The Solvita Quality Seal of Approval

The Woods End *Solvita Quality Seal of Approval* program is based on specific, identified uses. Six end-use categories are presently recognized. The program provides specific tests designed to assure users that a particular compost or product meets basic quality expected for that particular use. Anyone who produces or distributes a compost or soil amendment product, may seek the Solvita Quality Seal of Approval. See **Resources** for more information on their program.

Summary

Composting organic wastes is an environmentally sound means of recycling raw organic materials into valuable soil amendments with many uses. As you begin your composting operation, keep in mind these five points for a successful outcome:

- Be clear why you are making compost, and what you intend the final use of the compost to be.
- Choose equipment and management methods based on your location and the intended use of the finished product.
- Determine the right mix of ingredients to optimize C:N ratio, moisture content and porosity.
- Monitor the composting process: temperature, oxygen, moisture and odors.
- Test the finished compost to ensure it has the qualities you need for the intended use.

To your compost's health!

Resources

On-Farm Composting Handbook. Rynk R, 1992. Northeast Regional Agricultural Engineering Service Pub. No. 54. Cooperative Extension Service. Ithaca, N.Y. 1992; 186pp. A classic in on-farm composting. \$20 from NRAES, Cooperative Extension, 607-255-7654 or 607-254-8770. email: nraes@cornell.edu. Website: www.nraes.org

The Field Guide to On-Farm Composting. 1999. 128 pages. A sturdy reference guide developed as a companion to the NRAES publication. On-Farm Composting Handbook (NRAES-54). \$14.00 from NRAES - see phone numbers above.

Field Guide to Compost Use. The U.S. Composting Council. 1996.

The Composters Answers Book. Volume 1. 1999.

Composting Manure for Value-Added Products. 2001.

Composting for Manure Management.
Biocycle, Vol. 39, April 1998. <http://www.jgpress.com/>

Websites

The U.S. Composting Council
<http://compostingcouncil.org/index.cfm>
promotes research, public education, compost standards and expansion of compost markets.

Woods End Research Laboratory
pioneers in compost quality analysis and standards.
<http://www.woodsend.org/>

Cornell Composting
http://www.cfe.cornell.edu/compost/Composting_homepage.html

US EPA's Composting Web Page <http://www.epa.gov/compost/> includes Innovative Uses of Compost and other EPA compost publications.

The California Quality Compost Council <http://www.ccqc.org/>

WasteNOT Organics
www.wastenot-organics.wisc.edu/wno
Research-based information from the University of Wisconsin-Madison about organic by-products and their use as soil amendments.

BioCycle - Journal of Composting & Recycling on-line
<http://www.jgpress.com/>

Recycler's World - equipment and services
www.Recycle.net/recycle/organic

Composting News on-line newsletter for the composting industry <http://www.recycle.cc/>

Internet Recycling and Composting Resource Page - equipment and services <http://www.recycle.cc/resource.htm>

Vermicomposting

Worms for Composting from the ATTRA (Appropriate Technology Transfer for Rural Areas - pdf file 211K) www.attra.org/attra-pub/PDF/vermicomp.pdf

Worm Digest www.wormdigest.org/
Email: mail@wormdigest.org

Compost Recipes

The Cornell Compost Recipe Maker. <http://www.cfe.cornell.edu/compost/download.html>.
Downloadable Excel spreadsheets with compost mixture calculations for up to four ingredients (Mac or PC)

Compost Recipe Maker by Herb Brodie. An excellent DOS-based computer software program. \$40 from Pat Lupo, University of Maryland. Tel: 301-405-1198.

Compost Maturity

Solvita(r) Compost Maturity Test kits <http://www.woodsend.org/solvita.htm>

How Do I Know If My Compost Is Mature? The California Compost Quality Council's maturity index (pdf file- 100 K) <http://www.ccqc.org/downloads.htm>

Compost Quality Standards

Woods End Compost Research Lab <http://www.woodsend.org>
Solvita Quality Seal of Approval program <http://www.woodsend.org/sqa.htm>

Seal of Testing Assurance Program (STA) <http://tmec.org/sta/index.html> (from The U.S. Composting Council at <http://compostingcouncil.org/index.cfm>)

References

Will Brinton, Jr. *On farm composting evaluation of manure blends and handling methods for quality composts.* (1998)
Woods End Research Laboratory. Report to USDA
Tech Center, Chester PA

Lopez Real, J. and M. Baptista. 1996. *A preliminary comparative study of three manure composting systems and their influence on process parameters and methane emissions.*
Compost Science and Utilization Vol. 4, No. 3: 71-82.

Rynk, R. *On-Farm Composting Handbook.* NRAES Pub. 54, 1992.

Cornell Waste Management Institute <http://www.cfe.cornell.edu/compost/odors/inadeq.porosity.html#txt1>

US Environmental Protection Agency, Organic Materials Management Strategy EPA530-R-97-003. Washington, DC. Government Printing Office, 1998.