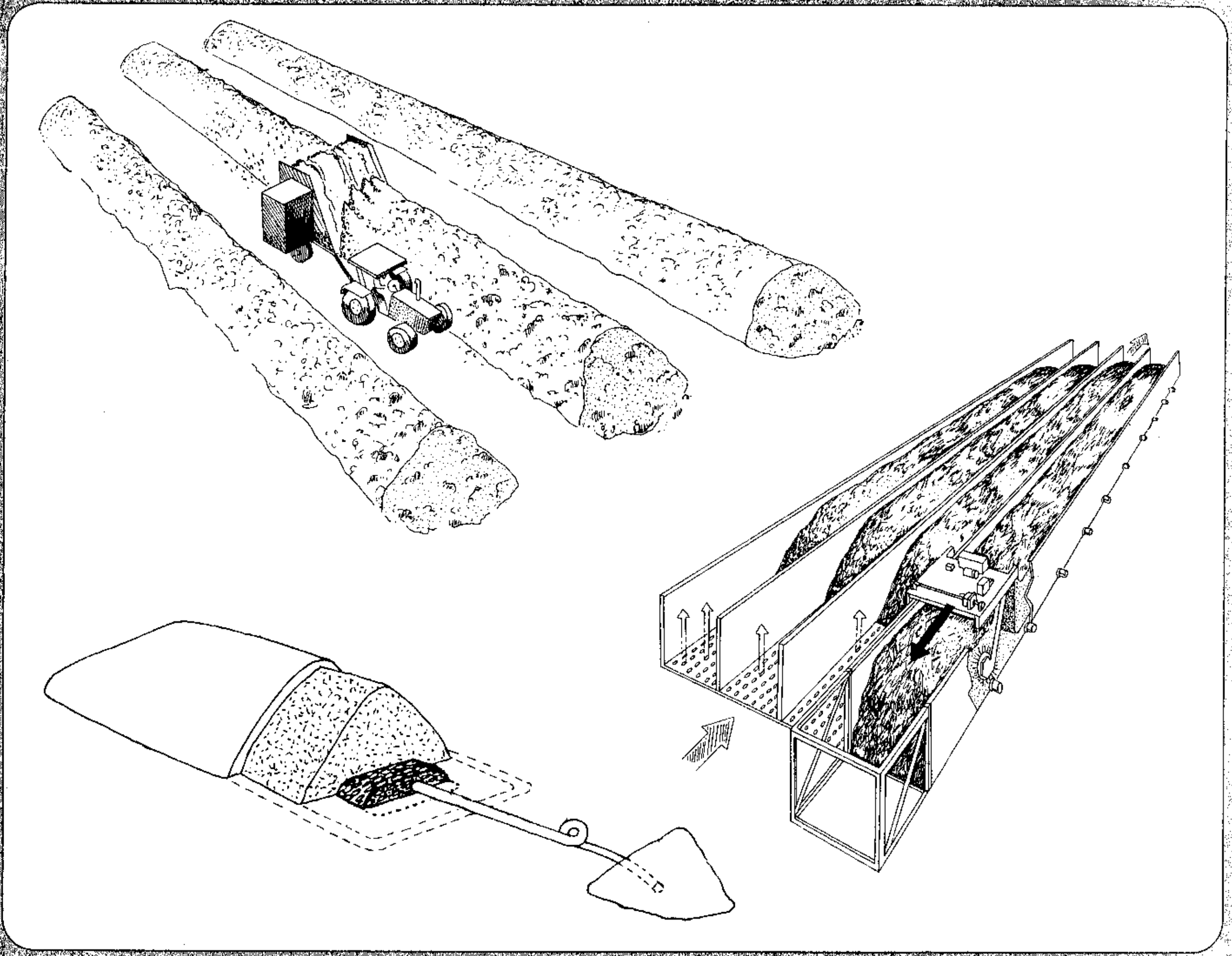
NRAES–54

On-Farm Composting Handbook



Northeast Regional Agricultural Engineering Service
Cooperative Extension

Acknowledgments

The development of this bulletin began in 1987 when a committee was established to address the need for information concerning on-farm composting. Robert Rynk, former extension agricultural engineer at the University of Massachusetts, led the committee and wrote and edited many drafts of the manuscript. During the project, most of the authors were not employed in the land grant system and donated their time to the development of the handbook. NRAES is grateful to the authors for their commitment to this project.

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Credits

Portions of the material on grinders and shredders in chapter 5 were taken from *Yard Waste Management: A Planning Guide for New York State* by Richard, Dickson, and Rowland. A portion of the discussion on screens in chapter 5 was taken from *Composting Fish By-Products: A Feasibility Study* by Brinton and Seekins. Special thanks must go to the farmers and composters who provided most of the real-world information that made the case studies in chapter 10 possible: Marvin Glaum, Glaum Egg Ranch; Elizabeth Henderson and David Stern, Rose Valley Farm; Wayne Gerster and Fred Feit, Gerster & Sons, Inc.; Karl Hammer and Nels Johnson, Moody Hill Farms; Brett Kreher, Kreher Poultry Farms; Tom Richard, Hardscrabble Farm; Gary Tennant, Cornell University Farm Services; and David Allen, Farmer Automatic of America, Inc. The authors are grateful to the compost equipment manufacturers and other commercial enterprises that gave permission for their information and illustrations to be used in developing this handbook. Chapter 1 includes a brief description of parasitic protozoans and the potential for these pathogens to be destroyed during the composting process. The following persons from Cornell University assisted in developing the text: Alice Pell, Associate Professor, Animal Science; Susan Wade, Director, Parasitology Division, Diagnostic Lab, New York State College of Veterinary Medicine; William Ghiorse, Associate Professor, Microbiology; Lynne J. Brundage-Anguish, Research Support Specialist, Microbiology; and Keith Porter, Director, New York State Water Resources Institute.

Reviewers

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Disclaimers and Further Notes

Throughout the text, certain illustrations were developed from commercial products, and trade names and equipment manufacturers' names are used. Trade names and commercial products are used for illustrative purposes and to simplify information. They do not imply an endorsement of any particular product or a preference for a particular trade name.

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Introduction

Composting is a biological process in which microorganisms convert organic materials such as manure, sludge, leaves, paper, and food wastes into a soil-like material called compost. It is the same process that decays leaves and other organic debris in nature. Composting merely controls the conditions so that materials decompose faster.

Composting and the use of compost offer several potential benefits including improved manure handling, enhanced soil tilth and fertility, and reduced environmental risk. The composting process produces heat, which drives off moisture and destroys pathogens and weed seeds. With good management, it produces a minimum of odors.

Compost is quite different from the original materials that it was derived from. It is free of unpleasant odors, is easy to handle, and stores for long periods of time. Compost has a variety of uses which make it a valuable and saleable product. For all of these reasons, composting is attracting the attention of farmers, waste-generators, public officials, and environmentalists.

Agriculture is well-suited to composting. The amount and nature of farm wastes, the availability of land, and the benefits which compost brings to soil make farms an ideal place to practice composting. Anyone familiar with basic agricultural principles should have little difficulty grasping the technology of composting. Often the equipment needed already exists on the farm.

Composting is not a new technology, nor is it new to agriculture. Written references of deliberate composting can be found in the Bible. Farmers in eighteenth- and nineteenth-century America practiced composting. A century ago, composting methods and speed differed little from the decomposition of organic materials which occurs naturally. It wasn't until the twentieth century, beginning with the Indore method in India, that scientific principles were applied to composting, speeding the process with selected materials, mechanical devices, and specific methods of constructing composting piles. However, by this time, farming had also become more scientific. Mechanization, chemical fertilizers, and specialization changed farming. Compost was perceived to be unnecessary, and waste disposal was not yet a major problem. As a result, composting largely disappeared from farms.

Later in this century, interest in composting shifted to municipalities, where it offered a means to treat solid waste and sewage sludge. Now, with shrinking landfill space and increasing concern about the environment, composting is becoming popular. Both the number and variety of applications have increased. Composting is now seen as a way to turn problem materials such as sewage sludge, municipal solid wastes, and agricultural wastes into a valuable product which can be recycled back to the land.

This handbook presents a thorough overview of composting as it is practiced on the farm. It explains how to produce, use, and market compost. The information is intended to help farmers decide whether composting or the use of compost is appropriate for their farm. For waste producers, environmental regulators, and public health officials, the handbook provides insight about agricultural composting and what it can reasonably accomplish.

It is important to emphasize that the information presented here reflects current composting technology at the time the book was written. However, composting practices, equipment, and environmental regulations continue to develop at a fast pace. Popular journals such as *BioCycle* magazine offer a good way to stay current with composting technology. These journals report on composting applications and research findings and update the availability of commercial equipment. USDA agencies, including the Cooperative Extension System and the Soil Conservation Service, are showing increasing interest in composting. These agencies, as well as state environmental agencies and organizations promoting agriculture, recycling, and environmental conservation, can be valuable sources of current information, advice, and technical assistance.

Using the Glossary and References Sections

A glossary is included beginning on page 169. It contains terms used throughout the bulletin. Glossary words are indicated in *italics* the first time they appear in a chapter. The glossary defines terms as used in this publication (that is, in the context of composting). General usage may at times conflict with definitions given.

For the convenience of readers, two sections of reference materials are given at the end of this handbook. They are meant to complement one another. The references section is arranged alphabetically by authors' last names and contains complete information on all materials used in compiling this guide. The suggested readings section is arranged in categories based on specific chapters and sections and includes addresses for ordering certain publications. Readers who want further information on specific topics (beyond the discussions in this handbook) should first consult the suggested readings section for a particular book or publication and then check the references section for a complete listing.

1

Benefits and Drawbacks

The first question that you should ask is "Why bother *composting* on the farm?" Composting performs two functions. It turns nuisance-causing waste products into an easily handled material, and it creates a valuable commodity. Either function could provide the primary reason for composting on a farm, but both provide potential benefits. On the negative side, composting is a major undertaking. You cannot simply pile *manure* behind the barn and expect to have *compost* several weeks later. A successful composting operation deserves the same commitment given to other farm tasks like milking, egg handling, or pest control. Like any enterprise, drawbacks come with the benefits (table 1.1).

The Benefits

Benefits of on-farm composting include soil conditioning, having a saleable product, improved manure handling, improved *land application,* lower risk of *pollution* and nuisance complaints, pathogen destruction, using compost as a *bedding* substitute, disease suppression, and processing or *tipping fees.*

Soil Conditioning

Compost is an excellent *soil conditioner.* When applied to cropland, compost adds *organic matter,* improves *soil structure,* reduces fertilizer requirements, and reduces the potential for soil erosion.

Saleable Product

One of the most attractive features of composting is that there is a market for the product. Potential buyers include home gardeners, landscapers, vegetable farmers, turf growers, operators of golf courses, and ornamental crop growers. The price of compost varies considerably because it is often viewed as a waste product. Bulk compost prices start at about $5 per *cubic yard* and average about $10 per cubic yard. Farm-produced compost has sold for as high as $50 per cubic yard. The price depends on the local market, compost quality, and the raw materials used.

Improved Manure Handling

Composting reduces the weight, *moisture content,* and activity of manure. Compost is easier to handle than manure and stores well without odors or fly problems. Because of its storage qualities, compost can be applied at convenient times of the year. This minimizes runoff and nitrogen loss in the field. Although composting also reduces the volume of the manure, the addition of *amendments* to the composting mix makes up for this loss in volume.

Improved Land Application

Both compost and manure are good soil conditioners with some *fertilizer value.* Usually manure is put on the land directly, providing soil improving qualities comparable to those of compost. Therefore, soil conditioning by itself does not usually justify making compost from manure. However, there are benefits to be gained by composting manure.

1. Composting converts the nitrogen contained in manure into a more stable organic form. Although this results in some loss of nitrogen, what remains is less susceptible to leaching and further *ammonia* losses.
2. Highly bedded manures have a high *carbon-to-nitrogen ratio.* When applied to the land directly, the excess carbon in the manure causes nitrogen in the soil to be temporarily unavailable to the crop. Composting high-carbon manure/bedding mixtures lowers the carbon/nitrogen ratio to acceptable levels for land application.

Table 1.1
Benefits and drawbacks of on-farm composting

Benefits of composting	Drawbacks of composting
Excellent soil conditioner	Time and money involved
Saleable product	Land required for operations
Improves manure handling	Possibility of odors
Improves land application	Weather interferes with composting
Lowers risk of pollution and nuisance complaints	Marketing is necessary
Pathogen destruction	Diversion of manure and crop residues from cropland
Bedding substitute	Potential loss of nitrogen in manure
May reduce soilborne plant diseases	Slow release of nutrients in compost
Possible revenue from processing or tipping fees	Risk of being considered a commercial enterprise

3. The heat generated by the composting process reduces the number of weed seeds contained in the manure.

Lower Risk of Pollution and Nuisance Complaints

On a growing number of farms, manure is more of a liability than an asset. Disposal of manure is a problem where feed is not grown on the farm, when previously rented land is lost, or when herd size has increased beyond the farm's capacity to support it. Odor complaints are common in populated areas. Other concerns include runoff from manure spread on frozen ground and *nitrate contamination* of wells.

Composting has the potential to alleviate these problems. Disposal is less of a problem because there is usually a demand for compost. Storage and handling qualities of compost allow it to be transported farther than manure and other raw materials, possibly out of an over-burdened watershed. A well-run manure composting operation generates fewer odors and flies. Composting also converts nutrients into forms which are less likely to leach into ground water or be carried away by surface runoff.

Pathogen Destruction

While human *pathogens* are rarely a concern in farm-generated wastes, outbreaks of *Giardia* species and *Cryptosporidium parvum* have been reported in livestock. Both are protozoans that can cause recurrent diarrhea in humans and animals, particularly those with a weakened immune system. The protozoans are transmitted from infected animals as dormant cysts in fecal material. The cysts persist in the environment even under adverse conditions.

Livestock can be infected with these parasites by ingesting feed or water contaminated by fecal matter from infected animals, either domestic or wild. Young animals are more likely to become infected because of current management practices that group young animals in pens. They are also more likely to show clinical signs of infection.

When an animal has diarrhea because of these protozoans, the manure has high numbers of the protozoan cysts. Animals that do not show signs of infection may carry the protozoans and shed the cysts in their feces.

The protozoans are killed by exposure to a temperature of 140°F for thirty minutes. While temperatures within the compost pile can reach 140°F, material near the pile surface may not. Turning the pile improves the potential for all material to reach the required temperature. Literature suggests that exposing the protozoans to temperatures lower than 140°F for several days may kill the organisms. More research is needed to develop specific guidelines for reducing the protozoan populations during the compost cycle.

Bedding Substitute

Compost has been used for *poultry litter* and bedding in livestock barns. Research and experience have shown that compost is generally a safe and effective bedding material.

Disease Suppression

Properly prepared compost has been found to reduce soilborne plant diseases without the use of chemical controls. The disease-suppressing qualities of compost are just beginning to be widely recognized and appreciated.

Processing or Tipping Fees

The current waste disposal crisis has towns and waste generators searching for alternative disposal methods. This has created an opportunity for farmers to collect processing fees by composting certain off-farm waste materials. The fee collected for accepting waste materials is commonly referred to as a tipping fee.

Some municipal and industrial wastes may actually improve a farm's composting mix. Most manures need to be mixed with relatively dry materials that are good sources of carbon. Leaves, newspaper, cardboard, sawdust, bark, and shavings are all good for this purpose. Moist materials, like produce and food processing wastes, can be composted with dry farm residues such as straw. Some off-farm materials like leaves and *yard wastes* can be composted alone, taking advantage of the farm's land and equipment.

Composting off-farm wastes must be considered cautiously. First, tipping fees can be difficult to capture. Alternative uses for off-farm wastes often exist, and the competition for the waste producers' dollar can be strong. Second, waste materials may be difficult to handle or have the potential to create nuisances. A high tipping fee usually means that the material is more likely to be troublesome.

Composting off-farm wastes might lead to extra processing at the composting site, odor problems and odor control measures, resistance from neighbors, and more restrictive environmental regulations. The impact on the quality and value of the compost product must also be considered since the raw materials can determine the compost's market value and the concentration of contaminants (such as *heavy metals*) may affect its use.

The Drawbacks

Drawbacks to on-farm composting include time and money, odor, weather, marketing, diversion of manure and crop residues from cropland, potential loss of nitrogen, slow release of nutrients, and risk of losing farm classification.

Time and Money

Like any other operation, composting requires equipment, labor, and management. The initial investment for a composting operation can be very low, if existing farm equipment and facilities are used. This approach is fine where the volume of material is relatively small, but most medium- to large-scale farms have found that using only existing equipment requires too much labor. Many farm composters have found it necessary to purchase special composting equipment. With special equipment, it could cost as little as $10,000 or well over $100,000 to start a farm composting operation, depending on the equipment purchased.

Land

The composting site, storage for raw material, and storage for finished compost can occupy a considerable area of land and sometimes building space.

Odor

To say that composting is free of odors is misleading. Although the end products of the process itself are not odorous, the materials that are being composted sometimes do create offensive odors. Until they begin to compost, active materials like manure, *sewage sludge,* and food wastes can produce odors, especially if they have been in storage for a while. Odors can also be generated if the process is mismanaged.

A sensitivity to odors is essential. Some sites, because of their location, may require odor control measures. This information does not contradict earlier statements that composting can resolve odor problems. With most raw materials, the odors from a well-managed composting operation are periodic and short lived. In most cases composting still represents an improvement over conventional methods of handling manures.

Weather

Cold weather slows the composting process by lowering the temperature of the composting material. It can also cause other problems like freezing materials and equipment. The effects of rain and snow are potentially more serious. Heavy precipitation adds water to the composting mix; snow and mud limit access to *windrows.* It is possible that a heavy snow fall could interrupt the operation until spring. If this occurs, an alternative method to store or dispose of the wastes is necessary.

Marketing

Selling compost involves marketing. This means searching out potential buyers, advertising, packaging, managing inventory, matching the product to the customers' desires, and maintaining consistent product quality.

Diversion of Manure and Crop Residues from Cropland

Composting manure and then selling it as compost diverts the nutrients, organic matter, and soil-building qualities of that manure from cropland. This also holds true for crop residues that are composted rather than returned to the land. Buying commercial fertilizers to make up for the lost nutrients may not make good economic or agronomic sense.

Potential Loss of Nitrogen

Composted manure often contains less than half the nitrogen of fresh manure. A good manure handling system conserves most of the nitrogen, so composting represents a potential nitrogen loss. However, without soil incorporation and proper storage, manure quickly loses nitrogen to the atmosphere and eventually may retain even less nitrogen than compost.

Slow Release of Nutrients

The nutrients in compost are mostly in a complex organic form and must be mineralized in the soil before they become available to plants. For example, less than 15% of the total nitrogen in compost is typically available in the first cropping season. Compared to raw manure, initial applications of compost must be greater to achieve the same nitrogen fertilization level.

However, adding enough compost to satisfy 100% of the crop's nitrogen needs in a given year may not be desirable because of the large number of trips the spreader must make. In the following years, nitrogen from previous applications will gradually become available.

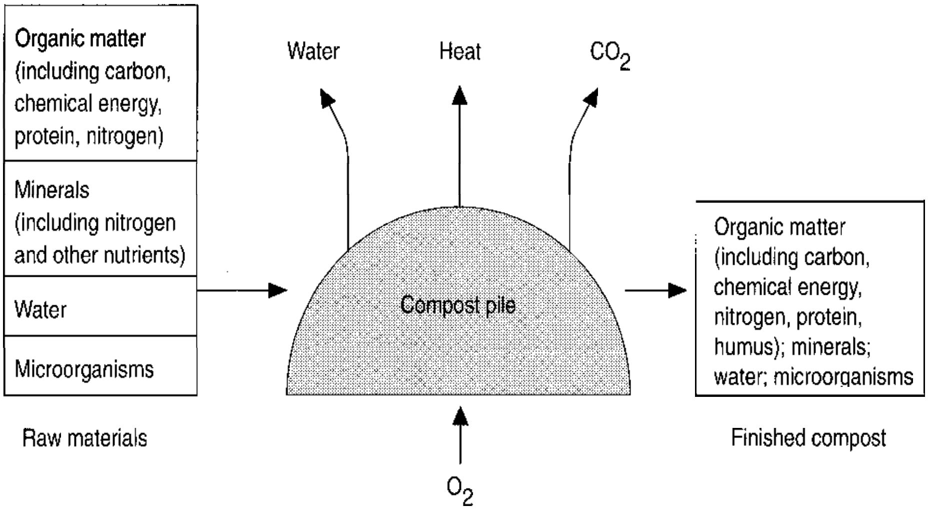
Risk of Losing Farm Classification

It is possible to be too successful. If a farm sells a large amount of compost or handles off-farm wastes for a fee, neighbors and local regulators may contend that the operation is a commercial enterprise, rather than an agricultural activity. A farm could conceivably lose its status as a farm in regard to zoning or environmental regulations. Consider this carefully before establishing or expanding your composting operation. Try to determine at what point and under what conditions a farm composting operation becomes a commercial enterprise in your state or community.

2

The Composting Process

Composting is the *aerobic*, or oxygen-requiring, decomposition of organic materials by *microorganisms* under controlled conditions. During composting, the microorganisms consume oxygen (O_2) while feeding on *organic matter* (figure 2.1). Active composting generates considerable heat, and large quantities of *carbon dioxide (CO_2)* and water vapor are released into the air. CO_2 and water losses can amount to half the weight of the initial materials. Composting thus reduces both the volume and mass of the raw materials while transforming them into a valuable *soil conditioner*.



The carbon, chemical energy, protein, and water in the finished compost is less than that in the raw materials. The finished compost has more humus. The volume of the finished compost is 50% or less of the volume of raw material.

Figure 2.1
The composting process.

Composting is most rapid when conditions that encourage the growth of the microorganisms are established and maintained (table 2.1). The most important conditions include:

- Organic materials appropriately mixed to provide the nutrients needed for microbial activity and growth, including a balanced supply of carbon and nitrogen *(C:N ratio)*
- Oxygen at levels that support aerobic organisms
- Enough moisture to permit biological activity without hindering *aeration*
- Temperatures that encourage vigorous microbial activity from *thermophilic* microorganisms

Many aspects of composting are inexact. The process occurs over a wide range of conditions and with many materials. The speed of composting and the qualities of the finished *compost* are largely determined by selection and mixing of raw materials.

What Happens during Composting

Composting begins as soon as appropriate materials are piled together. Initial mixing of raw materials introduces enough air to start the process. Almost immediately, the microorganisms consume oxygen and the settling of the materials expels air from the pore space. As the supply of oxygen decreases, aerobic decomposition slows and may eventually stop if the oxygen is not replenished. Aeration is continually required to recharge the oxygen supply. Aeration is provided either by passive air exchange (natural convection and diffusion) or by *forced aeration* (blowers/fans). Mechanical agitation of the composting materials, or *turning*, supplies a limited amount of oxygen; but this is quickly consumed and must be replenished by passive or forced air movement. Turning is required for good aeration. It restores the pore space within the pile so that air moves through materials more easily (figure 2.2).

Since the release of heat is directly related to the microbial activity, temperature is a good process indicator. Temperature increases resulting from microbial activity are noticeable within a few hours of forming a pile or *windrow* as easily degradable compounds, such as sugars, are consumed. The temperatures of the composting materials typically follow a pattern of rapid increase to 120–140°F which is maintained for several weeks. As active composting slows, temperatures gradually drop to 100°F and finally to *ambient air temperature*. This characteristic pattern of temperature over time reflects changes in the rate and type of decomposition taking place as composting proceeds (figure 2.3).

During the active composting period, the temperature falls if oxygen becomes scarce because microbial activity decreases. The temperature rises again after turning or forced aeration. If oxygen is available and the microbial activity is intense, the temperature can rise well above 140°F. At this point many microorganisms begin to die or become dormant. With the decreased microbial activity, the temperature may then stabilize or even fall. Cooling the pile by turning or forced aeration helps to keep the temperature from reaching these damaging levels.

Table 2.1
Recommended conditions for rapid composting

Condition	Reasonable range [a]	Preferred range
Carbon to nitrogen (C:N) ratio	20:1–40:1	25:1–30:1
Moisture content	40–65% [b]	50–60%
Oxygen concentrations	Greater than 5%	Much greater than 5%
Particle size (diameter in inches)	1/8–1/2	Varies [b]
pH	5.5–9.0	6.5–8.0
Temperature (°F)	110–150	130–140

[a] These recommendations are for *rapid* composting. Conditions outside these ranges can also yield successful results.

[b] Depends on the specific materials, pile size, and/or weather conditions.

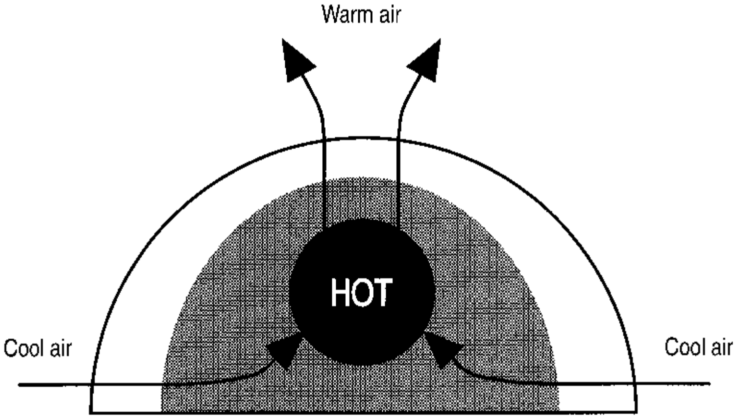


Figure 2.2
Natural (passive) air movement in a composting windrow or pile.
Source: Richard and Dickson, *Municipal Yard Waste Composting: An Operator's Guide.*

A *curing* period usually follows the active composting stage. While curing, the materials continue to compost but at a much slower pace. The rate of oxygen consumption decreases to the point where the compost can be piled without turning or forced aeration.

The composting process does not stop at a particular point. Material continues to break down until the last remaining nutrients are consumed by the last remaining organisms and until nearly all of the carbon is converted to carbon dioxide. However, the compost becomes relatively stable and useful long before this point. Compost is judged to be "done" by characteristics related to its use and handling such as C:N ratio, oxygen demand, temperature, and odor.

Factors Affecting the Composting Process

Factors affecting the composting process include oxygen and aeration; nutrients (C:N ratio); moisture; *porosity, structure, texture,* and particle size; *pH;* temperature; and time.

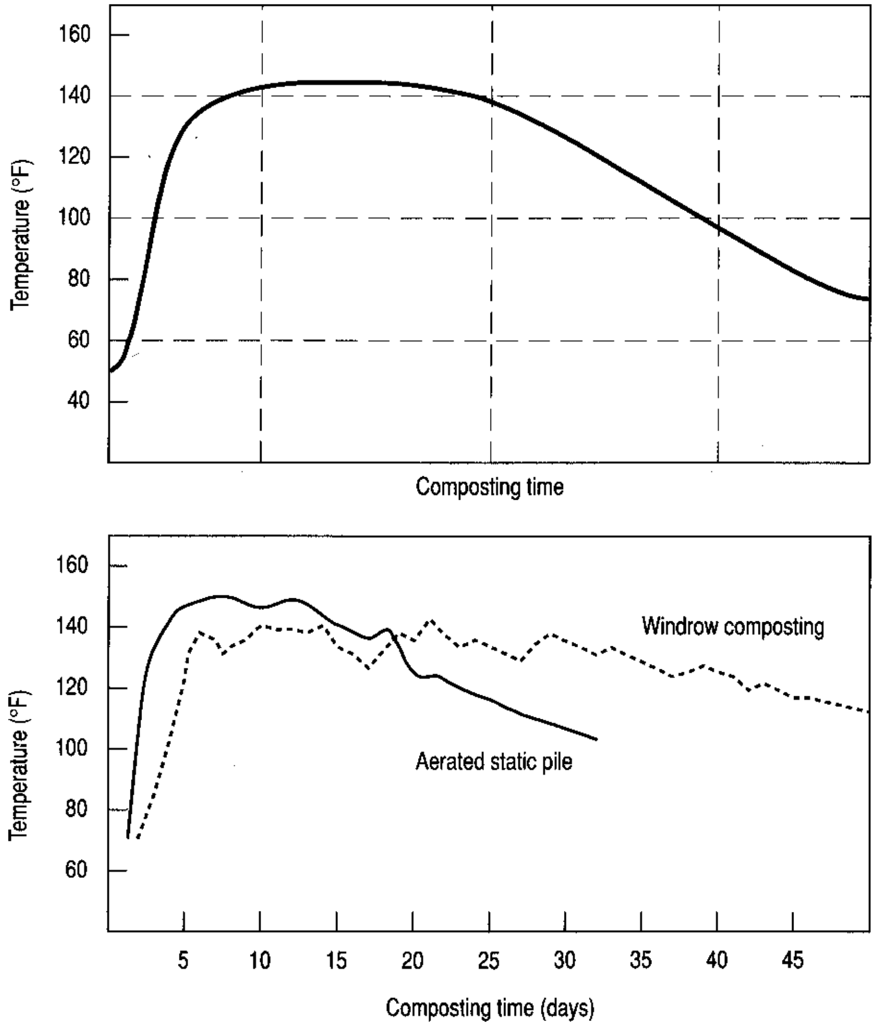


Figure 2.3
Time-temperature patterns for composting: general (top) and typical (bottom).

Oxygen and Aeration

Aerobic composting consumes large amounts of oxygen. During the initial days of composting, readily degradable components of the raw materials are rapidly metabolized. Therefore, the need for oxygen and the production of heat are greatest at early stages and then decrease as the process ages. If the supply of oxygen is limited, the composting process slows. A minimum oxygen concentration of 5% within the pore spaces of the composting pile is necessary (air contains about 21% oxygen).

Without sufficient oxygen, the materials become *anaerobic*. Anaerobic decomposition involves a different set of microorganisms and different biochemical reactions. Anaerobic processes are generally considered slower and less efficient than aerobic processes. Little heat is generated to evaporate water from the materials. Anaerobic processes develop intermediate compounds including methane, organic acids, *hydrogen sulfide*, and other substances. Many of these compounds have strong odors, and some present safety concerns. Although intermediate compounds (such as organic acids) form under aerobic decomposition, they continue to decompose when oxygen is available. Under anaerobic conditions, the intermediate compounds accumulate. An adequate supply of oxygen gives the more efficient aerobic organisms a competitive advantage over the anaerobes. Maintaining aerobic conditions is important in avoiding the offensive odors associated with anaerobic decomposition.

In addition to providing oxygen, aeration removes heat, water vapor, and other gases trapped within the composting materials. In fact, the required rate of aeration for heat removal can be ten times greater than that for supplying oxygen. Therefore, temperature often determines how much and how frequently aeration is required. The aeration rate required to reduce the *moisture content* is normally greater than that required for supplying oxygen but less than the heat removal rate.

Nutrients (C:N Ratio)

Carbon *(C)*, nitrogen *(N)*, phosphorus *(P)*, and potassium *(K)* are the primary nutrients required by the microorganisms involved in composting. Nitrogen, phosphorus, and potassium are also the primary nutrients for plants; so their concentrations also influence the value of the compost.

Many organic materials, including *manures*, plant residues and food wastes, contain ample quantities of nutrients. Excessive or insufficient carbon or nitrogen is most likely to affect the composting process. Microorganisms use carbon for both energy and growth while nitrogen is essential for protein and reproduction. In general, biological organisms, including humans, need about twenty-five times more carbon than nitrogen. It is, therefore, important to provide carbon and nitrogen in appropriate proportions. The ratio of carbon to nitrogen is referred to as the C:N ratio. A balanced C:N ratio usually ensures that the other required nutrients are present in adequate amounts.

Raw materials blended to provide a C:N ratio of 25:1 to 30:1 are ideal for active composting, although initial C:N ratios from 20:1 up to 40:1 consistently give good composting results. For many applications, C:N ratios of even 50:1 and higher are acceptable. With C:N ratios below 20:1, the available carbon is fully utilized without stabilizing all of the nitrogen. The excess nitrogen may then be lost to the atmosphere as *ammonia* or nitrous oxide and odor can become a problem. Mixes of materials with C:N ratios higher than 40:1 require longer composting times for the microorganisms to use the excess carbon.

Although the C:N ratio is a useful guide when formulating composting blends, the rate at which carbon compounds decompose must also be considered. For example, straw decomposes and releases its carbon to the microorganisms more easily than woody materials. This occurs because the carbon compounds in woody materials are largely bound by *lignins*, organic compounds which are highly resistant to biological break down. Similarly, the carbon in the simple sugars of fruit wastes is more quickly consumed than the *cellulose*-carbon in straw.

If the carbon is in a form that is difficult to decompose, the composting rate may be slow. Since decomposition occurs on particle surfaces, *degradability* can be improved by reducing the particle size (which increases the surface area) as long as porosity is not a problem (see following sections). If desired, the C:N ratio can be adjusted higher to compensate for poorly degradable sources of carbon, though a longer composting period may be necessary.

Moisture

Moisture is necessary to support the metabolic processes of the *microbes*. Water provides the medium for chemical reactions, transports nutrients, and allows the microorganisms to move about. In theory, biological activity is optimal when the materials are saturated. It ceases entirely below a 15% moisture content. In practice, however, composting materials should be maintained within a much narrower moisture content range, generally between 40% and 65%.

Experience has shown that the composting process becomes inhibited as the moisture content nears 40%. Below 40%, microbial activity continues slowly. At moisture levels above 65%, water displaces much of the air in the pore spaces of the composting materials. This limits air movement and leads to anaerobic conditions.

Since the moisture content generally decreases as composting proceeds, the starting moisture content should be well above 40%. For many compost mixtures, materials that are too dry are blended with materials that are too wet to achieve a 50–60% moisture content. With some dry materials, such as leaves, water is sometimes added directly.

During composting, moisture levels change as water evaporates from the pile and is added by rain and snow. Generally more water evaporates than is added, so the moisture content tends to decrease as composting proceeds. Moisture levels should be maintained such that materials are thoroughly wetted without being waterlogged or dripping excessive water. As a rule of thumb, the materials are too wet if water can be squeezed out of a handful and too dry if the handful does not feel moist to the touch.

The 40–65% moisture content range is a general recommendation that works well for most materials. The acceptable upper moisture limit actually depends on the porosity and absorbency of the raw materials. Highly porous materials can be wetter than densely packed materials with small particles. A mixture with highly absorbent materials may need to be maintained well above 40% moisture to support rapid composting.

Porosity, Structure, Texture, and Particle Size

Porosity, structure, and texture relate to the physical properties of the materials such as particle size, shape, and consistency. They affect the composting process by their influence on aeration. They can be adjusted by the selection of the raw materials and by *grinding* or mixing. Materials added to adjust these properties are referred to as *amendments* or *bulking agents*.

Porosity is a measure of the air space within the composting mass and determines the resistance to airflow. It is determined by the particle size, the size gradation of the materials, and the continuity of the air spaces. Larger particles and more uniform particles increase porosity.

Structure refers to the rigidity of the particles—that is, their ability to resist settling and compaction. Good structure prevents the loss of porosity in the moist environment of the compost pile.

Texture is the characteristic that describes the available surface area for aerobic microbial activity. Most of the aerobic decomposition of composting occurs on the surface of particles, because oxygen moves readily as a gas through pore spaces but much slower through the liquid and solid portions of the particles. A population of aerobic microorganisms builds up in the liquid layer surrounding the surface of particles. The microorganisms use the available oxygen at the particle surface, leaving the interior essentially unchanged in an anaerobic state (figure 2.4). The particle shrinks and decomposes as the composting microorganisms work their way inward.

Since the amount of surface area increases with smaller particle size, the rate of aerobic decomposition also increases with smaller particle size—that is, within limits. Smaller particles also reduce the effective porosity, so a compromise is needed. Good results are usually obtained when the particle sizes range from 1/8 to 2 inches average diameter.

For most raw materials and composting applications, an acceptable porosity and structure can be achieved if the moisture content is less than 65%. However, some situations benefit from special attention to porosity, structure, or texture. Composting methods that do not include turning require more structure to resist settling, so larger particles are necessary. Materials with a strong odor might be mixed with rigid materials to achieve greater than normal porosity in order to promote good air movement.

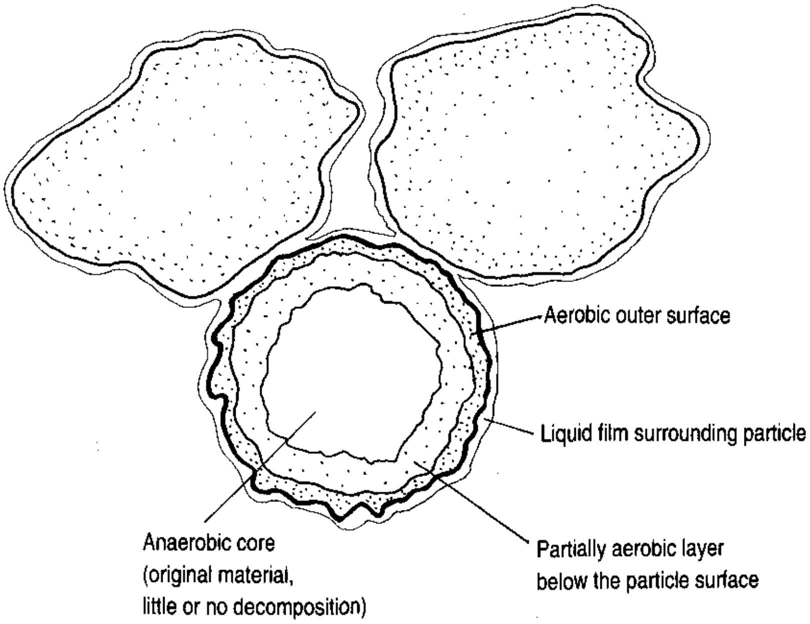


Figure 2.4
Decomposition of solid particles.

pH of the Materials

The composting process is relatively insensitive to pH, within the range commonly found in mixtures of organic materials, largely because of the broad spectrum of microorganisms involved. The preferred pH is in the range of 6.5–8.0, but the natural buffering capacity of the process makes it possible to work over a much wider range. Composting may proceed effectively at pH levels between 5.5 and 9. However, it is likely to be less effective at 5.5 or 9 than it is at a pH near neutral (pH of 7).

pH does become important with raw materials that have a high percentage of nitrogen. A high pH, above 8.5, encourages the conversion of nitrogen compounds to ammonia, which further adds to the alkalinity. Adjusting the pH downward below 8.0 reduces the ammonia loss (see chapter 6). Adjusting the pH upward by adding limes, ashes, or other additives is not usually necessary and often is not advisable because of the potential effect on ammonia losses. If such additives are used, they should be used in small quantities and should be thoroughly mixed with other materials.

Composting changes the materials and their pH as decomposition occurs. For example, the release of organic acids may temporarily lower the pH during early stages of composting, whereas the production of ammonia from nitrogenous compounds may raise the pH. Regardless of the pH of the starting materials, composting yields an end product with a stable pH that is close to neutral.

Temperature

As a matter of convenience, science has subdivided and given names to the ranges of temperatures within which certain microorganisms thrive. Composting essentially takes place within the two ranges known as *mesophilic* (50–105°F) and thermophilic (over 105°F). Although mesophilic temperatures allow effective composting, most experts suggest maintaining temperatures between 110° and 150°F. The thermophilic temperatures are desirable because they destroy more *pathogens*, weed seeds and fly larvae in the composting materials. Regulations set the critical temperature for killing human pathogens at 131°F. This temperature should destroy most plant pathogens as well. The critical temperature for destroying most weed seeds is 145°F.

Microbial decomposition during composting inherently releases large amounts of energy as heat. The self-insulating qualities of the composting materials lead to an accumulation of heat, which raises the temperature. At the same time, the materials continuously lose heat as water evaporates and as air movement carries away the water vapor and other warm gases. Turning and aeration accelerate the heat loss and, therefore, are used to maintain temperatures in the desired range. Cold weather and small piles increase heat loss.

Heat accumulation can push temperatures well above 140°F. When this occurs, microorganisms begin to suffer the effects of high temperature, and the composting process slows. The temperature can continue to rise above 160°F because of heat generated by ongoing microbial activity and the insulating qualities of the composting materials. At this point, many microorganisms die or become dormant. The process effectively stops and does not recover until the population of microorganisms recovers. To prevent this situation, temperatures should be monitored. When the temperature approaches 140°F, heat loss should be accelerated by forced aeration or turning of the materials. If thermal kill does occur, the recovery may be quickened by remixing the pile, preferably with material from other more active batches.

Since most of the heat loss in composting occurs by the evaporation of water, the materials should not be allowed to dry below a 40% moisture content. Low moisture increases the chance of damaging high temperatures as well as *spontaneous combustion* (see chapter 6).

Time

The length of time required to transform raw materials into compost depends upon many factors including the materials used, temperature, moisture, frequency of aeration, and user requirements. Proper moisture content and C:N ratio plus frequent aeration ensure the shortest possible composting period. Conditions which slow the process include lack of moisture, a high C:N ratio, low temperatures, insufficient aeration, large particles and a high percentage of resistant materials (such as woody materials).

The required composting period also depends on the intended use of the compost. It can be shortened if the compost does not need to be completely stable. For instance, if the compost is to be applied to cropland well before the growing season, it can be cured and finished in the field (see following section). The composting period is often extended for compost which must be particularly dry or stable.

In general, the entire decomposition and stabilization of materials may be accomplished within a few weeks under favorable conditions; but a period greater than two months is more common. Although some highly controlled mechanical systems claim less than one week to produce compost, a four- to eight-week curing period is usually recommended before the compost can be used. Typical composting times for several common applications are given in table 2.2.

A given process may achieve stabilization quickly by drying the materials to a low moisture content, which inhibits biological activity. This is fine if the end use for the compost does not dictate more thorough stabilization. However, partially stabilized composts are not suitable for most horticultural uses. It is also important to recognize that as the dried material regains moisture, biological activity resumes. Odor and other problems can then develop if adequate aeration is not provided.

Changes in Materials during Composting

During composting, the microorganisms transform organic raw materials into compost by breaking down the raw materials into simple compounds and reforming them into new complex compounds. This transformation changes the nature of the materials. The raw materials begin as a diverse mixture of particles and compounds, many of which are easily degraded and potentially odorous. By the time composting is complete, the mix of compounds becomes more uniform and less active biologically. Little or no trace of the original raw materials is discernible. The material becomes dark brown to black in color. The particles reduce in size and become consistent and soil-like in texture.

Table 2.2
Typical composting times for selected combinations of methods and materials

		Active composting time		
Method	Materials	Range	Typical	Curing time
Passive composting	Leaves	2–3 years	2 years	—
	Well-bedded manure	6 months to 2 years	1 year	—
Windrow—infrequent turning [a]	Leaves	6 months to 1 year	9 months	4 months
	Manure + amendments	4–8 months	6 months	1–2 months
Windrow—frequent turning [b]	Manure + amendments	1–4 months	2 months	1–2 months
Passively aerated windrow	Manure + bedding	10–12 weeks	—	1–2 months
	Fish wastes + peat moss	8–10 weeks	—	1–2 months
Aerated static pile	Sludge + wood chips	3–5 weeks	4 weeks	1–2 months
Rectangular agitated bed	Sludge + yard waste or Manure + sawdust	2–4 weeks	3 weeks	1–2 months
Rotating drums	Sludge and/or solid wastes	3–8 days	—	2 months [c]
Vertical silos	Sludge and/or solid wastes	1–2 weeks	—	2 months [c]

[a] For example, with bucket loader.
[b] For example, with special windrow turner.
[c] Often involves a second composting stage (for example, windrows or aerated piles).

In the process, the amount of *humus* increases, the C:N ratio decreases, pH neutralizes, and the *exchange capacity* of the material increases.

Composting leads to a volume reduction of one-quarter to more than one-half of the initial volume, depending upon the raw materials. Typical agricultural materials exhibit a large shrinkage in volume. Part of this volume reduction represents the loss of CO_2 and water to the atmosphere. Part of it occurs as loose, bulky raw materials are changed into crumbly, fine-textured compost. The composting materials also experience a large weight reduction, on the order of 40–80%, mostly because of water loss.

Some loss of nitrogen occurs as ammonia escapes from the composting pile. Nevertheless, composting retains most nutrients supplied by the raw materials and stores them within stable organic compounds. This reduces the immediate *availability* of nutrients to the plants but it also allows them to be released at a more gradual rate.

The C:N ratio gradually falls during composting, because of the loss of CO_2 from the starting materials. The amount of carbon lost during composting usually exceeds the nitrogen loss. However, if the starting C:N ratio is low, less than 15:1, the nitrogen losses may be large enough to cause little change in the C:N ratio.

The transformations that occur during composting require energy. Organic materials used in composting contain a significant amount of stored energy. The stored energy results from the transformation of solar energy to chemical energy during photosynthesis. By breaking the chemical bonds, microorganisms obtain energy for growth from the organic materials. During the process, some of the chemical energy is transformed to heat that increases the pile temperature and escapes to the surroundings.

Microorganisms decompose organic materials progressively, breaking them down from complex to intermediate to simple compounds. The nutrients that become available during decomposition remain in the compost within the bodies of new microorganisms and as humus. The final product has a low rate of microbial activity but it is rich in microorganisms and the remains of microorganisms.

Some organic compounds present initially in the raw materials pass through the composting process with little or no change. Lignins, found in woody materials, are difficult to break down in the typical time span of a composting pile. Lignins and other biologically resistant substances are concentrated in the compost. They are partially responsible for compost's characteristic qualities.

Composting Microorganisms

Composting occurs through the efforts of microorganisms. Although larger organisms such as worms and insects play a role in composting at lower temperatures, microorganisms are the main workers.

Composting involves a diverse group of microorganisms (figure 2.3). No one species of organism dominates because the materials and conditions vary and continually change. Conditions vary from one pile to the next, over time within a given pile, and at different sections of a pile at a given time. This creates many different localized environments, each populated by a mixed group of microorganisms. The diversity of microorganisms helps keep the composting process from collapsing when conditions change.

The major groups of microorganisms that participate in composting are *bacteria, fungi,* and *actinomycetes*. All three groups of microorganisms have mesophilic and thermophilic species.

Bacteria are small, simple organisms. They exist in a wide variety of forms and environmental conditions. In composting, they are the most numerous of the three groups of microorganisms. They are generally faster *decomposers* than other microbes.

Fungi are larger organisms. Many fungi form networks of individual cells in strands or filaments. They are more tolerant of low-moisture and low-pH conditions than bacteria but are less tolerant of low-oxygen environments. Fungi are also better at decomposing woody substances and other decay-resistant materials.

Actinomycetes form filaments like fungi, but because of their small size and cell structure, they are technically classified as bacteria. Like fungi, actinomycetes are primarily aerobic. They tend to become more pronounced after the easily degraded compounds are gone and when moisture levels are low. They have a low tolerance for acidic conditions.

Bacteria tend to flourish, especially in the early stages of composting, before the easily degraded materials are consumed. Fungi and actinomycetes become more important near the end of composting, feeding on the resistant materials that remain. As long as conditions remain favorable for composting, bacteria continue to dominate. However, at low pH, fungi gain an advantage. Low-moisture conditions favor fungi and actinomycetes. Low oxygen reduces fungi and increases anaerobic bacteria.

As the pile heats, thermophilic organisms of all groups play a larger role, though mesophilic organisms may continue to survive. If the temperature continues to rise above 160° F, nearly all active organisms die, leaving only the heat-resistant spores formed by certain species of bacteria and actinomycetes. As the pile cools again, spore-formers, thermophilic populations, and then mesophilic populations recover. Eventually, the pile cools enough to be inhabited by common soil microorganisms, protozoa, worms, mites, insects, and other large organisms that feed upon microorganisms and organic matter.

Curing

Curing is a critical and often neglected stage of composting during which the compost matures. Curing occurs at low, mesophilic temperatures. The oxygen consumption, heat generation, and moisture evaporation are much lower than in the active composting stage.

The importance of curing increases if the active composting stage is either shortened or poorly managed. A long curing period provides a safety net that helps to overcome the shortcomings of the composting method and also reduces the chance that an immature compost will be used. An immature compost continues to consume oxygen and thereby reduces the availability of oxygen to the plant roots. Immature compost can also contain high levels of organic acids, a high C:N ratio, and other characteristics which can be damaging when the compost is used for certain horticultural applications.

Curing furthers the aerobic decomposition of resistant compounds, organic acids, large particles, and clumps of material that remain after active composting. As a result, the pH shifts toward neutral, the C:N ratio decreases, the exchange capacity increases, and the concentration of humus increases. Some changes that take place occur only at low temperatures or with well-decomposed organic matter (which is not present during active composting). One example is the formation of *nitrate-nitrogen,* which becomes noticeable during the curing stage. Another is the recolonization of the pile by soil microorganisms, which can give the compost disease-suppressing qualities. The development of humus is also believed to occur more readily at these conditions.

Because curing continues the aerobic decomposition process, adequate natural aeration is a necessity. This limits the size and moisture content of the curing piles (see chapter 5). Compost that becomes anaerobic within the curing piles develops some of the same detrimental qualities found in immature compost.

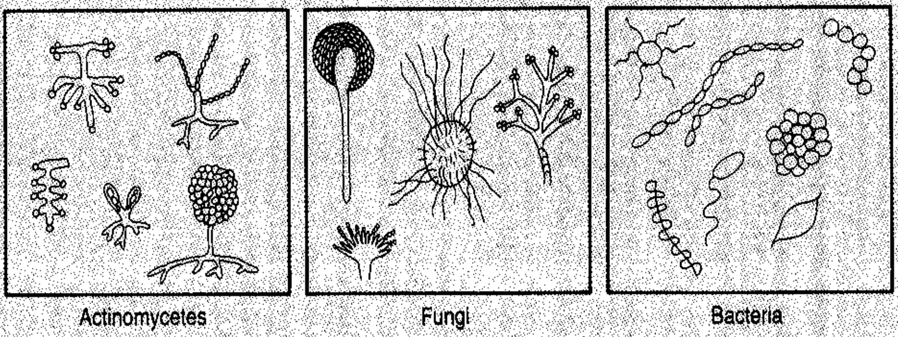
There is no specific point at which curing should begin or end. When the windrow temperature no longer reheats after turning, the curing stage begins. With forced aeration, curing begins after the pile temperature shows a steady decrease and approaches mesophilic levels (105°F, for example). Curing may be considered complete when the pile temperature falls to near ambient temperatures (without the pile being anaerobic or overly dry). The rule of thumb recommends a minimum curing time of one month. Again, a longer period is necessary if active composting was not completed.

Microorganisms which are deliberately added to the materials to improve composting are referred to as *inocula.* The use of inocula has been suggested as a way to accelerate composting or improve its efficiency by providing the proper set of organisms or *enzymes.* However, most studies have shown that inocula are neither necessary nor advantageous to composting.

The availability of microorganisms is rarely a problem in composting. Microbial competition and the composting environment ultimately determine which and how many organisms persist. The most effective and successful microorganisms are usually present naturally. However, inocula may be beneficial with a few materials that are slow to develop a large community of organisms. This situation, often referred to as a lag period, is rare but occurs with certain raw materials such as sterilized food wastes. In general, it is best to inoculate a material with active compost made from that same material.

Pathogens are organisms which are or can be harmful to humans, animals, or plants. Animal and plant pathogens can be found in manures, crop residues, and *yard wastes.* A few composting materials, primarily *sewage sludge,* contain human pathogenic organisms. The high temperatures achieved during composting, assisted by the competition and antagonism among the microorganisms, considerably reduce the number of plant and animal pathogens. While some resistant pathogenic organisms may survive and others may persist in cooler sections of the pile, the disease risk is, nevertheless, greatly reduced.

Several species of fungi associated with composting, most notably the fungus *Aspergillus fumigatus,* can cause allergic reactions in some individuals and may create complications for people with existing health problems. Although such adverse reactions are not common, it is important to recognize that they could occur and that appropriate safety measures should be implemented (see chapter 6).


Actinomycetes

Fungi

Bacteria

Figure 2.5
Primary groups of microorganisms involved in composting (magnified over 1,000 times).

3 Raw Materials

The ingredients for *composting* are organic by-products or waste materials. On farms such materials include animal *manures, bedding,* crop residues and some processing wastes. In most cases, there is a primary raw material to be composted, such as manure, and other materials are added. Often the primary material is a troublesome waste needing treatment and/or disposal.

It is rare that a given waste material, in its available condition, has all of the characteristics required for efficient composting. Therefore, it is usually necessary to blend together several materials, in suitable proportions, to achieve a mix with the desired overall characteristics (figure 3.1). This mix of materials is sometimes referred to as a *recipe*. For farms, a composting recipe is often a blend of manure and crop residues. Sometimes waste products from nearby lumber operations, such as sawdust or bark, are used. Sometimes leaves and *yard wastes* are obtained from local towns.

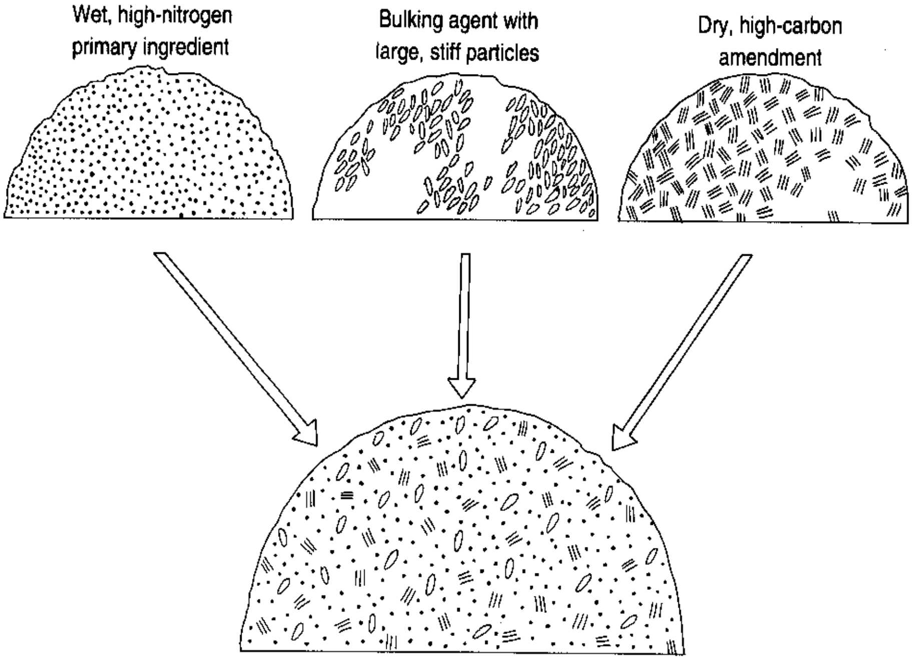


Figure 3.1
Combining raw materials to achieve the desired characteristics for composting.

The materials added to provide the desired characteristics are referred to as *amendments, bulking agents,* or carbon sources. Amendments are added to adjust any characteristic of the mix, such as *moisture content, texture,* or *C:N ratio.* A bulking agent provides *structure* so that the materials stand in a pile without collapsing and maintain pore spaces for air movement. Carbon sources are added to raise the C:N ratio. Although the three terms are often used interchangeably, amendment is the more general term and is used in this handbook to describe any ingredient added to improve the qualities of the primary material.

Since amendments must often be obtained from outside sources, cost and availability are important factors. For composting to remain economical, the raw materials obtained from outside sources must be inexpensive. Fortunately, many free or inexpensive materials are suitable and available for composting. In the best situation, a possible amendment is a nuisance to someone who is willing to pay to have it taken away. There may be an opportunity to supply a waste recycling service to nearby food processors or a municipality. This can generate additional farm income in the form of *tipping fees*. However, accepting off-farm wastes may also bring more restrictive regulations and neighborhood objections.

Table 3.1
Desired characteristics of raw material mixes

Characteristic	Reasonable range	Preferred range
Carbon to nitrogen (C:N) ratio	20:1–40:1	25:1–30:1
Moisture content	40–65%	50–60%
pH	5.5–9	6.5–8.5
Bulk density (pounds per cubic yard)	less than 1100 [a]	—

[a] 40 pounds per cubic foot.

Raw Material Characteristics

The previous chapter discussed the important raw material characteristics for composting. These are summarized in table 3.1. Ideally, the raw materials should be chosen and mixed in the right proportion to produce characteristics within the ranges listed in table 3.1. However, it is not always necessary or even possible to achieve these values. Composting is a flexible process. It occurs over a broad range of conditions which might be quite different from the ideal. The allowable deviation from the ideal depends on the time available to complete composting, the potential for odors, and the final use of the *compost*. For rapid composting or for materials with a high risk of odors, it is important to stay close to the ranges in table 3.1.

Moisture content and C:N ratio are the raw material characteristics of greatest concern and, together, will probably determine the recipe of the mix. In most cases, the primary ingredient is wet and high in nitrogen. Therefore, dry carbon-containing amendments are in great demand. *Porosity* and *bulk density* cannot be predicted with accuracy from individual ingredients. For the mixture, bulk densities less than 35–40 pounds per cubic foot are usually adequate.

Although material recipes are determined by moisture and C:N ratio, raw materials have other qualities that can be just as important to the composting operation. These include *degradability*, odor potential, and cleanness.

Not all organic materials degrade equally well. For instance, woody materials decompose slowly because of a high proportion of *lignin*. Large particles degrade slower than small particles of the same material.

The potential for odor should be a prime consideration in determining raw material recipes. Materials that have a strong odor or turn rancid quickly require special handling. In locations that are vulnerable to odor complaints, strong-smelling materials such as fish processing waste or swine manure are best avoided. (Odor control strategies are discussed in chapter 6.)

Cleanness refers to the degree of *contamination* from unwanted materials, chemicals, and organisms. Some examples include staples on cardboard boxes, glass and other trash carried in with leaves, pesticide residues from crops, *heavy metals* or human *pathogens* in sludge, or sludge itself. Materials that present environmental or health risks bring more restrictive regulations. In many cases, the acceptable level of cleanness depends on the final use of the compost. The market value of a compost may depend on the ingredients used to make it.

Common Raw Materials for Farm Composting

The list of materials appropriate for composting is almost endless. Only those commonly available to farmers are discussed here and summarized in table 3.2. Table A.1 (pages 106–113) provides a list of selected raw materials and their characteristics (percent nitrogen, C:N ratio, moisture content, and bulk density).

Other materials, abundant on the farm or available locally, may be very good components of a composting mix. Trucking raw materials is usually cost-prohibitive beyond 50 miles, so farmers should seek out local sources of clean organic materials. They should be evaluated in the same manner as the materials discussed below.

Cattle Manure

Nitrogen-rich and very wet. Moisture content and C:N ratio depend on the amount of bedding used, management practices, type of operation, and climate. Generally requires a large amount of dry, high-carbon amendment, often two to three volumes of amendment per volume of manure. Relatively low odor risk if composted within a few weeks. Decomposes quickly. *Bedded pack* manure is moderately dry with a good C:N ratio. *Liquid manure* or slurries must be screened or dried unless only small amounts are used in the composting mix. Some trash may be present. Overall, a very good composting material.

Poultry Manure

Very high nitrogen content and moderately moist. Needs a high carbon amendment. *Litter* with sawdust or wood shavings is well suited to composting and may be partially composted when removed from the barn. Nitrogen loss and odor from *ammonia* is a potential problem because of the high nitrogen content and high *pH*. Low

Table 3.2
Summary of common raw materials for farm composting

- Bark
- Cardboard
- Cattle manure
- Crop residues
- Fertilizer and urea
- Finished compost
- Fish processing wastes
- Food processing wastes
- Fruit and vegetable wastes
- Grass clippings
- Horse manure
- Leaves
- Lime
- Newspaper
- Livestock manure
- Paper mill sludge
- Peat moss
- Poultry manure
- Sawdust and shavings
- Seaweed and other aquatic plants
- Septage and sewage sludge
- Slaughterhouse and meat packing wastes
- Spoiled hay and silage
- Straw
- Swine manure
- Wood ash
- Wood chips

Note: Each item is discussed in the text. Additional information is provided in Appendix A (page 106).

pH amendments may be needed to lower the alkalinity. Decomposes quickly. The high nitrogen content can result in a fertilizer-grade compost. Good to very good composting material.

Horse Manure

Usually contains large amounts of bedding; therefore, dry with a high C:N ratio. Composts well alone or as an amendment for wet cattle manure. Low odor potential. Decomposes quickly, especially if bedding is straw. Often available at little or no cost from local stables, racetracks, pleasure horse owners, fairs, and schools. Some stable wastes contain medication containers, soda cans, and other trash. Excellent composting material.

Swine Manure

Nitrogen-rich and very wet. Needs a dry, high-carbon amendment. Strong potential for odors. High moisture content and odor make composting more difficult than other manures. With bedding, solids separation, and/or odor-control measures, it can be a fair to good composting material.

Other Livestock Manure

Sheep, goat, rabbit and other livestock manures are usually good for composting. They are collected mostly from bedded manure packs and are, therefore, relatively dry with a high C:N ratio. Without bedding, the manure is nitrogen-rich and wet. Bedded material may be used as an amendment to other livestock manures. Relatively low odor potential. Decomposes quickly. Good composting material.

Crop Residues

Variable characteristics depending upon the material but generally moderate to high moisture and moderate C:N ratio. The C:N ratio and moisture content depend on the age and the amount of fruit and seeds present. Generally older vegetation is drier and contains less nitrogen. Usually very good structure and good degradability. Some residues may be dry and high in carbon (corn stalks). Plant pathogens are a concern if compost does not reach high temperatures in all parts of the pile. Excellent to good *composting amendments*, depending on the material.

Spoiled Hay and Silage

Moderately dry to wet, depending on conditions. Moderate to high C:N ratio. In most cases, available only occasionally. Added to compost mix as a disposal method and not as a reliable amendment. Good structure and degradability. Possible problems include odor and *leachate* from silage and weed seeds in hay. Moderate composting material.

Straw

Dry and carbonaceous. Good degradability. Provides very good structure and odor absorption. If used as bedding, it can precondition manure for composting. Availability and cost can be disadvantages. Excellent composting amendment.

Sawdust and Shavings

Dry and carbonaceous. Moderate to poor degradability; sawdust degrades faster than shavings. Good moisture and odor absorption. Can also have a dual use as bedding. Usually available at a moderate to low cost. Good to moderate composting amendment.

Leaves

Relatively dry. High in carbon. Good degradability if shredded. Moderate moisture absorption. Low odor potential. Composts alone or as an amendment. Often contains trash, rocks, plastic bags, and so on—especially if collected from streets. Large quantities available but seasonal supply requires storage and/or special handling/scheduling. Leaves can be obtained free, or a tipping fee may be available. Good to moderate composting material (see chapter 11).

Wood Chips

Dry and high in carbon. Large particle size provides excellent structure but poor degradability. Often used as a bulking agent for *forced aeration* composting. Must be screened from final compost but can be reused. Moderate to low cost. Has a competing use as a *mulch* product. Chips from preservative-treated and painted wood should not be used. Very good bulking agent but poor amendment otherwise.

Bark

Qualities are similar to that of wood chips except, for a given tree species, bark contains slightly more nitrogen and easily degradable compounds. May be composted alone for use in potting media or for mulch. Good bulking agent but poor as a general amendment. Good material for specialty compost products (mulch, potting media) though the composting time is relatively long.

Grass Clippings

Moderately wet to dry. Slightly low C:N ratio. Decompose quickly. Moderate to high odor potential depending upon management. Good source of nitrogen for leaf and yard waste mixtures. Usually available free, or a tipping fee may be available. Good composting material, if mixed with coarse materials. Alone, grass clippings tend to compact and become *anaerobic.*

Newspaper

Dry. High carbon content. Moderate degradability. Potential for dual use as bedding. Good moisture absorption but poor structure and porosity. Black inks are generally non-toxic. Large quantities of colored inks and glossy paper are best avoided or should be analyzed because of possible heavy metals and other contaminants. Available in large quantities at little or no cost, or a tipping fee may be available. May need *shredding* and some sorting initially. Possible problems include storage, dust, and trash around the farmstead. In general, a good to moderate amendment depending upon the structure of the mix.

Cardboard

Dry and high carbon content. Good degradability. Good moisture absorption and structure. Large quantities available for little or no cost, or a tipping fee may be available. Shredding, storage, and some sorting may be needed. Staples in cardboard boxes may need to be removed. Glues in corrugated cardboard may contain high boron levels. Good to fair amendment.

Finished Compost

Compost can be recycled as an amendment for wet wastes, either alone or in combination with other amendments. Moderately dry. Moderate to low C:N ratio. Provides a good initial supply of *microorganisms.* Frequent recycling may potentially lead to high salt concentrations but, otherwise, no significant disadvantages. Loss of compost product after recycling is small. Good amendment, especially for lowering the mix moisture content without raising the C:N ratio.

Peat Moss

Acidic fibrous material which has resulted from years of anaerobic decomposition. Low in nitrogen. Highly absorbent of water, nutrients and odors. May hold over ten times its weight in water. Except in regions where natural deposits exist, *peat* moss is expensive, partly because of its competing uses as an amendment for potted plants and other horticultural crops. Peat moss passes through the composting process virtually unchanged, producing a potentially high valued compost. Its odor- and water-absorbing qualities make it an excellent amendment, but cost limits its use.

Fruit and Vegetable Wastes

Peels, tops, trimmings, culls, damaged/spoiled fruit. Moderate to wet with a moderate to low C:N ratio, depending upon the nature of the waste. Except for pits, good degradability. Poor to fair structure. Standing piles of many fruits and some vegetable wastes quickly collapse into a wet mess once decomposition begins. The potential for tipping fees exist. Slight to moderate risk of odor problems. Possible trash from packing operations and markets. Good to fair composting material.

Food Processing Wastes

Variable characteristics depending upon the process. *Filter press cakes* generally are moderately dry and have high to moderate carbon content. Other food processing by-products are generally wet with moderate to low C:N ratios. Possible problems include high risk of odors; *vermin* (rats, mice, flies); contaminants from machinery and cleaning solutions used at the processing plant; and poorly degradable components such as pressing aids. A major advantage is the opportunity to receive a tipping fee. Good to poor composting material depending upon the nature of the waste.

Slaughterhouse and Meat Packing Wastes

Paunch manure, blood, miscellaneous parts. Wet and low C:N ratio. Good degradability. High risk of odors and vermin. More restrictive regulations may apply. Large amounts of amendment are required to lower moisture content and control odors. Except for paunch manure, composting should be considered only if direct *land application* and other options are not practical.

Fish Processing Waste

Racks, frames, heads, tails, shells, gurry. Variable characteristics depending on waste, but generally moderately to very wet and high in nitrogen. Lobster, crab, shrimp, and mollusk shells provide good structure. All but mollusk shells decompose quickly. The high risk of odor along with the high moisture requires large amounts of dry amendment and/or special handling. More restrictive regulations may apply. Potential for tipping fee. Wet materials—racks or gurry—are troublesome, and composting should be considered after other options. Shells are moderate to good composting materials if managed properly.

Seaweed and Other Aquatic Plants

Water hyacinth, pond cleanings, waste water treatment species. High to moderate moisture content, depending on previous drying. C:N ratios vary from low (seaweeds) to moderate (water hyacinth). Good degradability. Generally poor structure, especially for seaweeds. Good sources of minor nutrients, but salt content of seaweed is a possible problem if used in large quantities. Possible trash and weed seeds included with beach cleanings. Low to moderate odor risk. Good composting material with added structure.

Paper Mill Sludge

Wet or moderately wet if pressed. Moderate to high C:N ratio. Requires a dry amendment with nitrogen—a difficult combination. Good degradability but poor structure. Slight to moderate risk of odor if mismanaged. Organic contaminants are occasionally found in paper sludge. Potential for tipping fee. Fair composting material.

Wood Ash

Very dry with little or no carbon and nitrogen. Contains a fair amount of other nutrients, particularly potassium. The concentrations of heavy metals may be a concern with some ashes. In a composting mix, wood ash would absorb moisture and raise the pH of the mix. It has also been proposed as an odor adsorbing agent. Handling is difficult as the ash is a fine powder which blows around and creates dust. Particles tend to cement together after they become wet. Tipping fees may be available. Fair to good composting amendment for wet acidic mixes. Should not be used if the pH is high.

Septage and Sewage Sludge

Raw and digested. Nitrogen-rich and very wet. Requires two to four volumes of dry amendment per volume of sludge. *Septage* and raw sludge decompose quickly, digested sludge moderately. Strong odor potential for septage and raw sludge, strong to moderate for digested. Possible contamination from human pathogens and heavy metals. Special regulations apply for pathogen reduction. Restrictions on land use apply for heavy metals. Composting these materials usually involves operational and land application permits, process monitoring, and product analysis. The one advantage is the opportunity to collect a fee for composting these materials. In general, *sewage sludge* and septage bring many restrictions and regulations. Though exceptions exist, it is best to avoid these materials for farm composting operations.

Fertilizer and Urea

Fertilizers, urea, or other concentrated nitrogen sources are sometimes considered as additives to lower the C:N ratio of high carbon materials such as leaves. Although such materials do reduce the initial C:N ratio, the benefits are short-lived. Nitrogen from such sources tends to be available much more quickly than the carbon in the organic materials. Initially the available carbon and nitrogen are in balance; but as the easily available carbon is depleted, a surplus of nitrogen soon develops. Eventually the excess nitrogen is lost as ammonia.

Lime

Like fertilizers, lime is also considered as an additive, either to adjust pH or to control odors. Generally, lime is an unnecessary ingredient and can be detrimental. pH adjustment is rarely necessary in composting. If lime is used for odor control, it can raise the pH enough to cause an excessive loss of ammonia. The same effects should be expected for other concentrated sources of alkalinity, including cement kiln dust and wood ash.

Determining Composting Recipes

Many composters combine raw materials by trial and error, based on the look and feel of the mix. More manure or water is added if the mix feels dry, or dry amendments are added until the mix stands in a pile without slumping. Usually this involves some judgment about the moisture content, structure, and porosity of the mix. With experience, this approach to determining composting recipes can be successful, especially when the composting does not need to be rapid or closely controlled. When the raw material characteristics are not known, the "look and feel" approach may be the only alternative. However, when the composter is unfamiliar with the materials or the process or when it is important to establish near optimum composting conditions, it is better to develop composting recipes based on calculations. The calculations predict the moisture content and C:N ratio of a mix from the characteristics of the individual raw materials.

Developing a composting recipe is a balancing act because both the C:N ratio and the moisture content need to be within acceptable ranges. Usually one of these characteristics takes priority, and an appropriate recipe is determined. Then, if necessary, the proportions are adjusted to bring the second characteristic in line without excessively changing the first. Sometimes this is not possible, and a different set of ingredients must be considered.

With wet materials, the moisture content is particularly critical because a high moisture content leads to anaerobic conditions, odors, and slow decomposition. The consequences of a poor C:N ratio are less damaging. It is usually best to develop an initial composting recipe based on moisture content and then adjust it, if necessary, to achieve an acceptable C:N ratio. Dry materials can be proportioned on the basis of C:N ratio, since it is relatively easy to add water to a mix.

The formulas for calculating a composting recipe are given in table 3.3. The calculations are done on a dry weight basis. For each ingredient, the moisture content, the percentage of nitrogen (dry weight) and either the percentage of carbon (dry weight) or the C:N ratio must be known. If it is necessary to convert from weight to volume or vice versa, you must also know the *density* of the ingredients. The carbon content of many materials is sometimes difficult to find in literature. If the literature or test results report the percentage of ash, the carbon content can be roughly estimated by the following equation.

$$\%\ \text{Carbon} = \frac{(100 - \%\ \text{Ash})}{1.8}$$

Table 3.3

Formulas for determining composting recipes

Formulas for an individual ingredient

Moisture content = % moisture content ÷ 100
Weight of water = total weight x moisture content
Dry weight = total weight – weight of water
= total weight x (1 – moisture content)
Nitrogen content = dry weight x (% N ÷ 100)
% carbon = % N x C:N ratio
Carbon content = dry weight x (% C ÷ 100)
= N content x C:N ratio

General formulas for a mix of materials

$$\text{Moisture content} = \frac{\text{weight of water in ingredient a + water in b + water in c + ...}}{\text{total weight of all ingredients}}$$

$$= \frac{(a \times m_a) + (b \times m_b) + (c \times m_c) + \ldots}{a + b + c + \ldots}$$

$$\text{C:N ratio} = \frac{\text{weight of C in ingredient a + weight of C in b + weight of C in c + ...}}{\text{weight of N in a + weight of N in b + weight of N in c + ...}}$$

$$= \frac{[\%\,C_a \times a \times (1 - m_a)] + [\%\,C_b \times b \times (1 - m_b)] + [\%\,C_c \times c \times (1 - m_c)] + \ldots}{[\%\,N_a \times a \times (1 - m_a)] + [\%\,N_b \times b \times (1 - m_b)] + [\%\,N_c \times c \times (1 - m_c)] + \ldots}$$

Symbols

a = total weight of ingredient *a*
b = total weight of ingredient *b*
c = total weight of ingredient *c*
$m_a, m_b, m_c, \ldots$ = moisture content of ingredients *a, b, c, ...*
$\%\,N_a, N_b, N_c, \ldots$ = % nitrogen of ingredients *a, b, c, ...* (% of dry weight)
$\%\,C_a, C_b, C_c, \ldots$ = % carbon of ingredients *a, b, c, ...* (% of dry weight)

Shortcut formulas for only two ingredients (for example, leaves plus grass clippings)

1. Required amount of ingredient *a* per pound of *b* based on the desired moisture content:

$$a = \frac{m_b - M}{M - m_a}.$$

Then check the C:N ratio using the general formula.

2. Required amount of ingredient *a* per pound of *b* based on the desired C:N ratio:

$$a = \frac{\%\,N_b}{\%\,N_a} \times \frac{(R - R_b)}{(R_a - R)} \times \frac{(1 - m_b)}{(1 - m_a)}$$

Then check the moisture content using the general formula.

Symbols

a = pounds of ingredient *a* per pound of ingredient *b*
M = desired mix moisture content
m_a = moisture content of ingredient *a* (for example, amendment)
m_b = moisture content of ingredient *b* (for example, manure)
R = desired C:N ratio of the mix
R_a = C:N ratio of ingredient *a*
R_b = C:N ratio of ingredient *b*

A procedure for calculating the recipe proportions, moisture content, and C:N ratio is given in the sample calculations on the next page. With only two ingredients, such as manure plus an amendment, the amendment proportion can be calculated directly from the desired C:N ratio or moisture content, as shown in the example. However, if three or more ingredients are used, the recipes must be calculated by trial and error using the general formulas in table 3.3. In this case, the proportions of the ingredients are first assumed and then the corresponding C:N ratio and moisture content are calculated. If either the C:N ratio or moisture content is unacceptable, proportions are adjusted and calculations are repeated until an acceptable C:N ratio and moisture content are obtained. Although this task can be cumbersome, it becomes manageable with a computer spreadsheet program.

Sample Calculation: Recipe Proportions, Moisture Content, and C:N Ratio

A farm has chicken manure that usually has a moisture content of 70% when removed from the buildings. Both the moisture and the nitrogen contents are too high for optimum composting, and the manure needs greater porosity. Sawdust is available with a moisture content of 35%. Assume that the C:N ratio of the manure is not more than 10:1 with a nitrogen content of 6% and that the sawdust has a C:N ratio of about 500:1 and a nitrogen content of 0.11%. Determine an appropriate composting recipe.

Blending materials to the desired moisture content

weight of water = total weight x moisture content
weight of *dry matter* = total weight – weight of water
weight of nitrogen *(N)* = weight of dry matter x (%N ÷ 100)
weight of carbon *(C)* = C:N ratio x weight of N

1 pound of wet manure contains

Water	1 pound x 0.7	=	0.7 pounds
Dry matter	1 pound – 0.7	=	0.3 pounds
N	0.3 x 0.06	=	0.018 pounds
C	0.018 x 10	=	0.18 pounds

1 pound of damp sawdust contains

Water	1 pound x 0.35	=	0.35 pounds
Dry matter	1 pound – 0.35	=	0.65 pounds
N	0.65 x 0.0011	=	0.00072 pounds
C	0.00072 x 500	=	0.36 pounds

The moisture content should not exceed 60%. For 1 pound of wet manure:

$$\text{MC} = \frac{\text{weight of water in manure + weight of water in sawdust}}{\text{total weight}}$$

$$\text{MC} = 60\% = 0.6 = \frac{0.7 + (0.35 \text{ x } \mathbf{S})}{1 + \mathbf{S}}$$

where **S** is the amount of sawdust needed

$$\begin{aligned} \text{MC} &= 0.6\,(1 + \mathbf{S}) = 0.7 + 0.35 \text{ x } \mathbf{S} \\ 0.25\,\mathbf{S} &= .1 \\ \mathbf{S} &= \mathbf{0.4} \text{ pounds sawdust per pound of manure} \end{aligned}$$

Note: S is calculated from the above equation using a little algebra. Since there are only two ingredients, it is also possible to solve for S using the shortcut formulas in table 3.3 (page 19). In this case, S would be the same as *a* in table 3.3 (page 19). The manure would be represented by *b*. Therefore:

$$S = a = \frac{m_b - M}{M - m_a} = \frac{0.70 - 0.60}{0.60 - 0.35}$$

S = **0.4** pounds of sawdust per pound of manure

Check the C:N Ratio

$$\text{C:N} = \frac{C_{manure} + C_{sawdust}}{N_{manure} + N_{sawdust}} = \frac{0.18 + (\mathbf{0.4} \text{ x } 0.36)}{0.018 + (\mathbf{0.4} \text{ x } 0.00072)} = \mathbf{17.7}$$

Since this ratio is near the low end of the acceptable range and the moisture content is at the high end (60%), the amount of sawdust should be increased to raise the C:N ratio.

Blending materials to the desired C:N ratio

Assume that wheat straw is available which has a moisture content of 15%, a C:N ratio of 128:1, and a nitrogen content of 0.3%. Estimate the amount of straw needed with the chicken manure to obtain a mix C:N ratio of 25.

1 pound of wheat straw contains

Water	1 pound x 0.15	=	0.15 pounds
Dry matter	**1 pound – 0.15**	**=**	**0.85 pounds**
N	0.85 x 0.003	=	0.0026 pounds
C	0.0026 x 128	=	0.33 pounds

The desired C:N ratio is 25:1. For 1 pound of wet manure:

$$\text{C:N} = 25 = \frac{(\text{C in 1 pound manure}) + \mathbf{S} \text{ x } (\text{C in 1 pound straw})}{(\text{N in 1 pound manure}) + \mathbf{S} \text{ x } (\text{N in 1 pound straw})}$$

where **S** is the amount of straw needed

$$25 = \frac{0.18 + \mathbf{S} \text{ x } (0.33)}{0.018 + \mathbf{S} \text{ x } (0.0026)}$$

$\mathbf{S}$ = 1 pound of straw per pound manure

Note: Again, since only two ingredients are involved, the shortcut formulas of table 3.3 (page 19) can also be used to solve for S.

$$S = a = \frac{\%N_b}{\%N_a} \text{ x } \frac{(R - R_b)}{(R_a - R)} \text{ x } \frac{(1 - m_b)}{(1 - m_a)} = \frac{6\%}{0.3\%} \text{ x } \frac{(25 - 10)}{(128 - 25)} \text{ x } \frac{(1 - 0.70)}{(1 - 0.15)}$$

S = 1 pound

Check the mix moisture content

$$\text{MC} = \frac{\begin{matrix}\text{weight of water in} \\ \text{1 pound manure}\end{matrix} + \begin{matrix}\text{weight of water in} \\ \text{1 pound straw}\end{matrix}}{\text{total weight}}$$

$$\text{MC} = \frac{0.7 + (1 \text{ x } 0.15)}{2} = 0.425 = 42.5\%$$

This moisture content is low for a starting mix. Options: Use these proportions and hope for rain to wet the pile (risky); add water to the mix directly; decrease the amount of straw and accept a lower C:N ratio; add another damp material to the mix; or replace the straw with a wetter amendment.

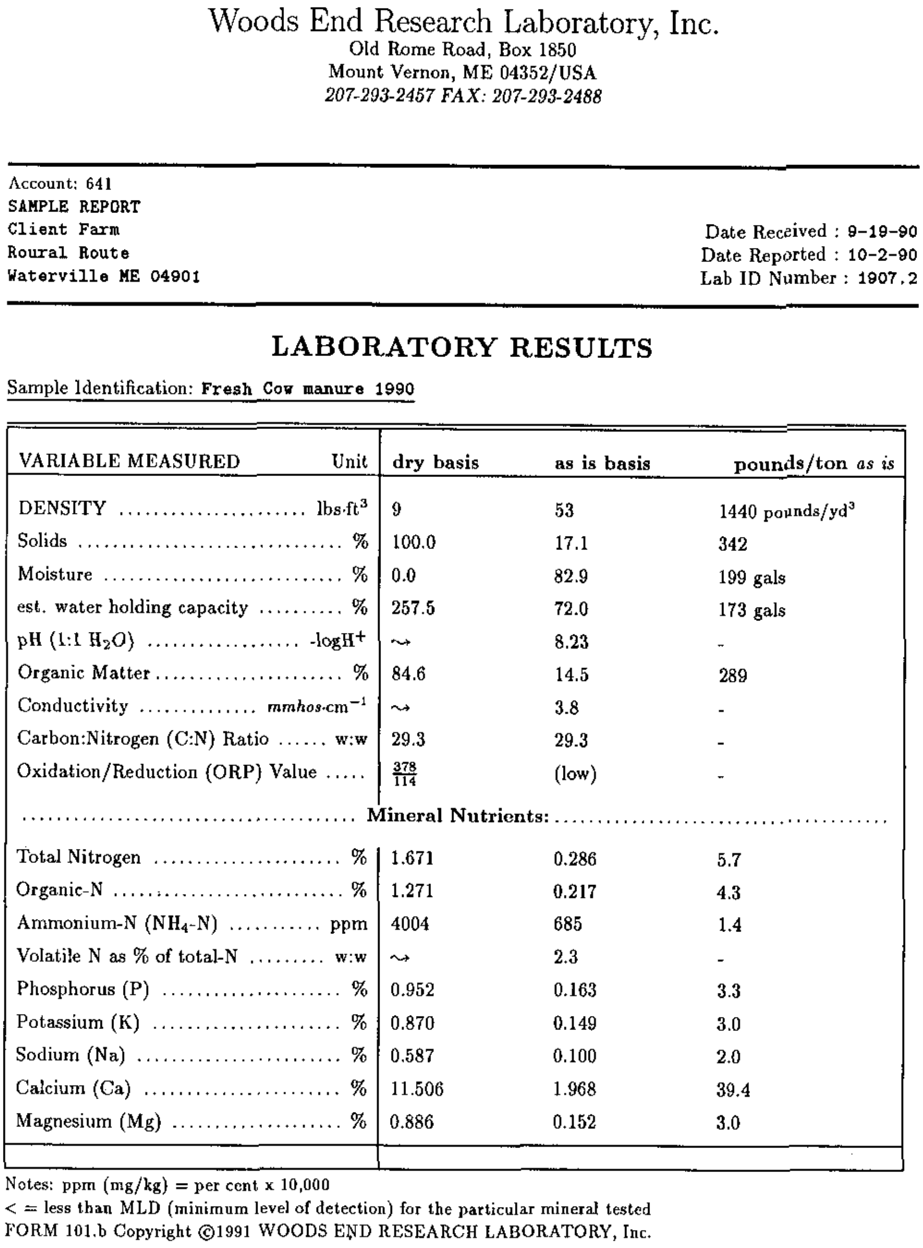
Testing Raw Materials for Composting

It is frequently helpful and sometimes necessary to analyze raw materials and compost for their physical and chemical characteristics (figure 3.2). Accurately knowing the material characteristics helps in developing raw material recipes, indicates a material's suitability for composting, determines the plant nutrient content, and identifies suspected contaminants. Values for the physical and chemical characteristics of many materials can be found in literature or estimated from experience. These provide a good starting point for planning, but more accurate analysis is often necessary to fine-tune the operation.

The most common reason for analyzing raw materials is to develop composting recipes. Important characteristics to determine include density, moisture content, carbon content, nitrogen content, and pH. Once these characteristics are known for all of the possible ingredients, several rough recipes can be developed. As an alternative, recipes can be developed from information obtained in literature and the actual mixes tested for the characteristics.

Certain raw materials or the compost made from them should be tested for suspected contaminants (heavy metals in sludge, pesticides in some crop residues). The timing and type of analysis depend on the suspected contaminants and the compost's intended use. If it is important to limit the amount of contamination in the composting mix, the raw materials must be tested. This situation occurs if the suspected contaminant is damaging to the composting process, poses an environmental risk at the site, or makes the compost useless or unmarketable. If it is important to know how much of the contaminant is in the end product only, just the compost needs to be tested.

Laboratory testing of materials is most important when an operation is just beginning. Later when procedures change or when new materials or a different source of materials is being considered, additional analysis is useful if not necessary. Otherwise, laboratory analysis is needed only for periodic quality control checks. Tests for determining density, moisture content, pH, and soluble salt content are relatively simple and can be conducted on the farm with a few basic pieces of equipment (see following section).



Woods End Research Laboratory, Inc.
Old Rome Road, Box 1850
Mount Vernon, ME 04352/USA
207-293-2457 FAX: 207-293-2488

Account: 641
SAMPLE REPORT
Client Farm
Roural Route
Waterville ME 04901

Date Received : 9-19-90
Date Reported : 10-2-90
Lab ID Number : 1907.2

LABORATORY RESULTS

Sample Identification: Fresh Cow manure 1990

VARIABLE MEASURED	Unit	dry basis	as is basis	pounds/ton *as is*
DENSITY	lbs·ft^3	9	53	1440 pounds/yd^3
Solids	%	100.0	17.1	342
Moisture	%	0.0	82.9	199 gals
est. water holding capacity	%	257.5	72.0	173 gals
pH (1:1 H_2O)	-logH$^+$	↝	8.23	-
Organic Matter	%	84.6	14.5	289
Conductivity	*mmhos*·cm^{-1}	↝	3.8	-
Carbon:Nitrogen (C:N) Ratio	w:w	29.3	29.3	-
Oxidation/Reduction (ORP) Value		$\frac{378}{114}$	(low)	-
Mineral Nutrients:				
Total Nitrogen	%	1.671	0.286	5.7
Organic-N	%	1.271	0.217	4.3
Ammonium-N (NH_4-N)	ppm	4004	685	1.4
Volatile N as % of total-N	w:w	↝	2.3	-
Phosphorus (P)	%	0.952	0.163	3.3
Potassium (K)	%	0.870	0.149	3.0
Sodium (Na)	%	0.587	0.100	2.0
Calcium (Ca)	%	11.506	1.968	39.4
Magnesium (Mg)	%	0.886	0.152	3.0

Notes: ppm (mg/kg) = per cent x 10,000
< = less than MLD (minimum level of detection) for the particular mineral tested
FORM 101.b Copyright ©1991 WOODS END RESEARCH LABORATORY, Inc.

Figure 3.2
Raw material lab analysis report.

Source: Woods End Research Laboratory, Inc.

Note: This laboratory report is included for illustrative purposes only. Mention of Woods End Laboratory does not imply an endorsement.

Testing Materials on the Farm

A few characteristics of raw materials and compost can be determined on the farm using simple procedures that require only available or inexpensive equipment. These characteristics include density, moisture content, pH, and soluble salts. At a minimum, a good weighing scale is required, one that is able to read numbers which are at least one-hundredth the size of the sample (for example, 1/8 ounce for a 1-pound sample or 1 gram for a 100-gram sample). Scales which can read to 0.1 grams are preferable. Other equipment required depends on the specific test.

Laboratory Safety. The tests discussed here are not hazardous, but a few simple safety precautions need to be observed. Gloves should be available and worn when hot containers are handled. Safety glasses or goggles should also be available. Work areas should be well-vented. Observe appropriate equipment precautions. For example, do not use metal containers in a microwave oven and do not leave a microwave oven unattended while samples are being heated.

Samples. The first step in testing materials is obtaining a representative sample. The sample should reflect the overall qualities of the material being tested. It is best to collect many samples from different locations in a pile and/or from several piles. Mix these samples together and then draw subsamples to be tested from the mixture. If a single sample is taken, collect it from a location which is typical of the whole pile. Avoid taking samples from the centers, edges, and outer surface, which are likely to have different qualities from the bulk of the material in the pile.

In the time that elapses between collecting and testing, it is possible for samples to lose moisture and undergo other changes. Therefore, samples should be collected shortly before testing. If samples must be collected some time in advance, they should be refrigerated in a covered container or at least kept away from heat, sunlight, and other conditions which might alter their characteristics.

The sample size should be convenient to work with and suited to the testing equipment and containers. Establish a standard sample size so that testing procedures will be consistent. The calculations can sometimes be simplified by using samples sizes which have round numbers, such as 100 grams, 1 pound, or 1 liter. In general, the larger that the sample is, the more accurate the testing results will be. However, this must be balanced with practicality. For example, larger samples take a longer time to dry for moisture content determinations.

Density. Density is calculated by dividing the weight of a substance by the volume that it occupies. In composting work, usually a material's bulk density is required. Bulk density is the mass of a pile or container of material divide by the volume of the pile or container. The volume includes the air spaces between particles. For example, it is more important to know the density of a pile of wood chips (bulk density) rather than density of an individual wood chip (particle density).

Density can be determined by filling a container of known volume and weight with the material to be tested and then weighing the filled container. The density equals the filled container weight minus the empty container weight divided by the container volume.

$$\text{Density} = \frac{\begin{matrix}\text{Filled} \\ \text{Container} \\ \text{Weight}\end{matrix} - \begin{matrix}\text{Empty} \\ \text{Container} \\ \text{Weight}\end{matrix}}{\text{Container Volume}}$$

When determining the bulk density, it is important for the material to fill the container with nearly the same degree of compaction that occurs in the storage or field stack. It must not be packed down; otherwise the bulk density will be overestimated. Filling the container properly can be tricky. Therefore, it is best to obtain and weigh several samples and then average the results.

Moisture Content. Moisture content is the portion of a material's total weight that is water. It is often expressed as a percentage. The non-water portion of a material is referred to as dry matter.

Moisture content can be determined by drying a sample of material to remove the water and then weighing the dried sample. Follow these steps:

1. Weigh the container.
2. Weigh the wet sample and the container.
3. Dry the sample (see sections on drying below).
4. Weigh the dried sample and container.
5. Subtract the dried weight from the wet weight and determine the moisture content, as explained below.

The difference between the sample's wet weight and dried weight is the weight of water removed from the sample. The moisture content equals the weight of water removed (that is, wet weight of the sample minus its dry weight) divided by the wet weight minus the weight of the container. Note that this is the wet-basis moisture content. The moisture content on a dry basis is the wet weight minus dry weight divided by the dry weight minus the container weight. To obtain the moisture content in percent, multiply this ratio by 100.

$$\text{Moisture content (\%)} = \frac{\text{Wet Weight}^* - \text{Dry Weight}^*}{\text{Wet Weight}^* - \text{Container Weight}} \times 100$$

* Total weight of the sample including the container

The goal in drying a sample is to remove the water while minimizing the loss of *volatile* dry matter *compounds* such as ammonia and organic acids. Samples are dried at relatively low temperatures over a long time period because high temperatures increase the dry matter loss, especially if a sample burns. There is a trade-off between accuracy and speed. Lower temperatures and larger samples generally improve accuracy but increase drying time.

The general procedure involves weighing the wet sample and then drying it until the sample no longer loses weight. To determine this, the sample must be dried in stages and then weighed after each stage. The sample is dry when its weight remains constant between two consecutive drying stages. For composting purposes, the sample can be considered dry if its weight changes by less than 1% of the original wet weight (for example, 1 gram for a 100-gram sample). The required drying time varies with the temperature, drying equipment, sample size, and sample moisture. After a number of experiments, typical drying times can be established. General guidelines are given below which provide starting points, but experimentation is still necessary to establish routine procedures for specific equipment and sample characteristics.

Methods for determining moisture content on the farm differ in the way that the sample is dried. Three common methods include air drying, conventional oven drying and microwave oven drying. Although the results produced by these methods are less accurate than laboratory procedures, *they are satisfactory for almost all* composting situations.

Air drying is perhaps the simplest method for determining the moisture of a sample. First obtain the weight the sample container and then weight the container full of material. The larger the sample the more accurate the results (that is, a gallon sample is more accurate than a pint sample). Next spread the sample material in a layer not to exceed one-half inch think on paper in a warm room with a fan to improve air circulation. Allow the sample to dry for twenty-four to forty-eight hours, stirring occasionally to obtain uniform drying of all particles. Pour the material back into the sample container and weigh again. It may be necessary to repeat the above steps, weighing every several hours, until the weight loss is negligible. Air drying removes most but not all of the water contained in the sample material and, therefore, tends to underestimate the actual moisture content. However, for most composting situations, air drying produces acceptable moisture content estimates.

Samples can be more thoroughly dried in a **conventional heated-air oven** at temperatures between 140 and 220°F. An oven temperature of 212°F is a good compromise between speed and accuracy for most composting materials. Rough estimates for drying a 4-ounce (100-gram) sample range from twenty-four hours (219°F) to seventy-two hours (140°F). Experimentation and periodic weighing are necessary to determine the required time for a given temperature and sample material. Drying can be quickened by spreading the sample in a thin layer.

Drying time is considerably reduced by using a **microwave oven** to dry samples. Again, experimentation is necessary to determine the drying time for a given microwave oven and sample. As a start, use a 4-ounce (100-gram) sample of moist material and heat it for eight minutes at full power in a microwave oven with at least 600 watts of power. For a less powerful microwave oven, increase the heating period (or reduce the sample size). For relatively dry materials, such as finished compost, decrease the heating period to six minutes. After this initial heating, remove the sample from the oven and weigh it. Then reheat the sample for another two minutes, rotating it 90° from its original position when replacing it in the oven. After reheating, weigh the sample again. Continue the cycle of heating and weighing at one-minute intervals until the weight change is negligible. If you notice the sample becomes burned or charred, start a new trial using less power and/or shorter heating times. After determining the required drying time for a particular microwave oven, sample size, and material, a continuous drying period can be used.

Microwave drying is a convenient and relatively accurate method of determining moisture content. However, care must be taken to avoid overheating and spot burning of the sample. Spreading the sample in a thin layer is helpful. Samples must be placed in microwave-safe containers. Metal should not be placed in a microwave oven! A paper plate is a good container because it is light weight and the sample can be spread out. For maximum accuracy, paper containers should be preheated to remove moisture.

pH and Soluble Salts: The Saturated Paste Method. The most common and reproducible method used for measuring pH and soluble salts is called the *Saturated Paste* method. This method can be mastered by almost anyone because it is simple and requires easily available supplies. The equipment needed includes a pH meter and a solu-bridge meter. Simple battery-operated pH and solu-bridge meters are available at reasonable costs, and they are easy to operate.

Because compost is rich in *ammonium,* the solutions used for preparing samples for measuring pH and soluble salts are different. Therefore, separate preparations have to be made for each measurement. When measuring pH, use only a 0.01M solution of calcium chloride. This is equivalent to approximately a slightly rounded teaspoon of U.S.P. grade calcium chloride dissolved into a gallon of distilled or deionized water. For measuring soluble salt, use either distilled or deionized water alone, without calcium chloride.

To make a saturated paste, use a paper or plastic drinking cup half filled with compost. Depending on which test you are conducting, add the appropriate solution in small quantities and stir constantly with a stirring spatula, kitchen knife, or plastic plant label. A saturated paste is achieved when there is just enough water to make a smooth paste of the compost so that when the cup is held in a horizontal position, all of the water will be held by the compost and none will flow to the sides of the cup. This mixture should be allowed to stand with the container covered at room temperature for at least four hours, preferably overnight, before measurements are taken. Just prior to taking measurements, stir the saturated paste. If it appears to have dried, you will need to add either the distilled or deionized water or the calcium chloride solution before measuring. If several samples are being tested, remember to rinse your stirring tool before stirring the next sample. The measurements are taken by plunging the base of the instruments into the saturated paste and taking readings as soon as the numbers stabilize.

4 Composting Methods

Manures and other organic wastes contain naturally occurring *microorganisms* capable of decomposing materials *anaerobically* or aerobically. By now it is evident that maintaining the presence of oxygen in the *composting* media is not only desirable but also imperative for rapid composting. The composting method determines how this is accomplished. The method also affects other process factors such as temperature control, materials movement, and odor control.

Four general groups of composting methods are used on farms: *passive composting, windrows,* aerated piles, and a group of methods known collectively as *in-vessel composting.*

Passive composting involves simply stacking the materials in piles to decompose over a long time period with little agitation and management. In the windrow method, the materials are formed into long narrow piles (windrows). The windrows are periodically turned using a *bucket loader* or special *turning* machine. The turning operation mixes the composting materials and enhances *passive aeration.*

Other methods eliminate the need for turning by providing air to the materials via pipes, which serve as air ducts. One such method relies on passive air movement through the pipes. The more common approach, the *aerated static pile,* uses blowers to force air through the pipes and into the pile. In-vessel methods contain the materials within bins, reactors, or buildings. These range from simple aerated bins to elaborate systems which combine the mechanical agitation of windrow composting and the *forced aeration* of aerated static piles.

Passive Composting of Manure Piles

Simply placing manure in a pile does not begin to satisfy the requirements for continuous *aerobic* composting. The manure itself is high in nitrogen and low in carbon. It has been digested in the stomach and intestines of animals and is now very attractive to microorganisms. Without considerable *bedding* material, the *moisture content* of manure exceeds the level which enables an open porous *structure* to exist in the pile. Little, if any, air passes through it. Under these circumstances, the anaerobic microorganisms dominate the degradation that inevitably takes place. All of the undesirable effects associated with anaerobic degradation occur—including low temperatures, slow decomposition, and the release of *hydrogen sulfide* and other malodorous compounds.

Since water in the pile is neither carried away by air nor vaporized by high temperatures, the pile remains wet and anaerobic. This combination conditions produces *leachate* containing partially degraded organic compounds. If the pile is undisturbed, a crust eventually forms on the surface. Later, when the crust is broken, the odors trapped within the pile are released.

When a livestock management system relies on bedding to add to livestock comfort and cleanliness, the bedding becomes mixed with the manure and creates a drier, more porous mixture. This provides some structure and, depending on the amount of bedding, enables the mixture to be stacked in true piles. The bedding also tends to raise the *C:N ratio* of the manure. If the pile of manure and bedding mixture is not overly large, it may begin to compost. Much of the pile may still decompose anaerobically, but at least the aerobic process is working in portions of the pile to remove moisture and further break down the products of the anaerobic decomposition.

A mixture of manure and bedding requires a considerable proportion of bedding to provide the *porosity* necessary for composting. At least equal volumes of bedding and manure are required. If the amount of bedding is too low to provide a porous mix, then additional dry *amendments* must be provided by either increasing the bedding used in the barn or adding amendments when piles are formed. Manure from horse stables or bedded manure packs can often compost in piles alone, whereas non-bedded manure from dairy, swine, and many poultry barns needs drying or additional amendments.

Manure piles of this nature will not compost successfully unless they are properly sized and managed. Proper management includes making sure that the mixture is porous enough to allow air to penetrate and periodically remixing the pile to rebuild its porosity. The pile must also be small enough to allow passive air movement, generally less than 6 feet high and 12 feet wide.

This passive method of composting is essentially windrow composting but with a much less frequent turning schedule. It is a common method used for composting leaves. It demands minimal labor and equipment. Passive composting is slow because of its low *aeration* rate, and the potential for odor problems is greater.

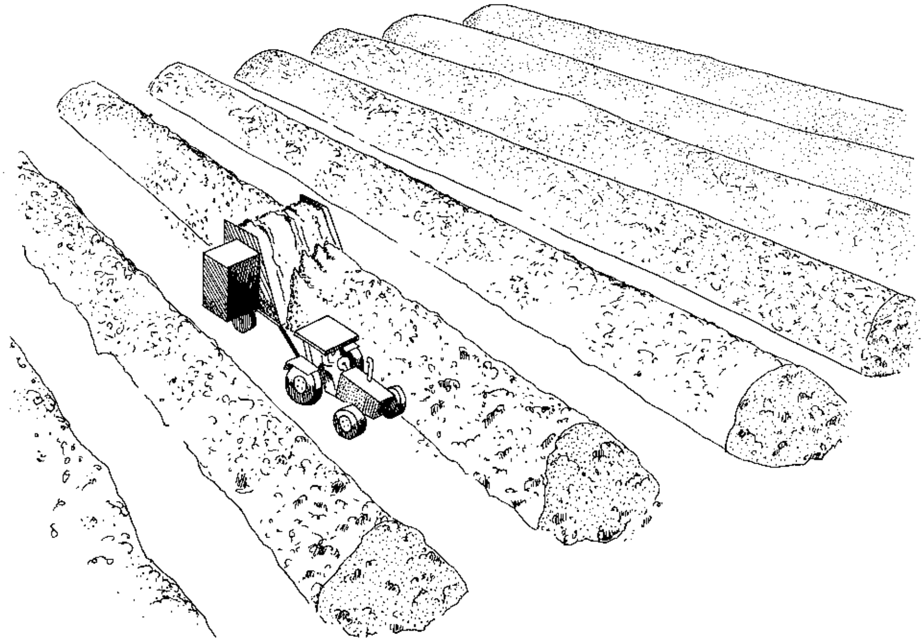
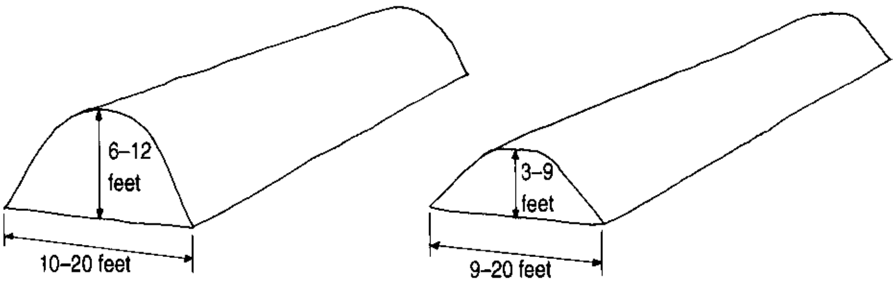


Figure 4.1
Windrow composting with an elevating face windrow turner.



Bucket loader

Windrow-turning machines

Figure 4.2
Typical windrow shapes and dimensions.

Windrow Composting

Windrow composting consists of placing the mixture of raw materials in long narrow piles or windrows which are agitated or turned on a regular basis (figure 4.1). Typically the windrows are initially from 3 feet high for dense materials like manures to 12 feet high for fluffy materials like leaves. The width varies from 10 to 20 feet. The equipment used for turning determines the size, shape, and spacing of the windrows (figure 4.2). Bucket loaders with a long reach can build high windrows. Turning machines produce low, wide windrows.

Windrows aerate primarily by natural or passive air movement (convection and gaseous diffusion), as in figure 2.2, page 7. The rate of air exchange depends on the porosity of the windrow. Therefore, the size of a windrow that can be effectively aerated is determined by its porosity. A light fluffy windrow of leaves can be much larger than a wet dense windrow containing manure. If the windrow is too large, anaerobic zones occur near its center which release odors when the windrow is turned. On the other hand, small windrows lose heat quickly and may not achieve temperatures high enough to evaporate moisture and kill *pathogens* and weed seeds.

Turning mixes the materials; rebuilds the porosity of the windrow; and releases trapped heat, water vapor, and gases. Although the pile is aerated by turning, the new oxygen within the pore spaces is quickly depleted by the microorganisms (in as little as thirty minutes). The most important effect of turning is rebuilding the windrow porosity. Turning fluffs up the windrow and restores the pore spaces eliminated by decomposition and settling. This improves passive air exchange.

Turning also exchanges the material at the windrow's surface with material from the interior. This exposes all material equally to the air at the outer surface and to the high temperatures inside the windrow. In this way, the materials compost evenly; and more weeds seeds, pathogens, and fly larvae are destroyed by the high interior temperatures. In addition, turning further blends raw materials and breaks up particles into smaller pieces, which increases surface area.

Turning Equipment

For small to moderate scale operations, turning can be accomplished with a front end loader or a bucket loader on a tractor (figure 4.3). The loader simply lifts the materials from the windrow and spills them down again, mixing the materials and reforming the mixture into a loose windrow. The loader can exchange material from the bottom of the windrow with material on the top by forming a new windrow next to the old one. This needs to be done without driving onto the windrow in order to minimize compaction. Windrows turned with a bucket loader are often constructed in closely spaced pairs and then combined after the windrows shrink in size.

The time that it takes to turn windrows with a loader is roughly proportional to the size of the bucket. Typically, a loader can lift, maneuver, and drop a load of material in about one minute. General estimates of turning rates for tractor and skid loaders range from 20 to over 70 *cubic yards* per hour (see chapter 10).

If additional mixing of the materials is desired, a loader can also be used in combination with a manure spreader. Spreader flails and augers provide a good mixing action for continued blending of the raw materials. In this case, materials from an existing windrow are loaded into the spreader. When the spreader is full, it redeposits the material in a new windrow adjacent to the existing one. Although this approach provides better mixing than turning with a loader alone, it also involves additional equipment and slightly more time.

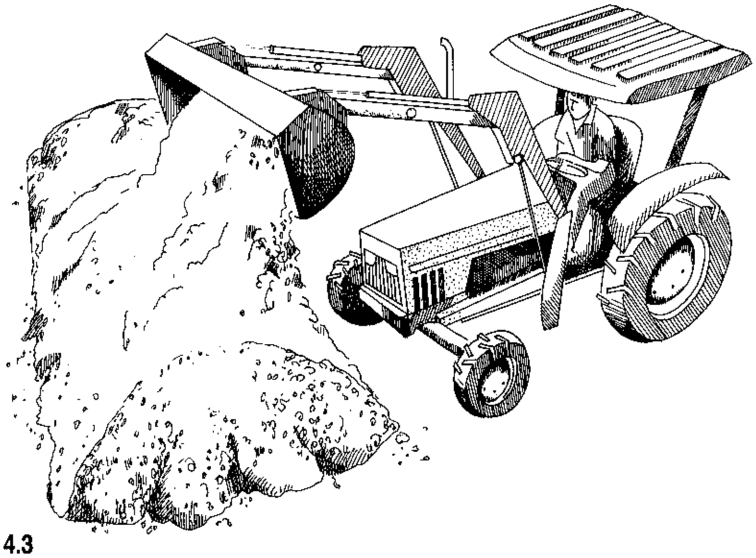


Figure 4.3
Turning windrows using a bucket loader.

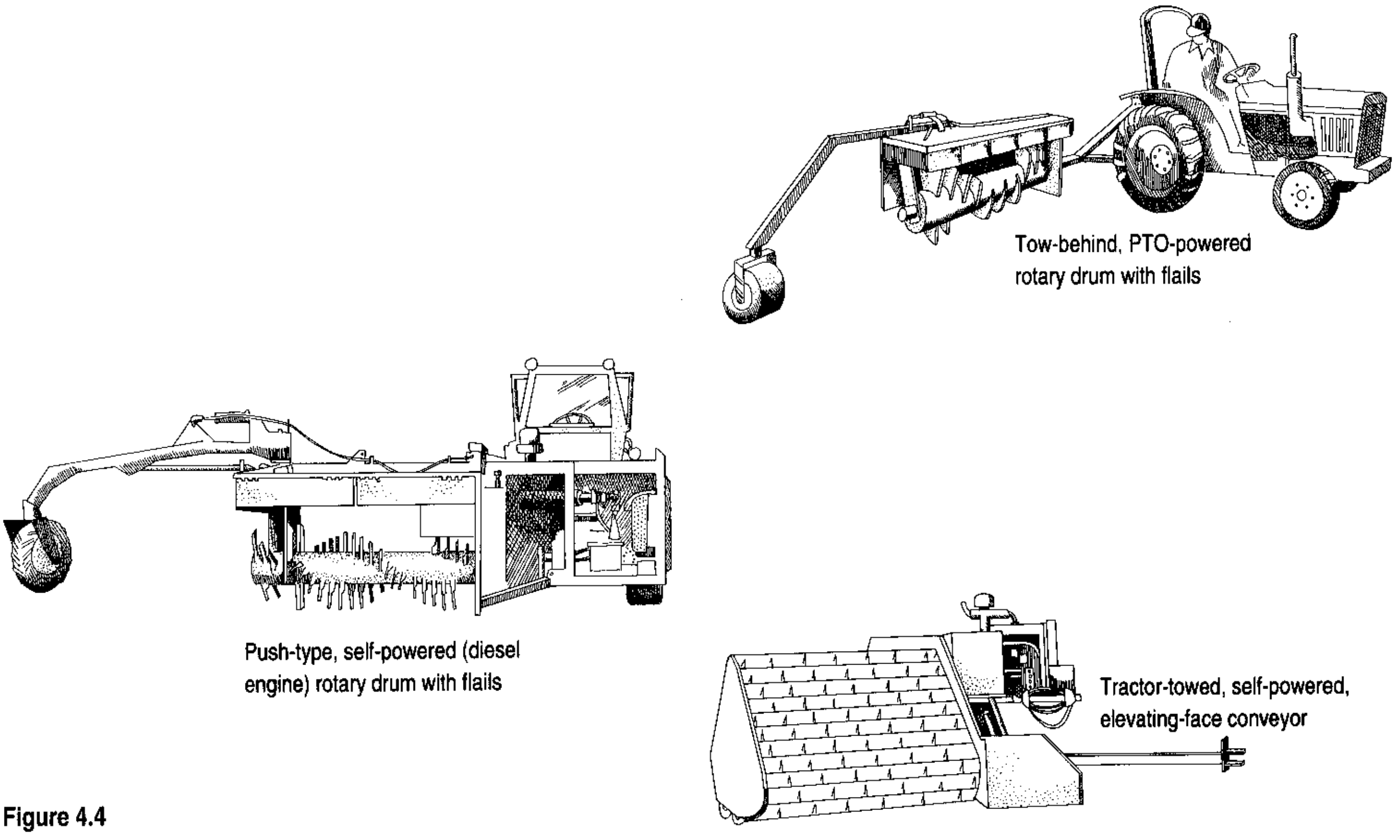
A number of specialized machines have been developed for turning windrows (see appendix B, table B.1, pages 115–119). These machines greatly reduce the time and labor involved, mix the materials thoroughly, and produce a more uniform *compost.* Some of these machines are designed to attach to farm tractors or front-end loaders; others are self-propelled. A few machines also have the capability of loading trucks or wagons from the windrow.

Tractor-assisted turners can be either pulled or pushed by a tractor or a front-end loader (figure 4.4). They ride to one side of the tractor, turning the windrow as the tractor travels in the aisle. One type of machine tills the windrow, lifting and mixing the materials with a series of flails on a rotating drum shaft. Another turner lifts the material with a wide-faced inclined elevating conveyor. Most tractor-drawn machines turn only half the windrow in a single pass. Two passes are necessary for each windrow (figure 4.5). A few tractor-assisted windrow-turners are single-pass turners. In this case, aisle space for the tractor is required between every other windrow.

The least expensive turners rely on the tractor for both travel and power (through the power take-off, or *PTO).* The specifications vary among turner models, but generally the tractor must supply at least 80 horsepower to the PTO and travel less than 1 mile per hour while powering the turner. This requires a tractor with a creeper gear or hydrostatic drive. An alternative is to use a second vehicle to tow the tractor/turner combination. If an appropriate tractor is not available or cannot be obtained economically, the next step is to purchase a self-powered turner which requires a tractor for travel only. These turners are powered by diesel engines. They otherwise operate in the same manner as the tractor-powered units.

Other compost turners are totally self-driven (figure 4.6). Some of these machines use augers or paddles to turn over the windrows, shifting the material (and the windrow) to one side. Other self-propelled turners straddle the windrow, mixing the materials with hammers or flails on a rotating drum shaft. The elevating face conveyor type is also available as a self-driven unit. In addition to eliminating the need for a second piece of equipment, these machines allow closer spacing of windrows and may turn windrows more quickly.

A unique type of windrow composting is practiced by mushroom growers to produce growing media for the mushrooms. In this application, the windrows are called ricks. Ricks are formed and turned by special machines which produce a tall, narrow, and nearly rectangular shaped pile. The tall rectangular shape is made possible by the dry mixture of materials used and by the turning machine, which includes side-wall forming mechanisms. This shape encourages natural air movement and helps maintain even temperatures within the ricks.



Tow-behind, PTO-powered rotary drum with flails

Push-type, self-powered (diesel engine) rotary drum with flails

Tractor-towed, self-powered, elevating-face conveyor

Figure 4.4

Tractor-assisted windrow turners.

Elevating-face conveyor is adapted with permission from Scat Engineering. Rotary drum turner is adapted with permission from Wildcat Manufacturing.

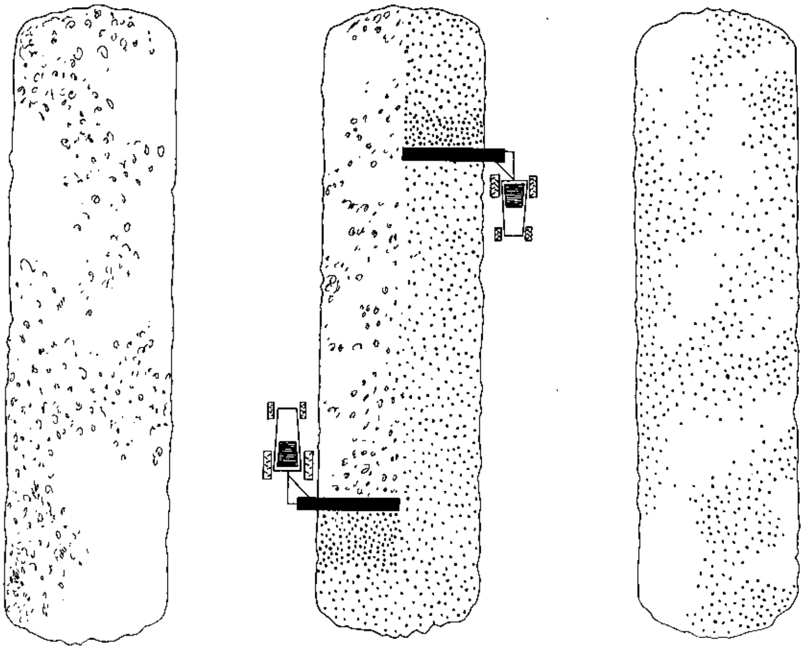


Figure 4.5

Two passes are necessary for most tractor-drawn turners.

All turners, regardless of their design, require regular maintenance. Routine maintenance is needed on the engine and hydraulic system. Flails, knives, and hammers also tend to break or wear and need periodic replacement. Broken or worn pieces can upset the balance of drum shafts and other rotating parts and lead to excessive vibration.

For smaller-scale operations, it may be possible for an innovative farmer to avoid the expense of special turners by adapting idle farm equipment to the task. In one case, an unused potato digger was converted into a compost turner (refer to Whitney et al). Other potentially adaptable equipment include rock pickers, augers, conveyors, and various harvesting mechanisms with elevated points of discharge.

Windrow Management

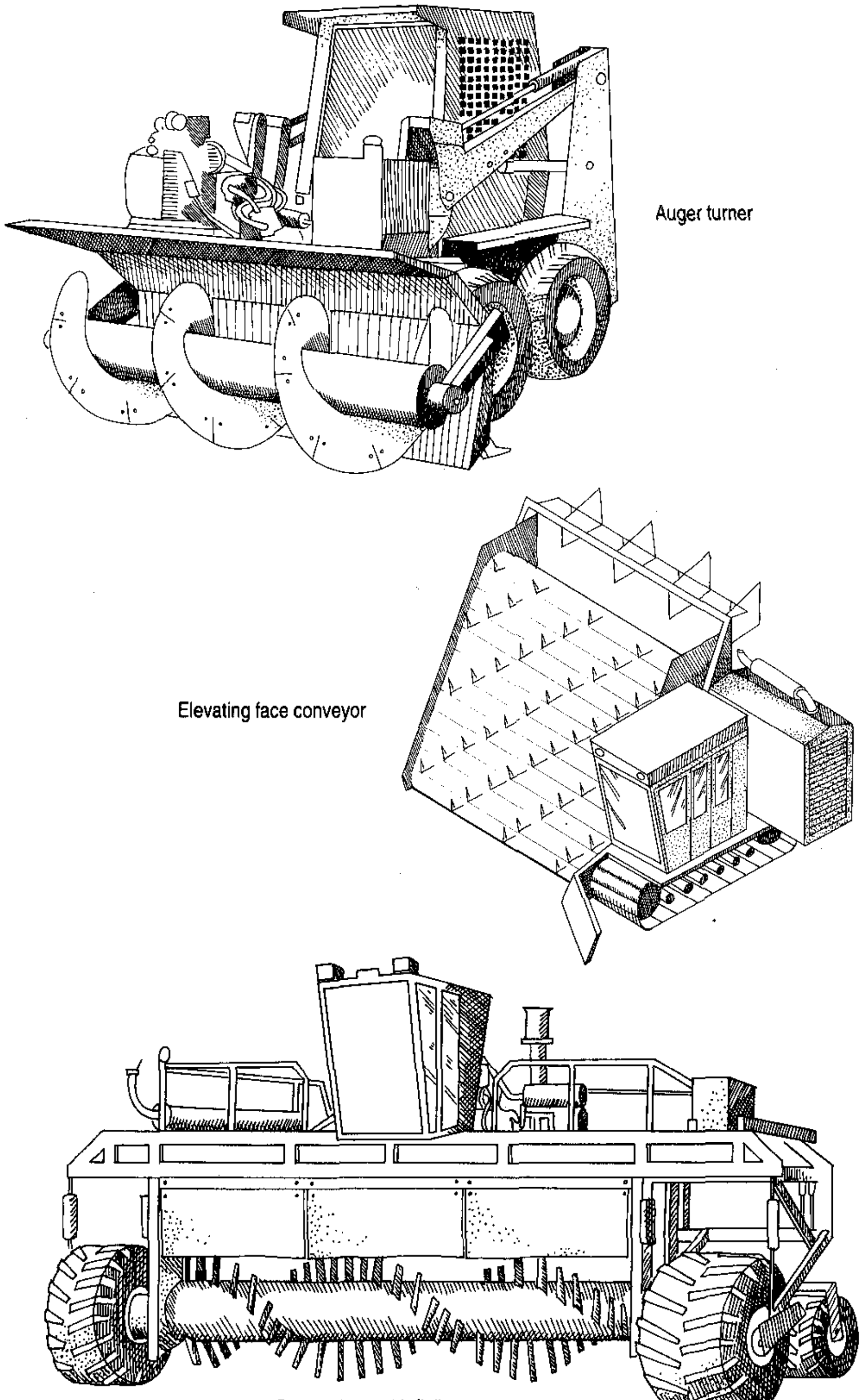
It is very important to maintain a schedule of turning. The frequency of turning depends on the rate of decomposition, the moisture content and porosity of the materials, and the desired composting time. Because the decomposition rate is greatest at the start of the process, the frequency of turning decreases as the windrow ages. Easily degradable or high-nitrogen mixes may require daily turnings at the start of the process. As the process continues, the turning frequency can be reduced to a single turning per week.

Windrow temperatures or odors indicate when turning is needed. Low temperatures and/or odors signal the need for more oxygen. When the average temperature of the windrow drops below a desired level—120°F, for example—the windrow should be turned. A large drop in temperature over four or five consecutive days may also call for turning. Isolated cool or hot spots indicate unmixed material or other problems which turning may remedy. Turning is required for cooling when the windrow gets too warm (above 140°F). If high temperatures cannot be controlled by turning alone, the windrow size may need to be reduced. Through experience, the operator will eventually gain a feel for the turning schedule and learn how to troubleshoot problems in the windrow (see chapter 6).

A dial thermometer with a 2- to 3-foot stem is an inexpensive, good tool for determining windrow temperatures. Portable electronic temperature probes also work well. Measurements should be taken at about 50-foot intervals along the windrow length.

During fly season, windrows should be turned at least once per week to break the flies' reproductive cycle, regardless of the windrow temperature. Since some species of flies develop into adults in as few as five days, windrows may require turnings every four days for fly control.

By the end of the first week of composting, the windrow height diminishes appreciably and by the end of the second week it may be as low as 2 feet. It may be prudent to combine two windrows at this stage and continue the turning schedule as before. Consolidation of windrows is a good wintertime practice to retain the heat generated during composting. This is one of the ad-


Auger turner

Elevating face conveyor

Rotary drum with flails

Figure 4.6
Self-powered and self-driven windrow turners.

Auger turner is adapted with permission from Brown Bear Corporation. Rotary drum with flails is adapted from Richard, Dickson, and Rowland, *Yard Waste Management.*

vantages of windrow composting. It is a versatile system that can be adjusted to different conditions caused by seasonal changes.

With the windrow method, the active composting stage generally lasts three to nine weeks depending upon the nature of the materials and the frequency of turning. Eight weeks is a common period for manure composting operations. If three weeks is the goal, the windrow requires turning once or twice per day during the first week and every three to five days thereafter.

Passively Aerated Windrows

A method known as the *passively aerated windrow* system eliminates the need for turning by supplying air to the composting materials through perforated pipes embedded in each windrow. The pipe ends are open. Air flows into the pipes and through the windrow because of the chimney effect created as the hot gases rise upward out of the windrow.

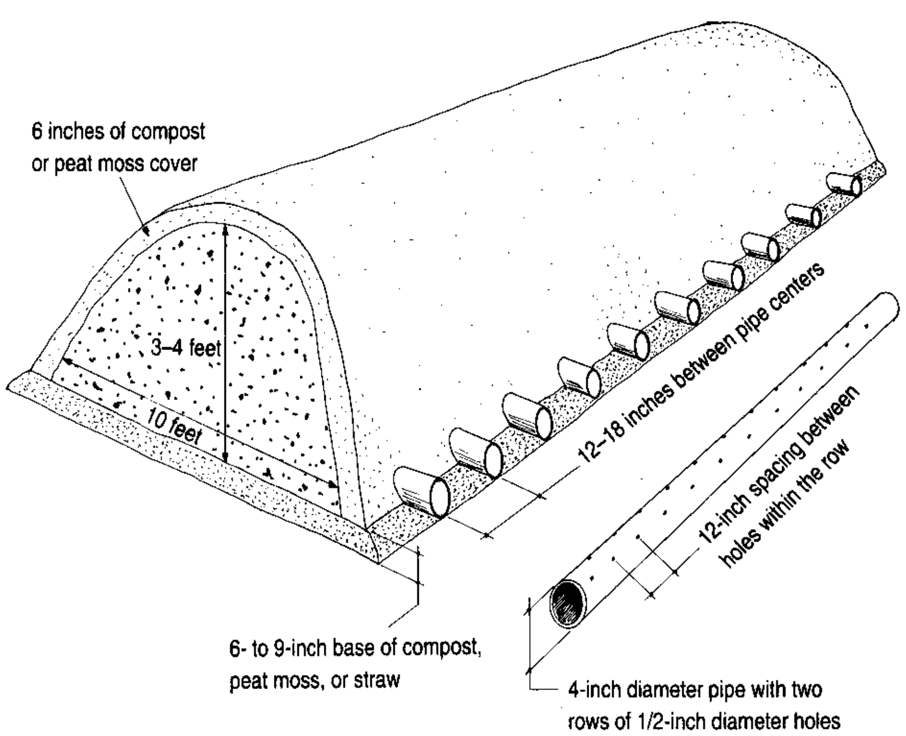


Figure 4.7
Passively aerated windrow method for composting manure.

The guidelines for composting manure using passively aerated windrows are shown in figure 4.7. The windrows should be 3–4 feet high, built on top of a base of straw, *peat* moss, or finished compost to absorb moisture and insulate the windrow. The covering layer of peat or compost also insulates the windrow; discourages flies; and helps to retain moisture, odor, and *ammonia*. The plastic pipe is similar to that used for septic system leach fields with two rows of 1/2-inch diameter holes drilled in the pipe. In many aerated pile applications, the pipe holes are oriented downward to minimize plugging and allow condensate to drain. However, some researchers recommend that the holes face upwards.

Windrows are generally formed by the same procedures described in the following section for the aerated static pile method. Because the raw materials are not turned after the windrows are formed, they must be thoroughly mixed before they are placed in the windrow. Avoid compacting the mix of materials while constructing the windrow. Aeration pipes are placed on top of the peat/compost base. When the composting period is completed, the pipes are simply pulled out, and the base material is mixed with the compost.

This method of composting has been studied and used in Canada for composting seafood wastes with peat moss, *manure slurries* with peat moss, and *solid manure* with straw or wood shavings. Manure from dairy, beef, swine, and sheep operations has been used. The research indicates that this method can successively compost these mixtures with the windrow temperature remaining below 140°F. Seafood/peat moss mixtures compost in six to eight weeks and the manure mixtures in ten to twelve weeks. This method has been found to contain odors and conserve nitrogen effectively because of both the lack of turning and the peat moss or compost cover.

The use of peat moss as an amendment for *slurry*-like materials is a factor in the performance of this method. The peat moss (at 50% moisture) comprises 40–50% of the mix by volume. It gives the mixture good structure and porosity, which allows passive aeration without periodic turning. The peat moss acidity also helps to reduce odors and ammonia loss. Finished compost can be used in place of peat moss in nearly the same volume proportions, though it is not acidic. Other amendments which provide good structure, such as straw and wood chips, can also be used, particularly with more solid materials like bedded manure. The key is establishing good structure and porosity in the windrow.

Aerated Static Pile

The aerated static pile method takes the piped aeration system a step further, using a blower to supply air to the composting materials. The blower provides direct control of the process and allows larger piles. No turning or agitation of the materials occurs once the pile is formed. When the pile has been properly formed and if the air supply is sufficient and the distribution is uniform, the active composting period will be completed in approximately three to five weeks.

With the aerated static pile technique, the raw material mixture is piled over a base of wood chips, chopped straw, or other very porous material (figure 4.8). The porous base material contains a perforated aeration pipe. The pipe is connected to a blower, which either pulls or pushes air through the pile.

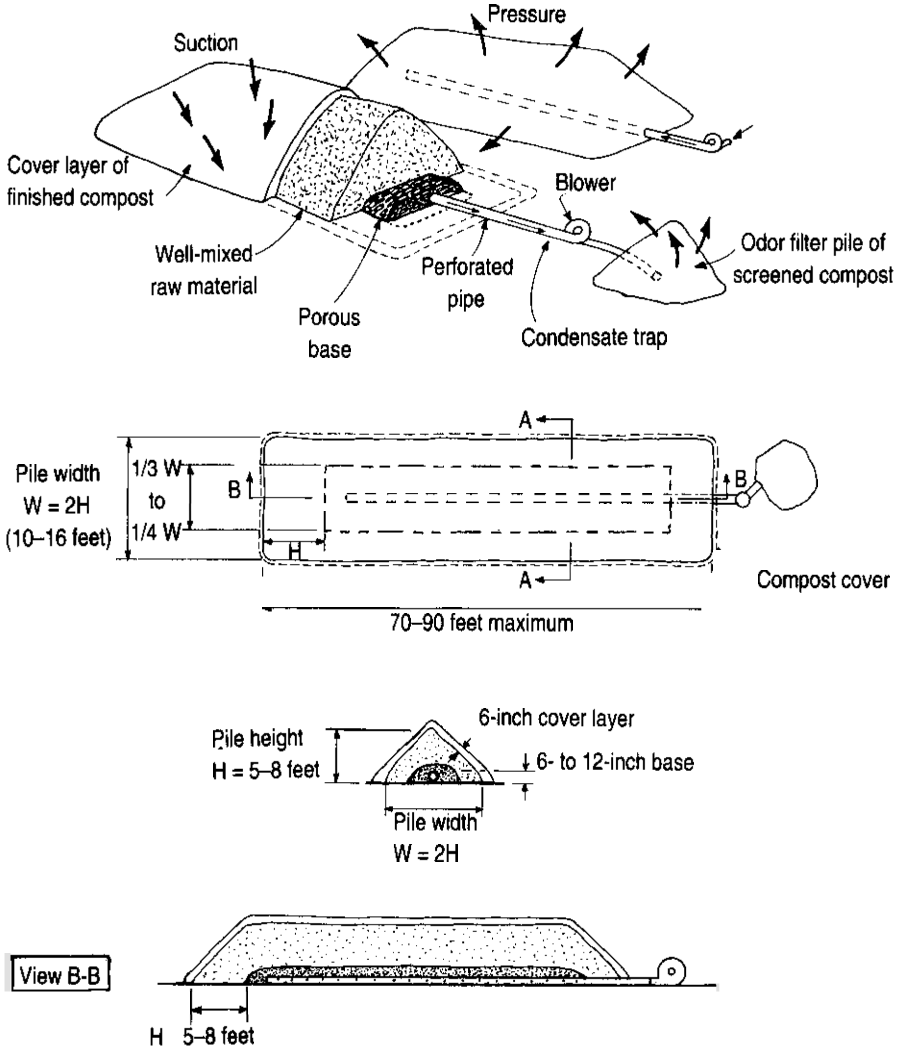


Figure 4.8

Aerated static pile layout and dimensions.

Adapted from Willson, *Manual for Composting Sewage Sludge by the Aerated Pile Method.*

The initial height of piles should be 5–8 feet high, depending on the material porosity, weather conditions, and the reach of the equipment used to build the pile. Extra height is advantageous in the wintertime to retain heat. It may be necessary to top off the pile with 6 inches of finished compost or *bulking agent.* The layer of finished compost protects the surface of the pile from drying, insulates it from heat loss, discourages flies, and filters ammonia and potential odors generated within the pile.

The porous base distributes air between the pile material and the aeration pipe. When the air is pushed through the pile (positive pressure), the porous material at the base disburses the air from the supply pipe to the pile. When the air is pulled through (suction or negative pressure), the porous base collects the air from the pile. If the porous material extends to the edges of the pile, the air will short circuit out of the pile. Therefore, the width of the porous base should be only one-fourth to one-third of the width of the pile. It should stop short of the pile ends by a distance approximately equal to the pile height (figure 4.8).

The length of the pile is limited by air distribution in the aeration pipe. If the pile is too long, little air reaches the end farthest from the blower. Pile lengths of less than 70 or 90 feet are reasonable, depending on the aeration system (see the following section).

Pile Forms: Individual and Extended Piles

Two forms of aerated static piles are common: individual piles and *extended piles.*

Individual piles, as shown in figure 4.8, are long triangular piles with a width (10–16 feet, not including the cover) equal to about twice the pile height. The aeration pipe runs lengthwise beneath the ridge of the pile. Individual piles hold a single large batch of material or a few batches of roughly the same *recipe* and age (within three days, for example). Since a single pipe and blower serve the entire pile, all the materials in the pile must have about the same demand for aeration. Individual piles are practical when raw materials are available for composting at intervals rather than continuously—for example, if manure is cleaned from barns on a weekly basis or if short term storage of manure is possible. Individual piles are also useful for separating batches of material for experimentation or special management.

When raw materials are generated daily, an extended static pile is more practical (figure 4.9). An extended pile consists of a series of cells. Each cell contains one day's volume of material or a single batch of material. Cells are stacked against one another. This gives the pile a more rectangular shape and makes better use of the *pad* area. Cell widths are about equal to the pile height. The length corresponds to the daily volume of material handled. A minimum of two extended piles is necessary. One pile contains newly constructed cells, the other contains old cells nearing completion or being removed. The space between the two piles permits equipment to remove a mature cell from one pile and add a new cell to the other pile.

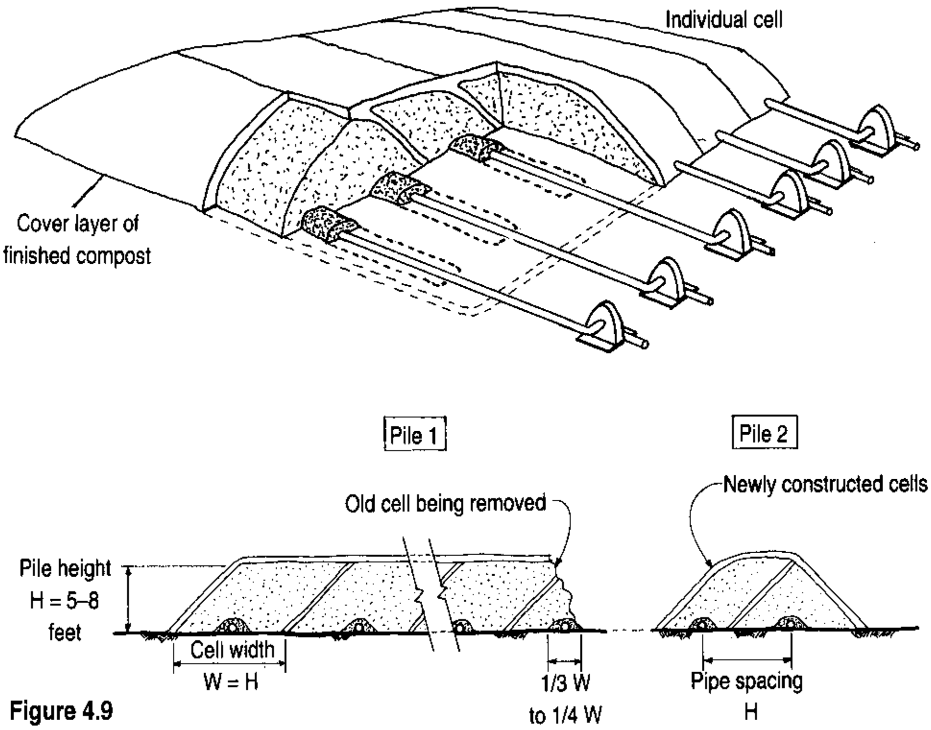


Figure 4.9
Extended aerated static pile layout and dimensions.
Adapted from Willson, *Manual for Composting Sewage Sludge by the Aerated Pile Method.*

Aeration pipe is installed in each cell within the porous base. The pipe spacing should equal the height of the pile. Generally, each cell is aerated by its own blower and controlled by its own timer or temperature sensor. Cells constructed on or about the same day can share a single blower by connecting the pipes with a header. Connecting several cells to one blower minimizes the number of blowers required but also complicates the blower control strategy and makes it more difficult to select the blower size.

Mixing and Pile Formation

Since the pile does not receive additional turnings, the selection and initial mixing of raw materials are critical. Otherwise, poor air distribution and uneven composting occur. Air channels form within the pile, causing the air to bypass much of the composting material. When this occurs, the resulting compost is non-uniform and may include clumps of anaerobic, uncomposted material. Additional mixing is usually necessary to correct this problem.

The pile must have good structure which maintains porosity through the entire composting period. This generally requires a fairly stiff bulking agent such as straw or wood chips. Wood chips are commonly used for composting *sewage sludge* by this method. Because of their large size, wood chips pass through the process only partially composted. They are usually screened from the finished compost and reused as bulking agents for an additional two or three cycles. Since straw decomposes over the composting period, a pile with straw as an amendment can gradually lose structure. This is partially compensated by the drying which takes place as composting proceeds. Other possible bulking agents and amendments for static pile composting include recycled compost, peat moss, corn cobs, crop residues, bark, leaves, shellfish shells, waste paper, and *shredded* tires. Uncomposted material like shredded tires and mollusk shells must eventually be screened from the compost and reused.

To obtain good air distribution, manure or sludge must be thoroughly blended with the bulking agent before the pile is established. A manure spreader can be used both to mix the materials and to form crude piles. A bucket loader is the most common mixing device. It can do a good job of mixing and building piles, especially after the operator gains experience using the loader for mixing. Batch-type feed mixers (wagons or truck-mounted), pug mills, and other mixing devices also work well (see chapter 5).

Some mixing devices can discharge the mix of materials directly onto the porous base to form a pile of the correct dimensions and size. If this is not possible, the pile must be shaped using a front-end loader or blade. It is important to avoid compressing the pile by running the tires of the front-end loader on the edge of the pile or by pushing the loader or blade into the pile without lifting at the same time. A frequent error made in static pile composting is to compress the mixture and smear or push manure into the pore openings that were created by the bulking agent.

Aeration Management: Time versus Temperature

The required airflow rates and the choice of blowers and aeration pipe depend on how aeration is managed—that is, how the blower is controlled. The blower can be controlled in several different modes. It can be run continuously or intermittently. In the latter case, the control mechanism can be either a programmed time clock or a temperature sensor.

Continuous operation of the blower permits lower airflow rates because oxygen and cooling are constantly supplied. However, continuous blower operation leads to less uniform pile temperatures. The areas near the air channels remain cooler than the areas that get little or no air directly. These cool spots may never achieve temperatures high enough to destroy pathogens. With intermittent operation, temperatures in different sections of the pile tend to equalize after the airflow stops.

When controlling aeration with a time clock, the blower is turned on and off based on a fixed time schedule. In a typical schedule, the blower operates one-half to one-third of the cycle time and is off for one-half to two-thirds of the cycle time (for example, ten minutes on, twenty minutes off). The blower off-time should not exceed thirty minutes. For a given application, the proper aeration schedule is usually best determined by on-site experiments and monitoring of the pile temperatures. As the temperature rises, the blower on-time can be extended to increase cooling. Later, when temperatures indicate that the composting rate has declined, the blower on-time can be shortened.

Timers are a simple and inexpensive way to control blowers. The time-control approach seeks to provide enough air to satisfy the process oxygen requirements and control temperatures to some extent. However, it does not necessarily maintain optimum temperatures. At times, the temperatures may exceed desired levels, and rate of composting will be limited by high temperatures (because of decreased microbial activity).

The temperature-control approach attempts to maintain optimum pile temperatures (for example, 130–140°F). Since temperature directly indicates the status of the process, electronic temperature sensors, such as thermocouples or thermistors, provide a means to control airflow as well as monitor the temperature. An electronic signal from the sensor causes a control relay to switch the blower on or off when the pile temperature reaches set limits. The blower comes on to provide cooling when the temperature rises above its high temperature set point, generally around 135°F. The system shuts the blower off when the piles cools below a low set point. The low set point is approximately 5°F below the high set point (for example, 130°F). During start up and whenever the pile temperature is below the low set point, the blower control shifts to a timer. The timer activates the blower on a fixed time schedule, if it is not triggered by high temperature.

When a temperature sensor is used to control the blower operation, it must be carefully placed to measure the typical temperature of the whole mass being composted. The sensor is placed at least 18 inches below the pile surface and at two-thirds the length of the pile measured from the blower end (figure 4.10). Experience eventually indicates the best location to monitor the pile temperature. A long-stem dial thermometer is still necessary to make spot checks of the pile and verify that the electronic sensors are providing the desired control. The electronic temperature sensor can give a false reading if it is located in a poorly mixed section of the pile.

From the standpoint of process management, temperature control is the better aeration strategy, since it prevents the process from being set back by high temperatures. However, compared to the time-control approach, temperature control involves greater airflow rates, larger blowers, and also a more expensive and sophisticated temperature-based control system.

Aeration System

Suggested specifications for aerated static pile blowers and pipe are summarized in table 4.1. The suggested airflow rates are based on the dry weight of the primary raw material, such as sludge or manure. These estimates account for the presence of typical amendments like wood chips, straw, and compost. Although the specifications given in table 4.1 are based on sludge composting experience, they should be reasonable for manure composting as well. However, they are only general estimates. In practice, it may be necessary to adjust the timer cycle, pile size, or blower, if possible, to suit the specific conditions and materials.

Blowers are usually centrifugal axial-blade type blowers. They range in size from 1/3 to 1/2 horsepower for time-control operation and from 3 to 5 horsepower for temperature-control operation. The required blower size and output depend on the type and amount of material in the pile or cell. In choosing a blower, there is a trade-off between minimizing the blower size and maximizing the process control. Ideally, the blower should be able to provide the peak airflow rates. However, the peak rates are needed for only a small proportion of the composting time. For

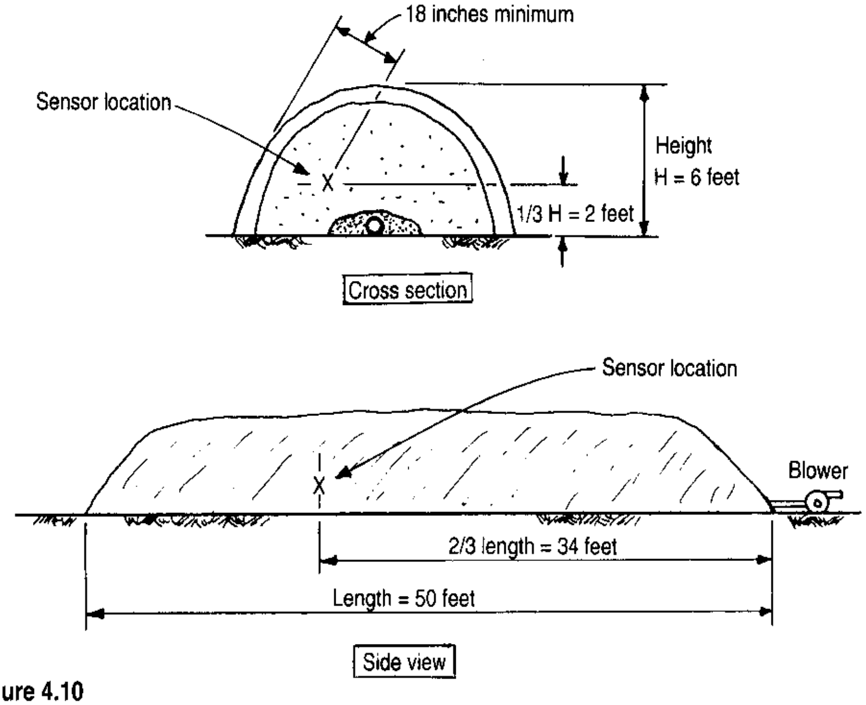


Figure 4.10
Temperature sensor location for an aerated static pile.

most of the composting period, the blower is oversized.

In order to select a blower, it is necessary to know the *air pressure loss* of the system as well as the required airflow rate. General estimates of the air pressure loss for composting sludge with wood chips range from 2 to 5 inches of water. Of this total, the pipe contributes 1–2 inches of pressure loss if properly sized. Pressure losses in the composting pile range from 1/2 to 1 inch of water. An odor-filter pile accounts for about 3 inches of pressure loss because the exiting air stream is concentrated in the smaller filter pile (high velocity). Pressure losses increase with greater velocity, higher piles, lower porosity, and smaller or longer pipe.

Usually the aeration pipe is made from inexpensive plastic piping, such as drainage pipe or leach field pipe. The pipe is discarded after composting if it is damaged by equipment in the process of removing the composted material. Metal pipe can also be used and pulled out of the pile before the compost is removed. Some composting facilities have recessed the pipe in the composting pad, protecting it with gravel and/or a metal grate. This approach has had limited success because the pipe tends to become clogged with particles of compost.

As a rough estimate, aeration pipes should be sized to maintain air velocity in the pipe below 2,000 feet per minute (fpm). Usually this corresponds to 4-inch diameter pipe for timer-controlled operations and 6-inch or 8-inch pipe for temperature-controlled operations. Double pipes can be used to reduce the pipe diameter, but they must be placed next to one another. The pipe holes should be located in two rows facing downward at about 5 and 7 o'clock (as shown in figure 4.11). The number and size of pipe holes should provide a total hole area equal to twice the cross-sectional area of the pipe (table 4.2). Hole spacing should be no greater than 12 inches within a row.

The pipe length is limited by the need to maintain a fairly even distribution of air to

Table 4.1
Aeration system specifications

		Specifications	
Component	Units	Time-based control system	Temperature-based control system
Typical blower size	horsepower	1/3–1/2	3–5
Airflow rate [a]	cubic feet per minute per dry ton of manure	25 [b]	100
Typical pipe diameter	inches	4	6–8
Maximum pipe length [c]	feet	75	50

[a] Based on experience with sludge-composting facilities. Should apply reasonably well to manure-based recipes.

[b] For timer on/off cycle of 1/3 on, 2/3 off. For 1/2 on/off, use 15–18 cubic feet per minute. For continuous operation, use 10 cubic feet per minute.

[c] Of the perforated section of the pipe, with even hole sizes and spacing. Length may be increased with unequal hole spacing or split pipe lengths.

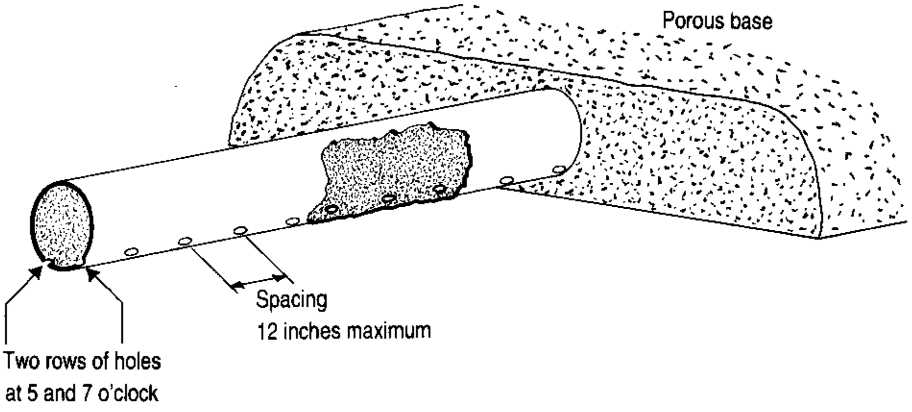


Figure 4.11
Aeration pipe specifications for an aerated static pile.

Table 4.2
Approximate hole size and spacing for aerated static pile aeration pipe

Pipe diameter (inches)	Pipe area (square inches)	Hole spacing[b] (inches)	Approximate hole diameter[a] (inches)						
			Length of perforated pipe[c] (feet)						
			20	30	40	50	60	70	80
4	12.6	6	5/8	1/2	7/16	3/8	3/8	5/16	5/16
4	12.6	9	3/4	5/8	9/16	1/2	7/16	7/16	3/8
4	12.6	12	7/8	3/4	5/8	9/16	1/2	1/2	7/16
6	28.3	6	15/16	3/4	11/16	5/8	9/16	1/2	1/2
6	28.3	9	1 3/16	15/16	13/16	3/4	11/16	5/8	9/16
6	28.3	12	1 3/8	1 1/16	15/16	7/8	3/4	11/16	11/16
8	50.3	6	1 1/4	1	7/8	13/16	3/4	11/16	5/8
8	50.3	9	1 1/2	1 1/4	1 1/8	1	7/8	13/16	3/4
8	50.3	12	1 3/4	1 7/16	1 1/4	1 1/8	1 1/16	15/16	7/8

Note: Based on a total hole area equal to twice the pipe cross-sectional area.

[a] General formula: hole diameter = $\sqrt{\frac{D^2 \times S}{L \times 12}}$, where D = pipe diameter (inches), L = pipe length (feet), and S = hole spacing (inches).

[b] Two rows of holes. Spacing shown is the distance between holes in the same row.

[c] Length of the perforated section of the pipe.

the pile along the length of the pipe. The air distribution becomes less even as the pipe length increases (figure 4.12). With equal hole spacing, the perforated section of the pipe should be no longer than 50 feet with temperature control and 75 feet with timer control. The pile can be slightly longer since the perforated pipe begins and ends a short distance from the pile's ends. If a longer pile is desired, a more complicated arrangement of hole sizes and spacings is necessary. Such a design requires either engineering analysis or experimentation. A long pipe can also be split into two legs and connected to the blower at half its length (figure 4.13).

Suction versus Pressure

For static pile composting, the air can be supplied in two ways: a suction system with the air drawn through the pile or a pressure system with the blower pushing the air into the pile.

Suction draws air into the pile from the outer surface and collects it in the aeration pipe. Since the exhaust air is contained in the discharge pipe, it can be easily filtered if odors are occurring during the composting process. The end of the discharge pipe can be inserted into a pile of finished compost (figure 4.8, page 30) or directed to another odor-treatment system. With a suction system, condensate from water vapor drawn from the pile must be removed before the air reaches the blower. An air-tight 55-gallon drum makes a simple, inexpensive condensate trap (figure 4.14). Placing the aeration pipe with the holes facing downward allows condensate to drain from the pipe. Although the ability to contain exhaust gases for odor treatment is an important advantage of suction aeration, it pays a penalty for this in terms of pressure loss. An odor filter more than doubles the pressure losses of the aeration system.

With positive pressure aeration, the exhaust air leaves the compost pile over the entire pile surface. Therefore, it is difficult to collect the air for odor treatment. If better odor control is desired, a thicker outer layer of compost can be used. Pressure aeration provides better airflow than suction aeration, largely because of the lack of an odor filter. The lower pressure loss results in greater airflow at the same blower power. Therefore, pressure systems can be more effective at cooling the pile and are preferred when temperature control is the overriding concern.

The sample calculation section on page 36 illustrates design of an aerated static pile system.

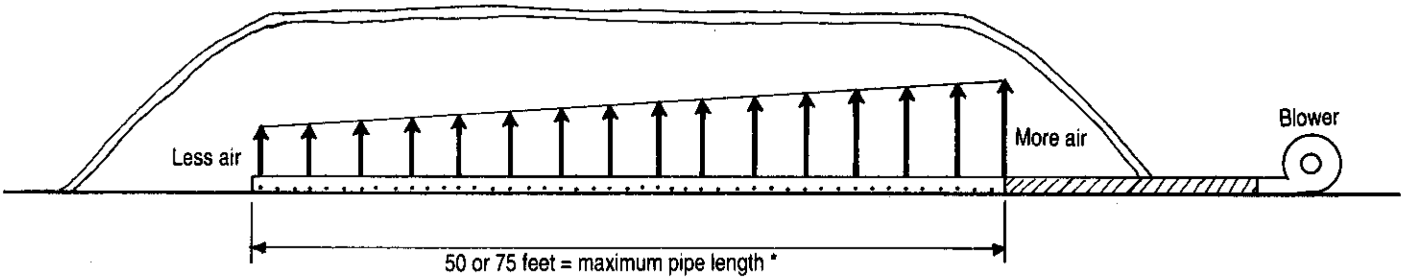


Figure 4.12
Air distribution pattern along the pile length.

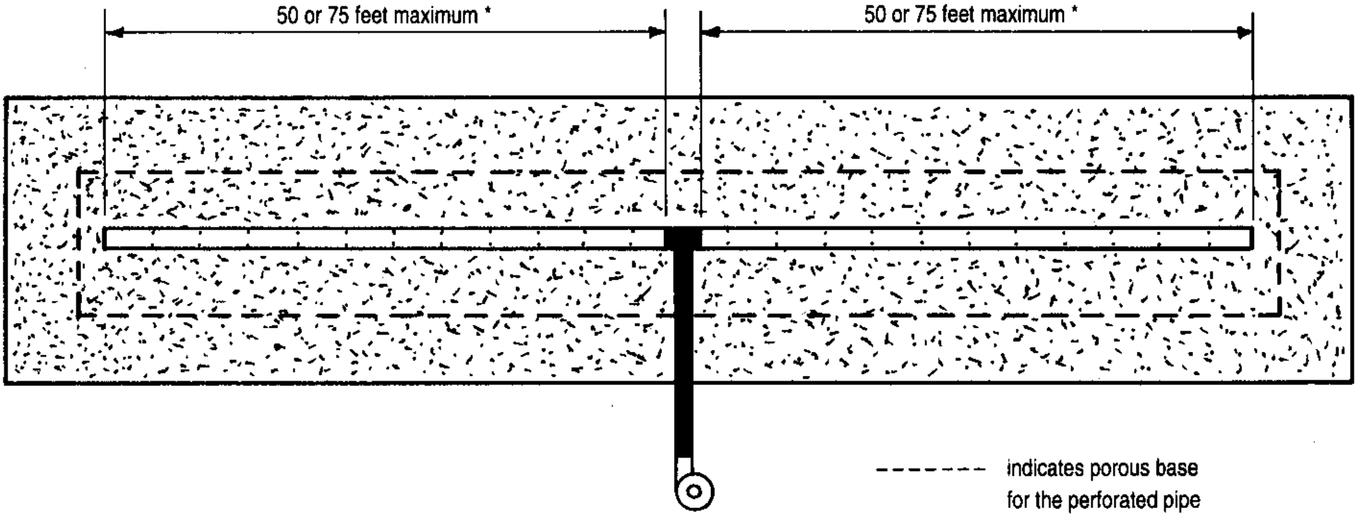


Figure 4.13
Split aeration pipe layout to increase the pile length for an aerated static pile.

------- indicates porous base for the perforated pipe

* 50 feet maximum for temperature-based control
75 feet maximum for time-based control

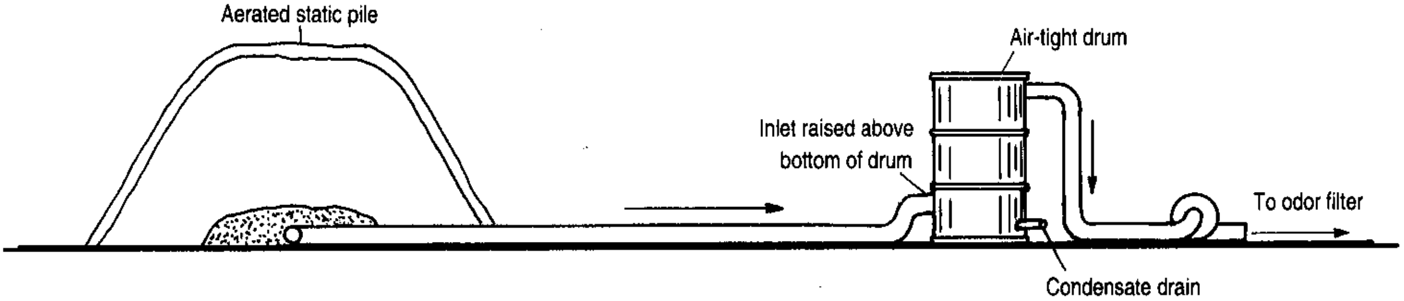


Figure 4.14
A 55-gallon drum condensate trap for a suction aeration system.

Sample Calculation: Aerated Static Pile—Aeration System Design

A farm with six hundred head of beef cattle composts manure and straw using an extended static pile with cells 6 feet high and 6 feet wide. The blower is controlled by temperature and operates in the pressure mode. The straw-to-manure ratio is 2:1 by volume. Average daily manure production is 24 tons or approximately 800 cubic feet at a moisture content of approximately 85% (15% dry solids).

Estimate the required blower airflow rate and determine the pipe specifications for a daily cell of the extended pile.

Calculate volume of material in the cell

Volume = manure + straw
= 800 cubic feet + 1,600 cubic feet
= 2,400 cubic feet

Note: Mixing several materials together usually reduces the overall volume. The volume reduction which occurs from mixing is often at least 20% of the combined volume of the individual materials. The cell volume calculated above is, therefore, conservative. As a result, the estimated cell length and pipe length may be slightly longer than necessary.

Calculate length of cell (6 feet high by 6 feet wide)

Area = height x width
= 6 feet x 6 feet

$$\text{Estimated length of cell} = \frac{\text{Volume}}{\text{Area}} = \frac{\text{2,400 cubic feet}}{\text{6 feet x 6 feet}}$$

$$= \frac{\text{2,400 cubic feet}}{\text{36 square feet}} = \text{67 feet}$$

Calculate estimated airflow rate

Dry weight of manure = 24 tons (wet weight) x 0.15
= 3.6 dry tons of manure

$$\text{Estimated airflow rate} = \text{3.6 dry tons x } \frac{\frac{\text{100 cubic feet}}{\text{minute}}}{\text{dry ton}}$$

$$= \frac{\text{360 cubic feet}}{\text{minute}}$$

Calculate pipe specifications

Estimated pipe size

$$\text{Area} = \frac{\frac{\text{360 cubic feet}}{\text{minute}}}{\frac{\text{2,000 feet}}{\text{minute}}}$$

= 0.18 square feet
= 26 square inches

$$\text{Diameter} = \sqrt{\frac{\text{26 square inches x 4}}{\pi}}$$

= 5.8 inches

Use 6-inch pipe.

Pipe spacing = pile height
= 6 feet

Perforated pipe length = pile length – (2 x pile height)
= 67 feet – (2 x 6 feet)
= 55 feet

Pipe hole size/spacing (from table 4.2, page 34)
Use 12-inch spacing with 3/4-inch diameter holes

Estimated pressure loss = 2–2.5 inches of water (pile + pipe)

Based on these calculations, the blower should produce 360 cubic feet per minute against a pressure of 2.5 inches of water.

In-Vessel Composting

In-vessel composting refers to a group of methods which confine the composting materials within a building, container, or vessel. In-vessel methods rely on a variety of forced aeration and mechanical turning techniques to speed up the composting process. Many methods combine techniques from the windrow and aerated pile methods in an attempt to overcome the deficiencies and exploit the attributes of each method.

There are a variety of in-vessel methods with different combinations of vessels, aeration devices, and turning mechanisms (see appendix B, table B.5, pages 140–141). The few methods discussed here have either been used or proposed for farm composting. They also serve as good examples of the types of in-vessel systems available. For information on other in-vessel techniques, consult the references listed at the end of the book.

Bin Composting

Bin composting is perhaps the simplest in-vessel method. The materials are contained by walls and usually a roof (see sidebar). The bin itself may simply be wooden slatted walls (with or without a roof), a grain bin, or a bulk storage building. The buildings or bins allow higher stacking of materials and better use of floor space than free-standing piles. Bins can also eliminate weather problems, contain odors, and provide better temperature control.

Essentially, bin composting methods operate like the aerated static pile method. They include some means of forced aeration in the floor of the bin and little or no turning of the materials. Occasional remixing of the material in the bins can invigorate the process. If several bins are used, the composting materials can be periodically moved from one bin to the next in succession. Most of the principles and guidelines suggested for the aerated pile should apply to bin composting as well. One exception relates to relatively high bins. In this case, there is a greater degree of compaction and a greater depth of materials for air to pass through. Both factors increase the material's resistance to airflow (pressure loss). A raw material with a stronger structure and/or a higher pressure blower may be required, compared to the aerated static pile method.

Rectangular Agitated Beds

The *agitated bed* system combines controlled aeration and periodic turning. In this system, composting takes place between walls which form long, narrow channels referred to as beds (figure 4.15). A rail or channel on top of each wall supports and guides a compost-turning machine.

Raw materials are placed at the front end of the bed by a loader. As the turning machine moves forward on the rails, it mixes the compost and discharges the compost behind itself. With each turning, the machine moves the compost a set distance toward the end of the bed. The turning machines work much like windrow turners, using rotating paddles or flails to agitate the materials, break up clumps of particles, and maintain porosity. Some machines include a conveyor to move the compost. The machines work automatically without an operator and are controlled with limit switches.

Most commercial systems include a set of aeration pipes or an aeration plenum recessed in the floor of the bed and covered with a screen and/or gravel. Between turnings, aeration is supplied by blowers to aerate and cool the composting materials. Since the materials along the length of the bed are at different stages of composting, the bed is divided into different aeration

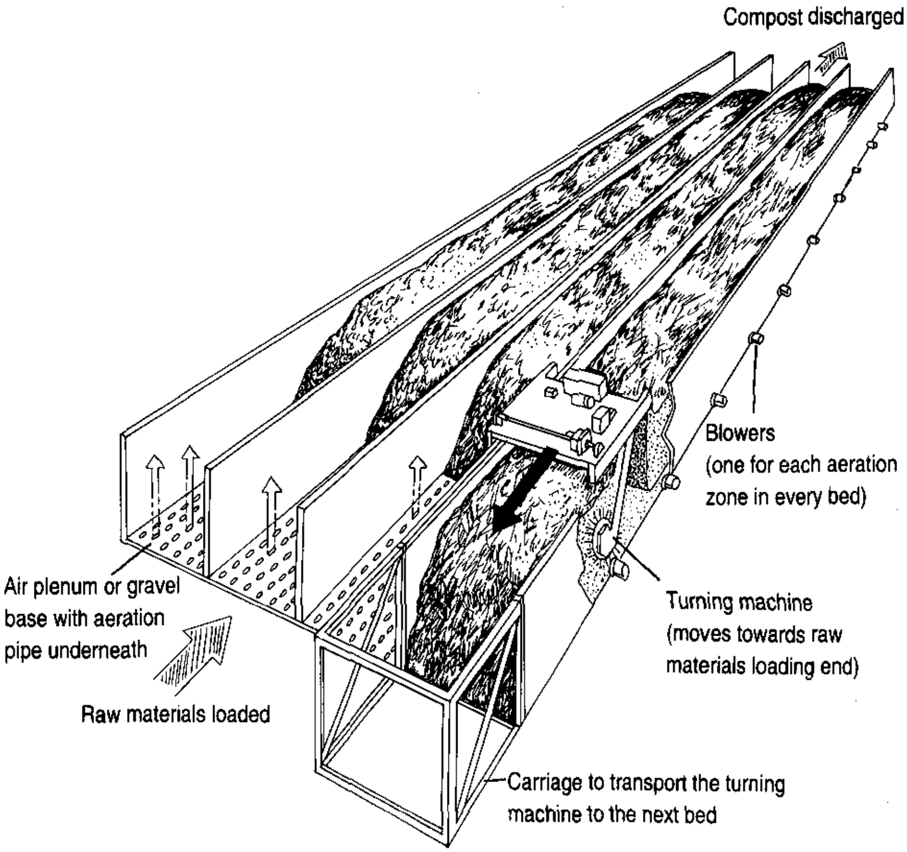


Figure 4.15
Rectangular agitated bed composting system.
Adapted with permission from Royer Manufacturing.

zones along its length. Several blowers are used for one bed. Each blower supplies air to one zone of a bed and is individually controlled by a temperature sensor or time clock.

The capacity of the system is dependent on the number and the dimensions of the beds. The width of the beds in commercially available systems ranges from 6 to 20 feet, and bed depths are between 3 and 10 feet. The beds must conform to the size of the turning machine, and the walls must be especially straight. Because the machine rides on top of the walls over a distance of 100 feet or more, little deviation in the distance between the walls can be accepted from end to end. The composting facility can contain several adjacent beds. One turning machine can handle several beds if a carrying device is available to transfer it from one bed to another. To protect equipment and control composting conditions, the beds are housed in a building or a greenhouse or, in warm climates, just covered by a roof.

The length of a bed and frequency of turning determine the composting period. If the machine moves the materials 10 feet at each turning and the bed is 100 feet long, the composting period is ten days with daily turning. It increases to twenty days if turning occurs every other day. Suggested composting periods for commercial agitated bed systems range from two to four weeks, though a long *curing* period may be necessary.

Agitated bed systems appear to have promise for farm composting. A handful of farms around the country have already invested in them. The short composting times, consistent compost quality, and labor savings are very appealing. However, the cost for a total system is very expensive. A small custom-built turning machine alone can cost at least $20,000; and commercially available machines cost over $200,000. The beds and the building represent the major costs.

Several commercial companies sell rectangular agitated bed composting systems and provide the technical expertise to design, build, and operate the systems. A number of vendors manufacture large systems on the scale of 150 tons per day or larger. Small systems of 20 tons a day or less, which are more likely to interest the majority of farmers, are not routinely available. Units capable of handling approximately 20–40 cubic yards of material per day are available commercially for about $100,000 to $175,000 in capital costs, including agitators, structure, site grading, concrete, and other costs. A few systems have also been custom-built.

Silos

Another in-vessel technique resembles a bottom-unloading silo (figure 4.16). Each day an auger removes composted material from the bottom of the silo and a mixture of raw materials is loaded at the top. The aeration system blows air up from the base of the silo through the composting materials. The exhaust air can be collected at the top of the silo for odor treatment. A typical composting time for this method might be fourteen days, so one-fourteenth of the silo volume must be removed and replaced daily. After leaving the silo, the compost is cured, often in a second aerated silo. This system minimizes the area needed for composting because the materials are stacked vertically. However, the stacking also presents compaction, temperature control, and airflow challenges which must be overcome. Because materials receive little mixing in the vessel, raw materials must be well mixed when loaded into the silo.

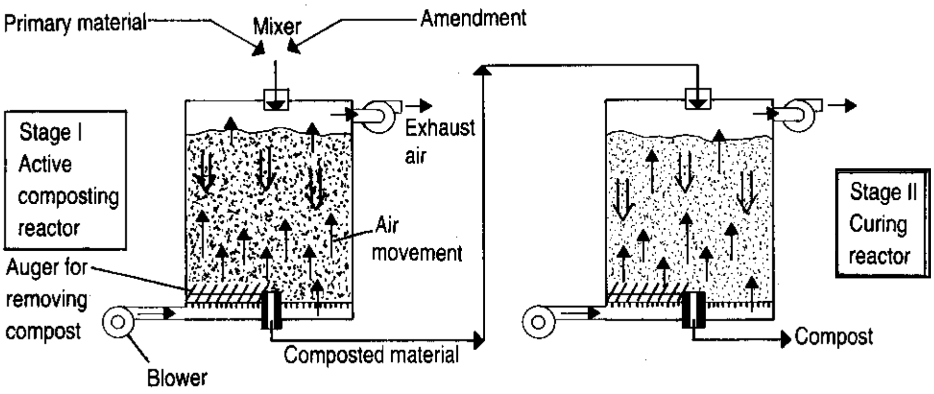


Figure 4.16
Silo composting system.

Rotating Drums

A different system uses a horizontal rotary drum to mix, aerate, and move the material through the system (figure 4.17). The drum is mounted on large bearings and turned through a bull gear. A drum 11 feet in diameter and 120 feet long has a daily capacity of approximately 50 tons with a residence time of three days. In the drum, the composting process starts quickly; and the highly degradable, oxygen-demanding materials are decomposed. Further decomposition of the material is necessary and is accomplished through a second stage of composting, usually in windrows or aerated static piles. In some commercial systems, the composting materials spend less than one day in the drum. In this case, the drum primarily serves as a mixing device.

Air is supplied through the discharge end and is incorporated into the material as it tumbles. The air moves in the opposite direction as the material. The compost near the discharge is cooled by the fresh air. In the middle, it receives the warmed air, which encourages the process; and the newly loaded material receives the warmest air to initiate the process.

The drum can be either open or partitioned. An open drum moves all the material through continuously in the same sequence as it entered. The speed of rotation of the drum and the inclination of the axis of rotation determine the residence time. A

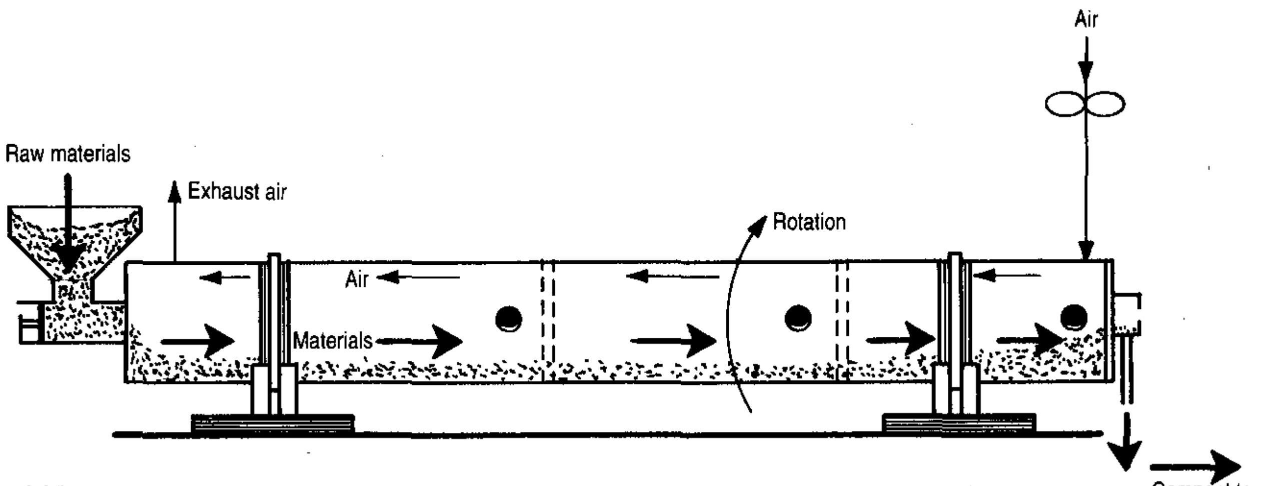


Figure 4.17
Rotating drum composter.
Source: Bedminster Bioconversion, Inc.

partitioned drum can be used to manage the composting process more closely than the open drum. The drum is divided into two or three chambers by partitions. Each partition contains a transfer box equipped with an operable transfer door. At the end of each day's operation, the transfer door at the discharge end of the drum is opened and the compartment emptied. The other compartments are then opened and transferred in sequence, and finally a new batch is introduced into the first compartment. A sill in place at each of the transfer doors retains 15% of the previous charge to act as an *inoculum* for the succeeding batch. Upon discharge, the compost can go directly into a screen to remove oversized particles which can be returned to the drum for further composting.

On a smaller scale, composting drums can be adapted from used equipment such as concrete mixers, feed mixers, and old cement kilns. Although less sophisticated than the commercial models, the functions remain the same: to mix, aerate, and get the composting process started rapidly.

Transportable Containers

A different type of in-vessel system, developed as a pilot project, relies on a transportable vessel and a central composting facility. A number of local farms participate and provide manure as a raw material. Each farm receives a transportable vessel which resembles a solid waste roll-off container. The container has aeration pipes in its base which are connected to a blower. At the farm, the manure and dry amendments are loaded daily into the container and aerated for several days until the container is picked-up and delivered to the central facility to finish composting. When the composting container is picked up, the farm is provided another empty container to continue the cycle. The farm supplies the manure and receives bulking agent, compost, and/or revenue in return.

Summary: Comparing the Composting Methods

In terms of cost, labor, management, and process speed, the windrow, passively aerated windrow, and aerated static pile systems are comparable. With the exception of simple bin methods and some agitated bed systems, in-vessel composting is in a different league. Therefore, the choice of a composting method for farms usually reduces to windrows, aerated piles, or aerated bins.

Windrow composting is more labor-intensive than aerated piles. Some activity is performed on the site almost daily. The aerated static pile and passively aerated windrow systems have labor peaks that occur when piles are constructed and removed. The material, once placed in the pile, is not handled again until it is ready to be moved to the curing pile.

Overall, the aerated pile is a more concentrated method of composting. It allows higher, broader piles and, therefore, requires less land area than either the windrow or passively aerated windrow methods. This makes it easier to cover the system with a roof or enclose it within a building. Mechanical aeration makes automation easier, permits closer process control, and shortens the composting period. The insulating layer of compost and the larger pile size reduce temperature variations. This improves conditions for destroying pathogens. The insulation layer and lack of turnings conserve nitrogen and limit the release of odors. Nearly all of the nitrogen can be conserved with aerated static piles, whereas over one-third may be lost in windrow composting. With a suction aeration system, odors can be collected and treated. For all of these reasons, the aerated pile method is common among sewage sludge composting facilities. One disadvantage is the potential for short circuiting and channeling of the airflow, which produces an unevenly composted product. Another problem is the clogging of openings in the aeration pipe.

The windrow method is common among farm composting operations. Many farm materials present less odor problems than sewage sludge, and odors tend to be more acceptable in the rural setting of most farms. Land is not usually limiting on farms. In some cases, windrows can be built in fields where the compost may later be applied.

Since no electricity is required, remote fields can be used. Windrow composting is similar in nature to other farming operations, and existing farm equipment can be used. Windrow composting also allows a greater choice of amendments. The turning process continues to mix and pulverize the composting material. This produces a more uniform compost and reduces the need for secondary operations like screening and *grinding*. A major disadvantage is that windrow composting is at the mercy of the weather. Rain, snow, and mud are more likely to cause problems with windrows than the aerated piles. Paved surfaces and open-sided buildings have been added to some windrow facilities to better cope with adverse weather, but at a significant expense.

The passively aerated windrow method shares features of both turned windrows and aerated static piles. Like the windrow method, it is more land-intensive but does not require electricity. Like aerated static piles, it conserves nitrogen, maintains even temperatures, and slows the release of odors; but the choice of amendments is more limited.

In-vessel composting systems methods are commercial systems which are purchased, licensed for use, and/or specially designed by consultants. They usually carry very high capital costs. Operation and maintenance also require greater expense and a higher level of knowledge and skill than the windrow and aerated pile methods. In exchange, in-vessel systems offer several potential advantages including reduced labor, few weather problems, potentially better odor control, closer process control, faster composting, reduced land area, and consistent compost quality. However, an in-vessel system does not, in itself, assure that these advantages will be realized. Many problems still occur, which often involve more expensive solutions. An increasing number of farms may find one of the lower cost in-vessel systems worth the investment, especially if quality control and rapid composting are important. Bins and rectangular agitated beds, in particular, have found a place on several farms.

Poultry Carcass Composting

Modern poultry farms are large, and the average size of production units continues to increase. For instance, the average broiler farm on the Delmarva Peninsula has increased in capacity from thirty-seven thousand head to fifty thousand head during the 1980s. On such large units, even moderate rates of mortality (for example, 0.1% per day) pose significant disposal problems. During the period when birds are approaching marketable weight, normal mortality may require the disposal of 200–500 pounds of carcasses per day on a typical farm.

Broiler farms also produce considerable quantities of bedded manure (*litter*), which is a valuable fertilizer. Poultry litter has a nearly ideal carbon-to-nitrogen ratio for composting. When sufficient moisture is available to activate it, broiler litter can serve as the major constituent in a composting system which reduces poultry carcasses to skeletal residues and which produces a safe and inoffensive fertilizer and *soil amendment*.

Poultry carcass composting was originally researched and field-tested at the University of Maryland Agricultural Experiment Station in Princess Anne. The Maryland method of composting birds is an adaptation of the traditional Indore method.

Litter, straw, and dead birds are added in successive layers to treated wooden bins (figure 4.18) as mortality accumulates. Litter, straw, and birds are added in weight proportions of 1.5:0.1:1.0, respectively (table 4.3). Conveniently for busy farmers, these weight proportions convert handily to volumetric proportions of 2:1:1 of broiler litter, straw, and birds. This mixture has an approximate moisture content of 40% and a C:N ratio of 20:1–25:1. As necessary, the mixture should be wetted to give it a damp sponge consistency. Bird carcasses are added in layers to the composting bins, with each layer covered with a six-inch layer of dry litter or compost each day to discourage flies, *vermin*, and odors. No inoculum is required to initiate microbial activity, since the litter is naturally seeded with substantial numbers of composting microorganisms.

Temperatures within the composting

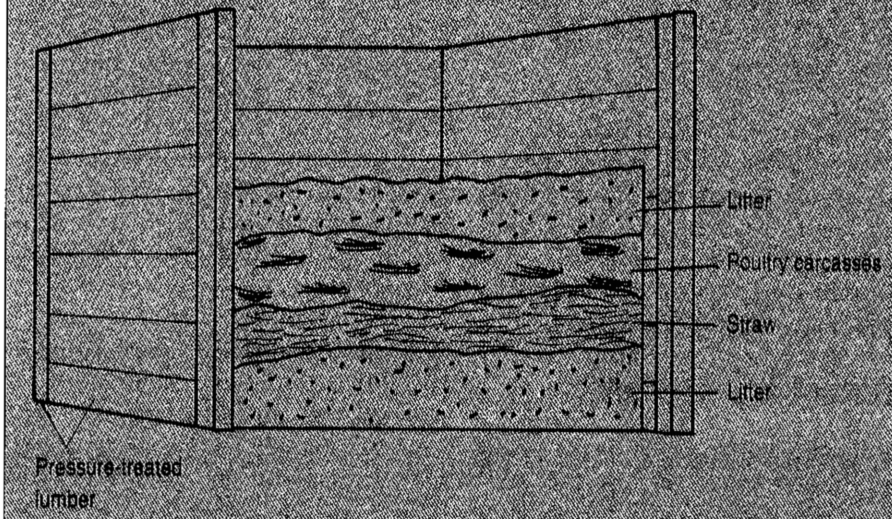


Figure 4.18
Poultry carcass composting bin.

materials rise to between 135°F and 160°F within five days of loading the bin. After seven to ten days of decomposition in this primary bin, the compost is turned with a bucket loader into a secondary bin where the reduction of carcasses is completed. Turning and moving batches of compost achieves two desirable results—the mass of materials is mixed to improve its homogeneity, and the materials are fluffed up and aerated. After seven to ten days in the secondary bin, soft tissue is completely consumed, and only bones and feather shafts remain.

The entire process requires twenty days to complete. It is inoffensive—flies, scavengers, and odors are not problems when appropriate structures are used (figure 4.19) and basic management procedures are followed. At

Table 4.3
Sample poultry carcass compost mixture

Ingredient	Volume	Approximate weight	C:N Ratio	Moisture
Manure [a]	2	1.5	25	22%
Poultry carcass	1	1.0	5 [b]	65%
Straw [c]	1	0.1	85	9%
Calculated mixture composition			20	38% [d]

[a] Manure includes built-up broiler and turkey litter, caked manure, deep-pit layer manure, and so on. Composition and optimal proportions with various materials.

[b] 2.4% nitrogen, mostly in organic form.

[c] Other non-woody carbon sources such as chopped corn stover, peanut hulls, and so on may be substituted for straw.

[d] Water should be added and mixed in *sparingly* to accelerate decomposition. Avoid saturating the pile.

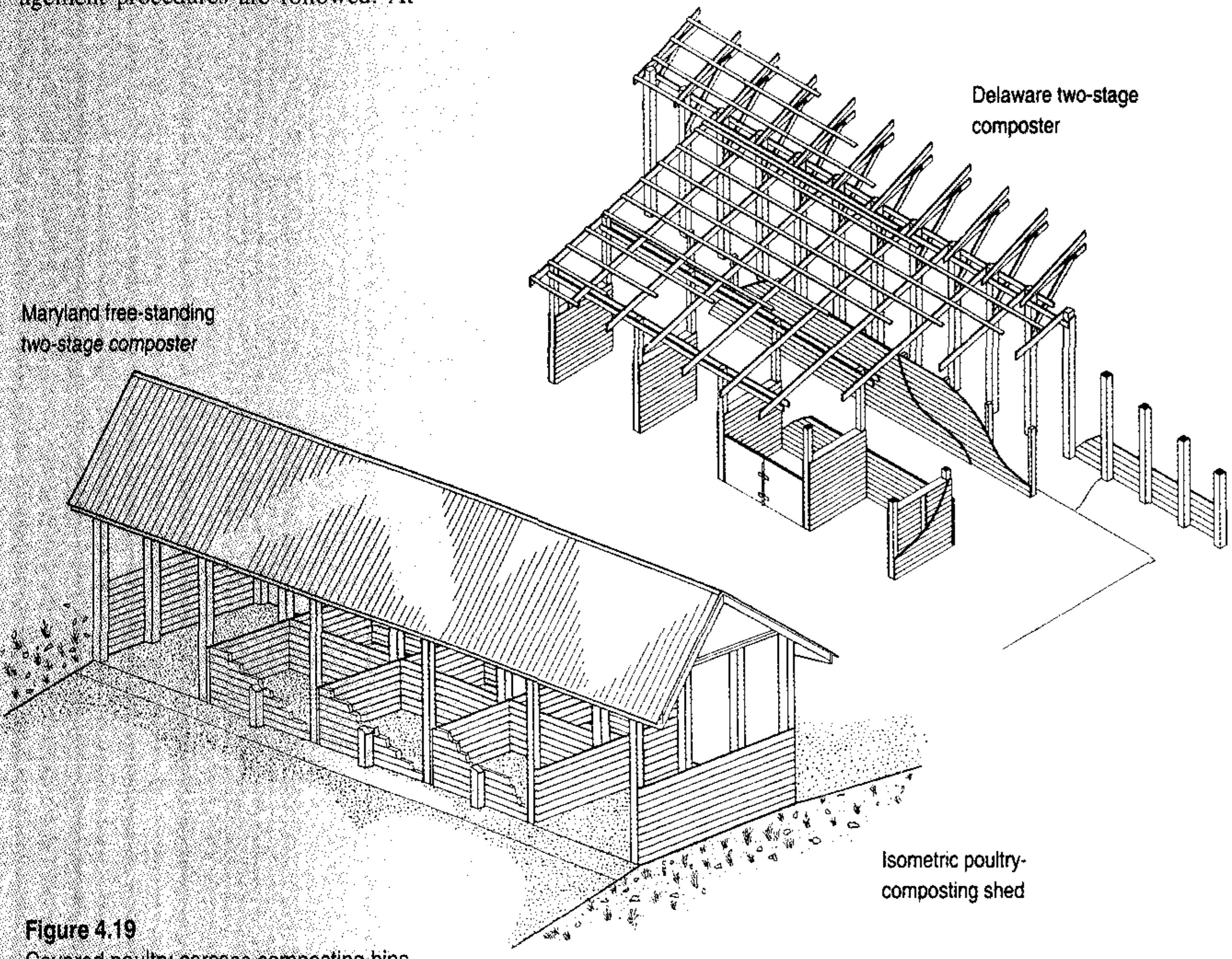


Figure 4.19
Covered poultry carcass composting bins.

Sources: Cooperative Extension, University of Delaware and University of Maryland.

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5 Composting Operations

The *composting* process, with its requirements for *turning* and *aeration,* is only one step in a larger system to produce *compost.* Once the composting process requirements are satisfied, producing compost becomes largely a matter of materials handling. Although aeration and other aspects of the composting process are critical and must not be neglected, most of the equipment and labor invested in a composting system involve moving, mixing, and manipulating the materials. Therefore, the choice of equipment and procedures for materials handling can be as important as the choice of the composting method.

A system implies that there is a succession of operations, including some that may be repeated at intervals. Figure 5.1 outlines the typical operations involved in a composting system and their usual sequence. In addition to the materials handling steps, several secondary operations are sometimes necessary to condition the raw materials for composting, to recover uncomposted materials from the finished compost, or to improve the compost's qualities for sale or use. Secondary operations include sorting, *grinding/shredding,* screening, drying, and bagging.

It is important to recognize that not all of the operations discussed here are necessary. Farm composting operations seldom involve more than storage and mixing of raw materials, pile/*windrow* formation, *curing,* and storage of the compost. However, a given composting facility may need to include one or more secondary operations depending on the raw materials and on the market for the compost product.

Raw Material Storage and Handling

Composting begins by collecting suitable organic materials that are then mixed to achieve the desired *C:N ratio, moisture content,* and pore space. Usually one material is the primary material, such as animal *manure,* and one or more *amendments* are added to it.

Initially, the materials must be collected and moved to the composting site. Usually amendments are stockpiled at the site, to be added to the manure or other primary material that is periodically brought to the site. A primary material like manure receives immediate attention because it can quickly become *anaerobic,* and emit undesirable odors when it is subsequently disturbed. Some materials, like cattle manure, may be stored for several days; but it is usually best to promptly handle the primary materials.

Amendments like straw, wood chips, leaves, and sawdust respond much more slowly to microbial activity because they have a high carbon content and are usually dry. They can be stored for an appreciable length of time before they begin to degrade. If they become wet, they begin to compost but at a slow rate because of the lack of nitrogen. Some ingredients which are neither primary materials nor dry amendments, such as crab shells, may pose a potential odor problem. These must be brought to the site just prior to composting or handled in a manner that prevents odor problems (see odor control section).

Most amendments can be stockpiled outdoors without a cover. A roof helps to minimize the initial moisture content of the mix and reduces the possibility of leaching nutrients from wet materials during storage. However, the trade-off in cost for the roof must be considered. Available space in existing farm buildings should be considered first. Most farm structures used for bulk storage should work well.

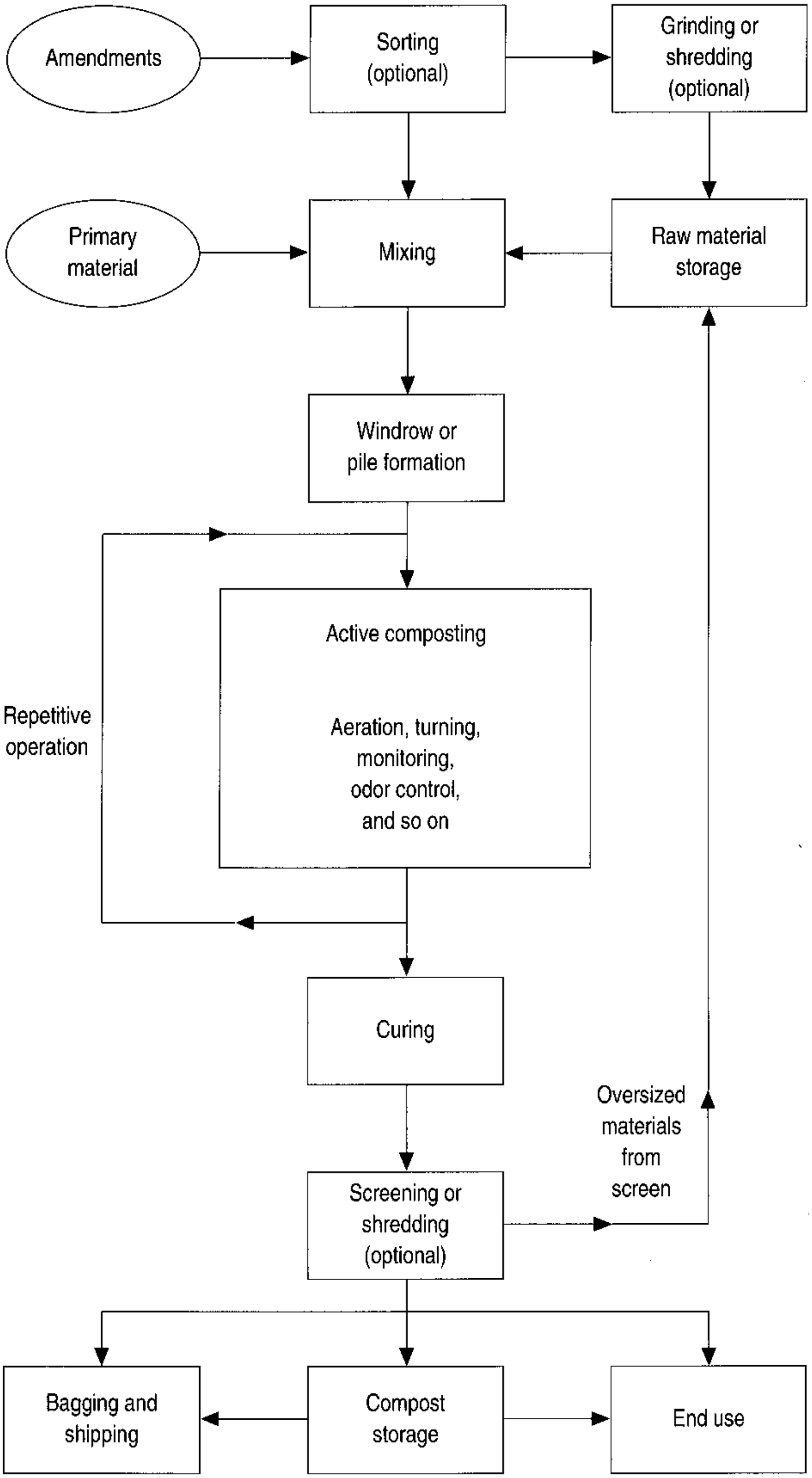


Figure 5.1
Composting system and operations.

Trash is a potential problem with several off-farm materials, especially paper. Such materials need to be stored and handled in a way that keeps them contained within the storage area. Shredded paper and cardboard should be bailed and/or stored inside if not composted immediately. The manner in which all raw materials are stored and handled greatly influences the neighbors' and the community's acceptance of the composting operation.

Occasionally, raw materials need to be sorted or separated prior to composting. For example, horse stable waste may contain miscellaneous trash, or leaves may include plastic bags. The ideal solution to sorting materials obtained from off the farm is to convince the supplier to sort them before delivery. However, this is not always possible, or it may require some negotiation of fees charged. In most cases, foreign objects can first be removed by hand when the material is delivered, and then continuously throughout the composting process. Turning and subsequent settling of piles and windrows tends to push both large and light objects to the surface of the pile, where they are noticeable and can be removed. For the rare case when raw materials contain a large amount of unwanted materials, mechanical separation is necessary (for example, screens and magnets). If the unwanted material is not damaging to the process or equipment, this can occur after composting.

Grinding/Shredding

Most raw materials used for farm composting do not require grinding or shredding, especially if a windrow turner is employed. Several raw materials that benefit from shredding include newspaper, corrugated cardboard, brush, and other *yard wastes.* Tree stumps and other large objects cannot be composted without size reduction. Shredding also allows materials like newspaper to be used as *bedding* prior to composting. Noise and dust created by grinding/shredding are potential problems.

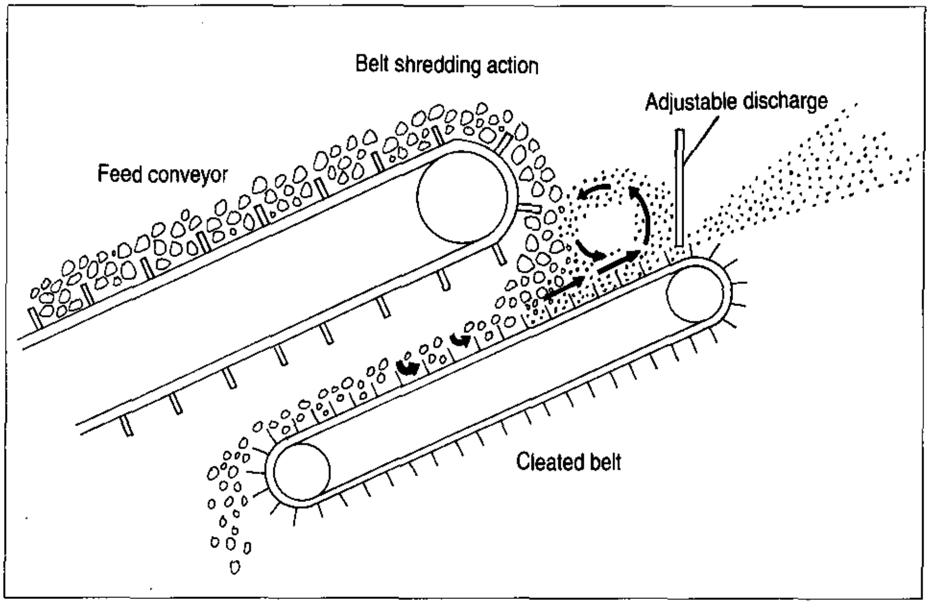
Appendix B (table B.2, pages 120–131) lists a variety of commercial grinding and shredding equipment promoted for composting systems, including equipment used on farms for shredding hay bales and preparing feeds. Other possible equipment choices include paper shredders, large garden shredders, mowers, and forage choppers. Some size-reducing mechanisms can be matched with accessory equipment, such as balers, dust separators, conveyors, and screens. The capacities shown in appendix B, as well as the costs, should be considered as rough estimates only. The actual capacity depends considerably on the materials, loading rates, and other specific conditions. Costs also vary a great deal with specific power requirements and accessory equipment. If a grinder or shredder is required for only several weeks a year, rental equipment should be considered.

The primary types of grinding/shredding equipment used for composting systems are shear shredders, hammer mills, tub grinders, and chippers.

Shear Shredders

One type of shear shredder is a stationary or trailer-mounted machine. This machine reduces the size of material through the action of a cleated belt, which forces material against stationary knives. Material is loaded into a receiving hopper, which feeds a conveyor. The conveyor drops the materials onto a cleated belt that undergoes a continuous raking action to shred the load (figure 5.2). Adjustable sweep fingers force oversized pieces back for further shredding while material such as sticks, stones, metal, and glass are rejected and discharged through a trash chute. Usually this type of shredder can handle only material less than 4–6 inches in diameter and may require a grate over the hopper to exclude oversize items.

A second type of shear shredder uses two counterrotating shafts with overlapping hooked cutter discs (figure 5.3). Cutters draw material down toward shafts at the base of a hopper. The cutters slice or tear the particles into smaller pieces until they pass through the spaces between the cutter discs. The size of the sheared particles is determined by the cutter disc size. Another commercially available machine performs similar shearing action with counterrotating augers instead of cutting discs.



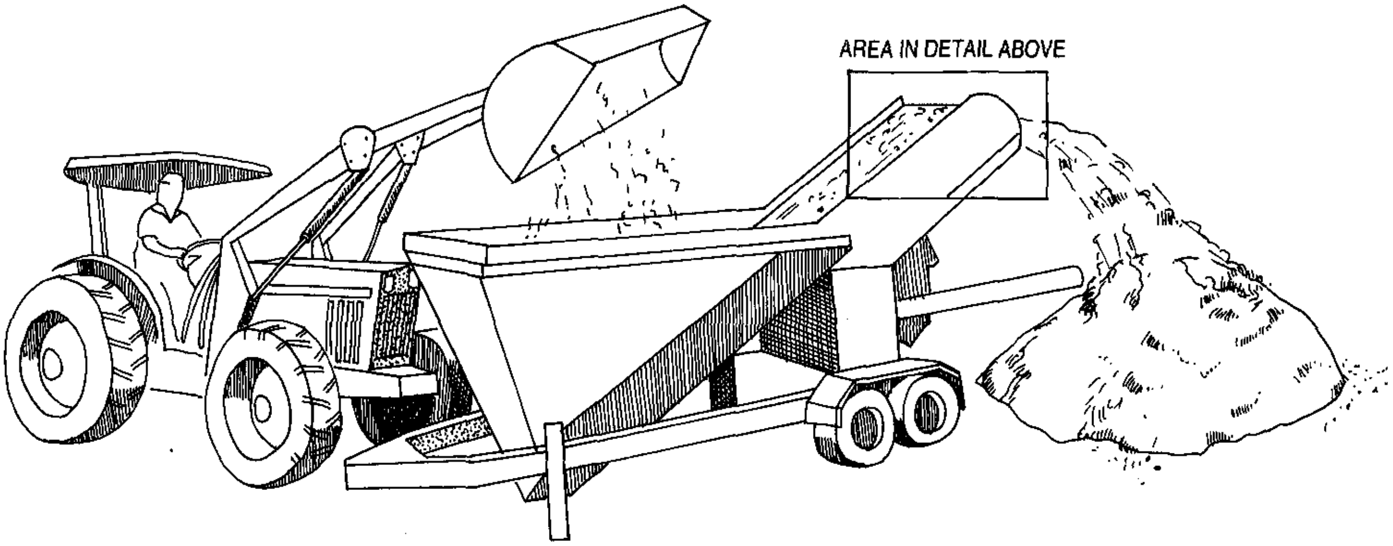


Figure 5.2
Belt-type shear shredder.
Inset is adapted with permission from Royer Manufacturing.

Rotating shear shredders can process a wide variety of raw materials. They are commonly used in processing solid waste materials. Many models can be trailer-mounted.

Hammer Mills and Tub Grinders

Material dropped into a hammer mill is size-reduced by free-swinging metal hammers mounted on a spinning shaft (figure 5.4). The hammers break apart material until it is small enough to drop through discharge openings. Hammer mills can be very large and are often stationary. They tend to create more noise than shear shredders because of their pounding action.

A tub grinder is a type of hammer mill that uses a rotating tub intake system to crush wood and brush (figure 5.5). The rotation moves materials across a fixed floor, which contains the hammers. As material is ground, it is forced through a screen or other restricted opening and then conveyed into standing piles or into a transfer vehicle. Tub grinders are loaded with a *bucket loader* or a conveyor.

Tub grinders are available in different models which have significantly different capabilities. Big, heavy-duty grinders are suitable for grinding large amounts of dry wood and brush. Portable units are available with diesel or gasoline engines ranging from about 300 to 550 horsepower. Stationary units use diesel or electric engines. Tub grinders can process 10–50 tons per hour, depending on factors such as the type of material processed, screen size, and moisture content. Proper mixing of wastes and the use of varying screen sizes reduce jamming and increase throughput efficiency. A complete set of screens (with openings from about 3/4 inch to 5 inches) should be obtained with the grinder. A tub grinder requires one person to operate it and a second person to load materials into the machine.

Grinders require regular maintenance, including rotation and replacement of the hammers. A new set of ninety-six hammers costs approximately $900 to $1,400

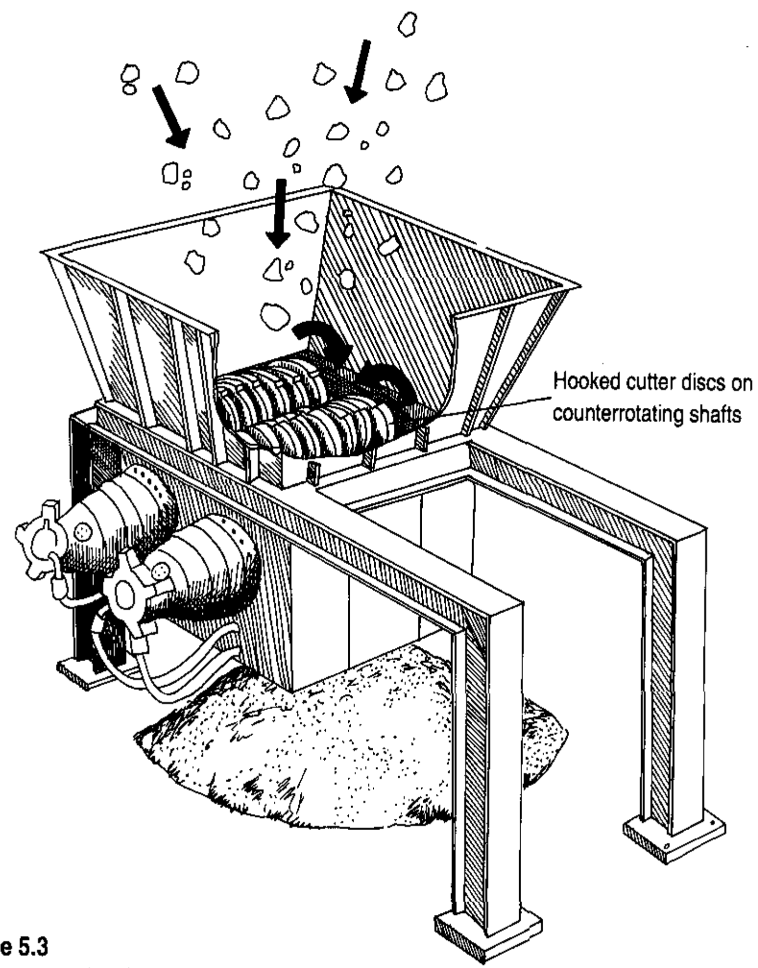


Figure 5.3
Rotary shear shredder.
Adapted with permission from Triple/S Dynamics.

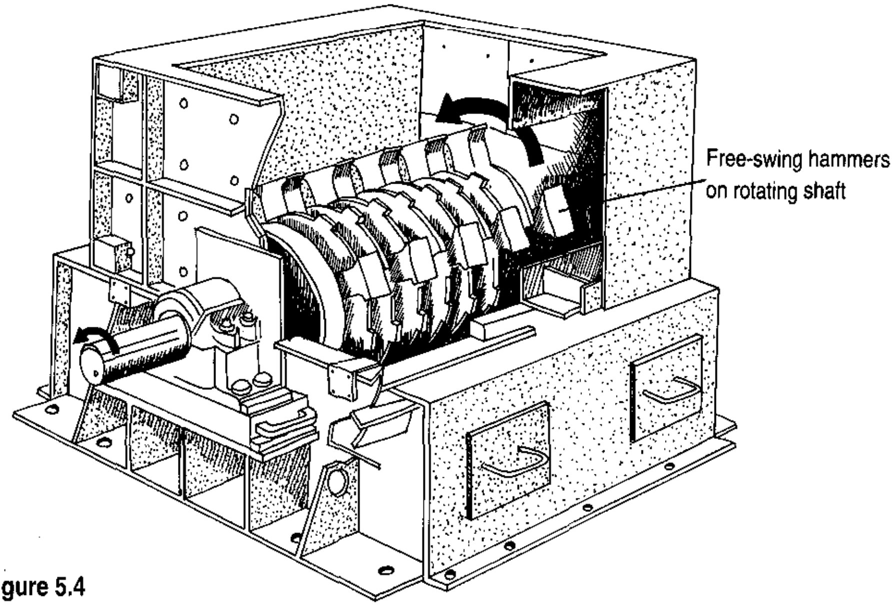


Figure 5.4
Hammer mill.
Adapted with permission from Dresser Industries, Jeffery Division.

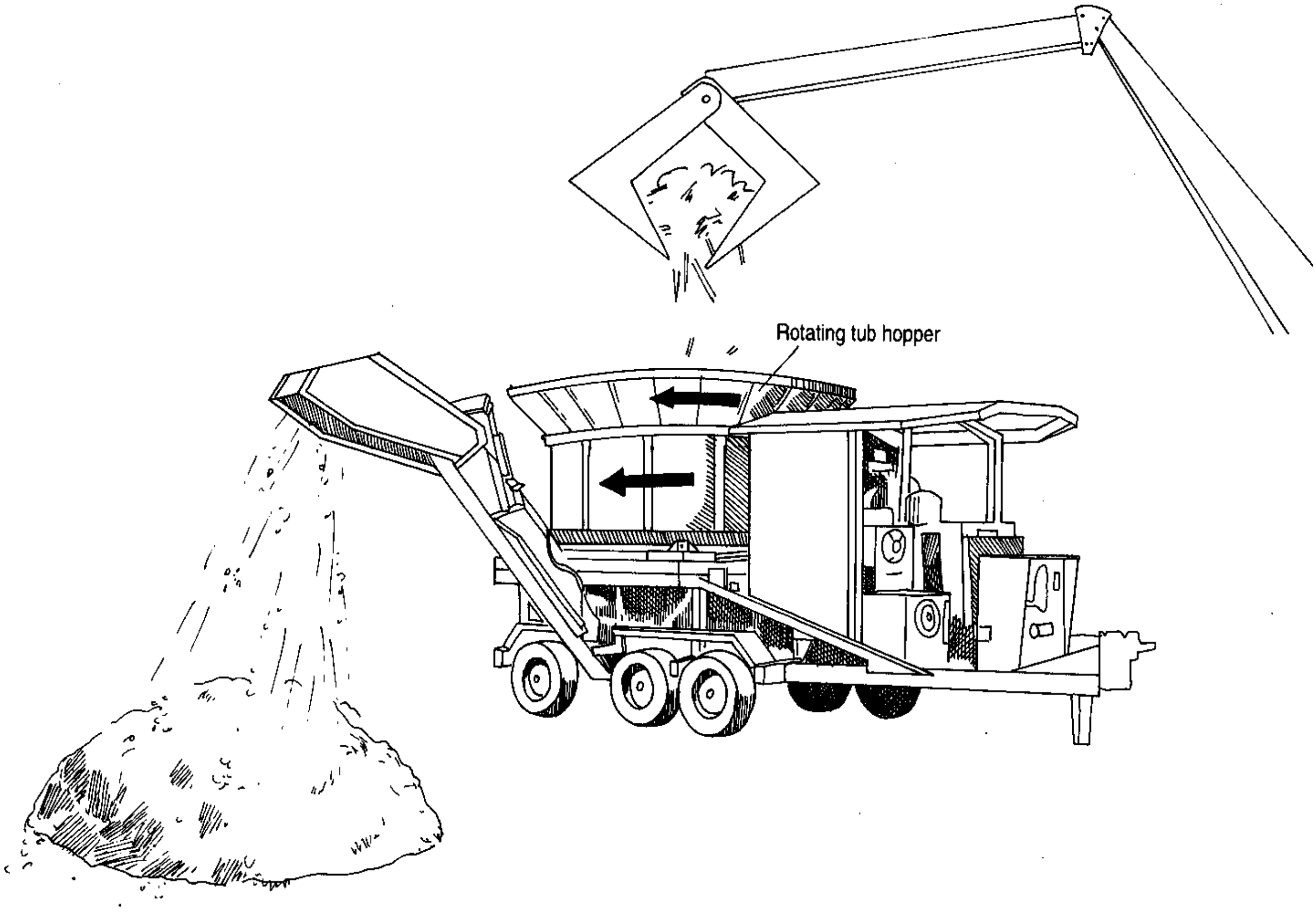


Figure 5.5
Tub grinder.

and takes two to three hours to install. Hammers typically need to be rotated after about fifty hours of operation and replaced after one hundred forty to two hundred forty hours of operation, but they may wear more quickly if the steel surfaces are poor quality or there is a lot of abrasive material in the woody debris.

Chippers and Other Grinders/Shredders

Other shredding, grinding, and chipping mechanisms reduce particle sizes with various combinations of rotating and stationary cutters plus restricted discharge openings. Chippers slice particles with knives mounted on a cylinder or disc that rotates within a fixed housing.

Forage harvesters have been tried for shredding paper and cardboard with limited success. The harvester shreds the paper well but corrugated cardboard tends to jam the chopper. There is a good deal of wear-and-tear on the machinery, and trash from blowing paper can be a problem. Safety is probably the forage harvester's biggest drawback since there are no safety provisions protecting the operator feeding the chopper. For this reason alone, a forage harvester is not a good shredding device.

Mixing and Pile Windrow Formation

The first essential step in the overall composting system is to mix the raw materials in the proper proportions and then form the mixture into a pile or windrow or load it into a vessel. With most *in-vessel* methods, the mixing step is built into the system. The materials need only to be loaded into a silo, hopper, or vessel using conventional materials handling equipment (conveyors, augers, and/or bucket loaders). The composting equipment does the rest. With the windrow and aerated pile methods, mixing and pile formation are distinct steps. For the *aerated static pile* system in particular, initial mixing is crucial. Mixing is performed once, and the quality of that mixing continues through the whole composting process. With the windrow system, the initial mixing must proportion the raw materials and blend them to some degree of consistency. Subsequent turnings mix the materials more thoroughly. Frequent turnings improve compost consistency and diminish the importance of the initial mixing.

Mixing and windrow/pile formation can be accomplished in several ways, depending on the composting method used, available equipment and labor, and the manure-handling practices of the farm (see appendix B, table B.3, pages 132–134, for mixing equipment). Loaders, manure spreaders, and other equipment already on the farm are usually adequate for mixing materials and forming windrows/piles. This is particularly true for windrow composting. However, mixing and windrow/pile formation demand more labor than other composting operations. To reduce the labor involved or improve the performance, it may be advantageous to obtain new equipment or alter existing equipment—for example, upgrade the manure spreader or purchase a larger bucket for the loader.

Bucket Loaders

Bucket loaders are the workhorse of most farms and most composting operations. They can perform almost all composting tasks including mixing and pile/windrow formation. Mixing occurs simply by repeatedly bucketing the ingredients together. Buck walls (figure 5.6) and a concrete *pad* in the mixing area make the task easier. Loaders are capable of producing a good mix, depending on the skill and experience of the operator. For aerated pile composting, the front-end loader must be used carefully to obtain a good mix. The manure tends to form balls several inches in diameter that are difficult to break up.

A bucket loader can also build piles and windrows. Windrows and *passive* piles can be mixed and formed in a single step by depositing the raw materials on the composting site in layers, forming a crude pile. The loader then mixes the materials together and works them into the desired shape until the materials are well-mixed. Aerated piles must be mixed and formed separately because of the underlying porous base and aeration pipe. Using a bucket loader to form piles and windrows allows larger piles and windrows. The pile/windrow dimensions should allow proper aeration or conform to the dimensions required by the windrow turner (see chapter 4).

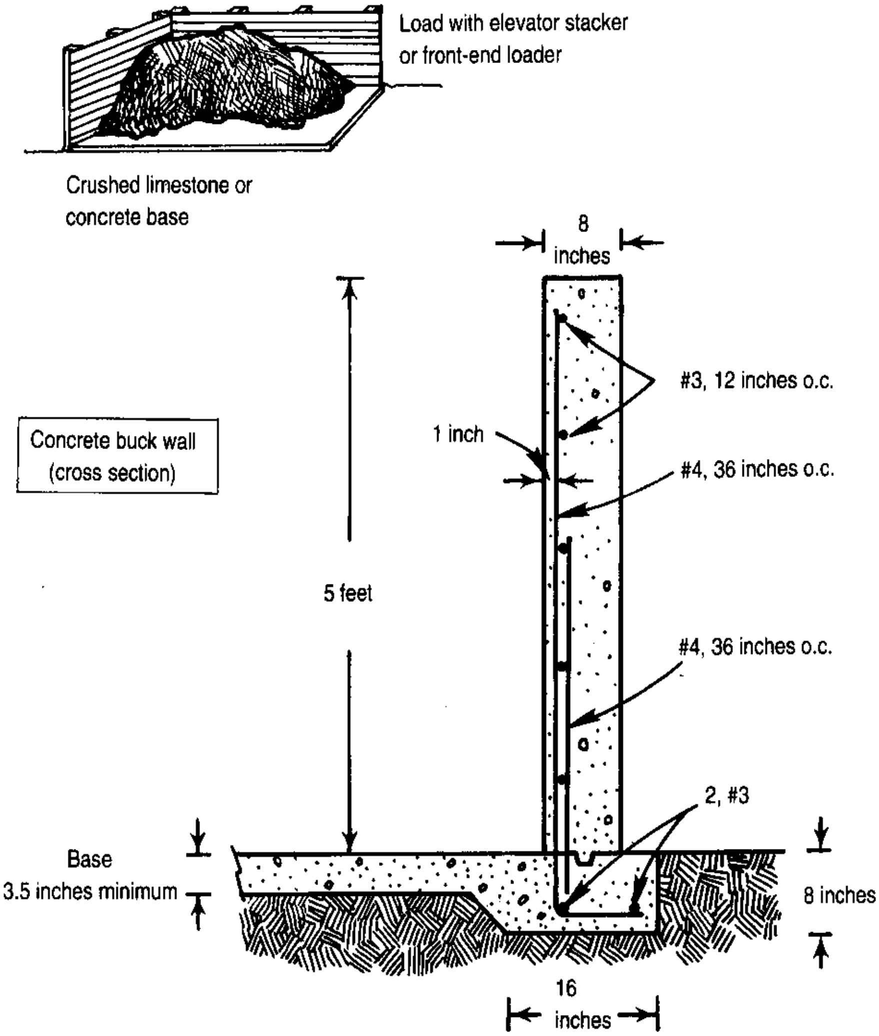


Figure 5.6
Buck wall design for mixing area.
Source: Northeast Dairy Practices Council, "Solid Manure Handling."

When the compost site is remote from the mixing area, dump trucks or wagons can transport the mix to the site and build the initial pile/windrow. The materials are unloaded by backing up to the end of the existing windrow and tilting the bed of the truck or wagon while slowly moving the vehicle forward (figure 5.7). The speed and truck or wagon dimensions determine the windrow/pile heights. If necessary, a loader can reshape or enlarge the pile/windrow formed.

Manure Spreaders

Mixing and forming windrows with a manure spreader is often a good option for farm composting. The mixing action of the spreader partially blends together the manure and amendments. The spreader discharges the load which falls in a rough windrow as the spreader is slowly pulled ahead (figure 5.8).

To improve the initial mixing, the manure and amendments should be loaded in the spreader in alternate loads (for example, two buckets of manure, four buckets of amendment, two buckets of manure, four buckets of amendment, and so on). Locat-

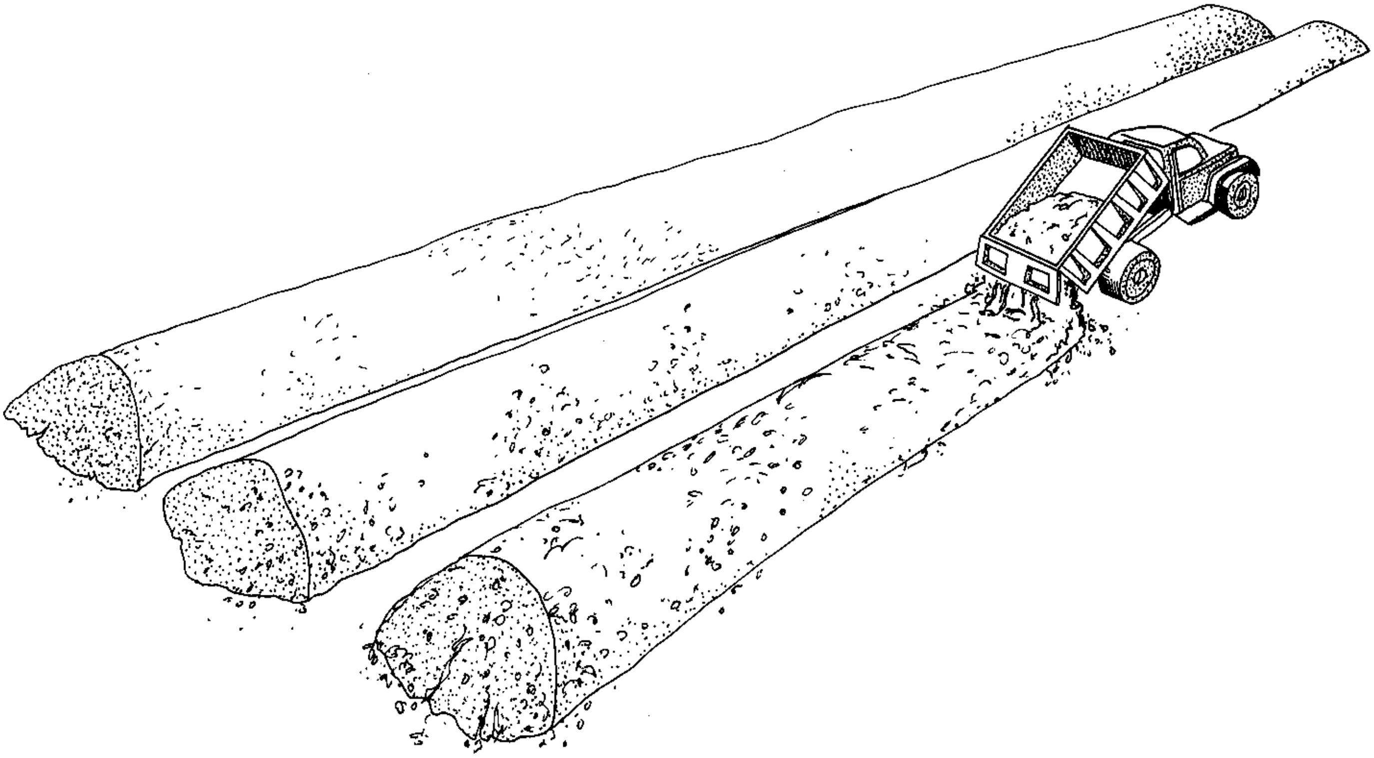


Figure 5.7
Move the dump truck forward slowly to form the windrow.

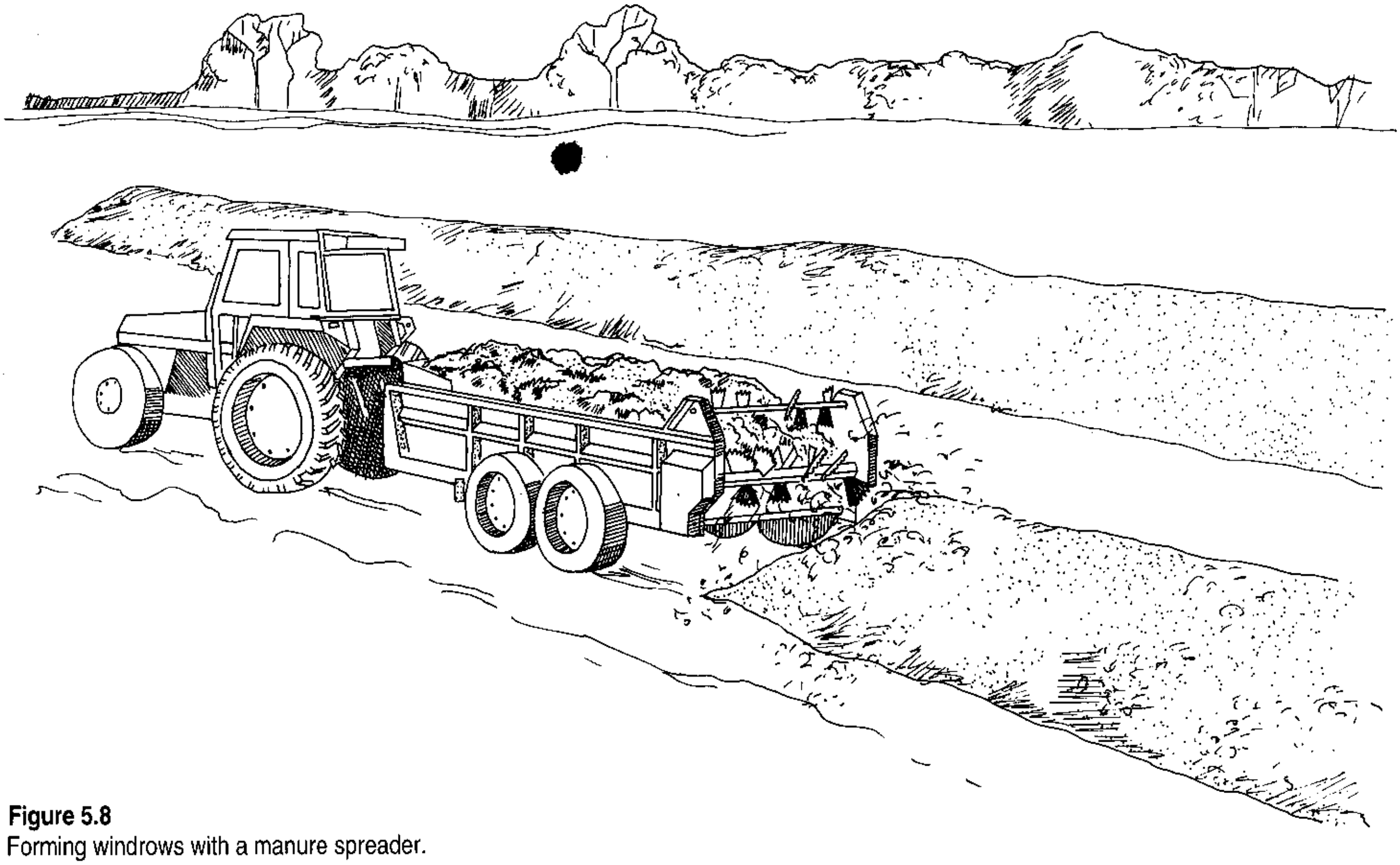


Figure 5.8
Forming windrows with a manure spreader.

ing the amendment storage near the source of manure reduces the labor involved in loading the spreader in this manner. Some materials pose problems for the typical spreader mechanism. For instance, long straw is more difficult to mix than chopped straw, so if equipment is available it is best to chop the straw.

The type of manure spreader available can be a limitation. Side-unloading spreaders cannot unload materials into a windrow form, though they can add manure to an existing windrow. Also, some rear-unloading spreaders are too low to build a windrow large enough for efficient composting. In this case, a loader can rebuild or combine two small windrows formed by the spreader.

Some features aid in windrow/pile formation. Truck-mounted spreaders which elevate the discharge point of the spreader work well for building windrows. Also, larger spreaders and more vigorous mixing mechanisms are advantageous.

Batch Mixers

Batch mixers such as those used to mix livestock feed are among the best mixers demonstrated to date (figure 5.9). Modified feed mixers are now marketed specifically for composting applications. Several types of *batch mixers* have been used and tested for composting including mixers that use augers, rotating paddles, and slats on a continuous chain. These all produce a good mix of materials. Most batch mixers can be truck- or wagon-mounted which eliminates the need for dump trucks, wagons, or manure spreaders to transport materials and form windrows/piles. If a feed mixer is used for the composting operation, it should not be used for mixing feed.

With batch mixers, the amendments are placed in the mixer and then the manure (and/or other dense ingredients) added on top. The mixture can be discharged through the side delivery elevator directly in a windrow, or onto an aerated pile as the mixer is pulled forward parallel to the air distribution pipe. The mixing mechanism should be operated only a few minutes. If it is operated too long (for example, ten minutes), the manure is forced into the void spaces created by the amendment and the *porosity* is destroyed. This is a common failure of this mixing device. As with a manure spreader, long straw is not easily handled by the mixing mechanism and needs to be chopped first or avoided with this mixer.

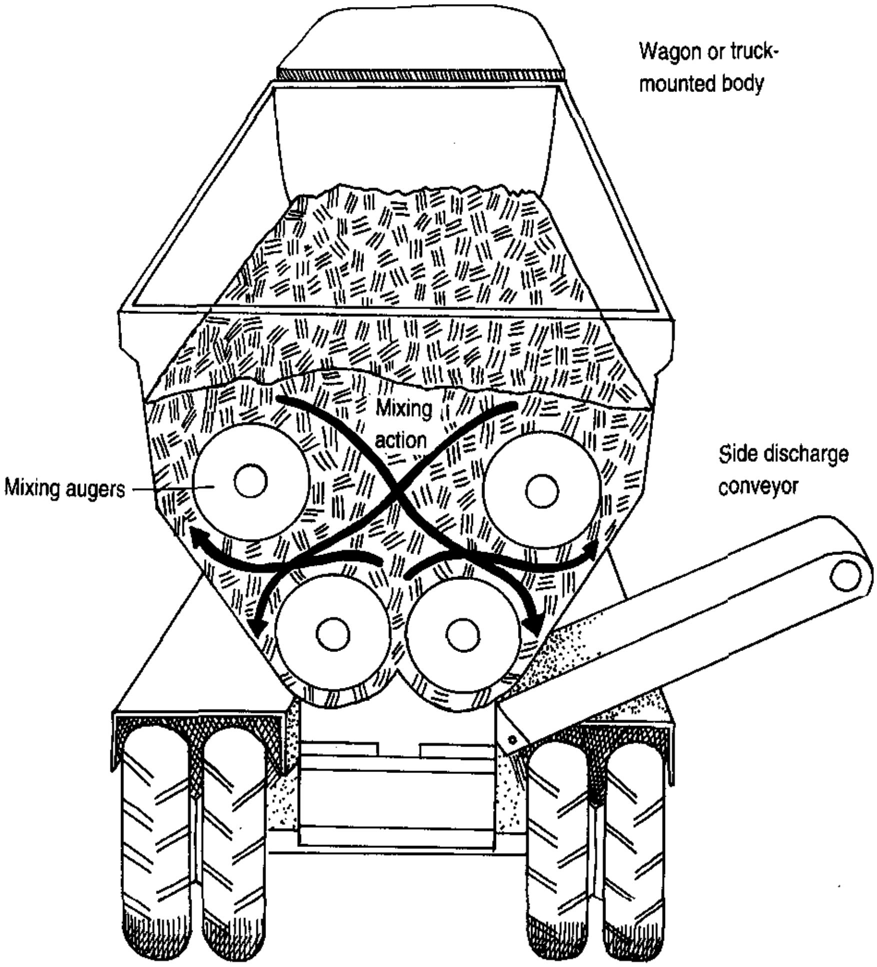


Figure 5.9
Mobile batch mixers can also be used to form windrows.
Adapted with permission from Sludge Systems International, Inc.

Other Mixers

Other machines and techniques to mix and form piles have been used and tested, primarily for sludge composting. Stationary pug mills, which use rotating paddles to mix materials, consistently produce a good mix and are able to work on a continuous basis. These work faster than the batch-operated mixers, primarily because the materials are fed continuously and are not dependent on a bucket loader. However, the ingredients must be made available to the mixer in the proper proportions during its operation. This type of mixer lacks the mobility provided by batch mixers (figure 5.10).

Rotary drum mixers have been used with varying success for mixing *sewage sludge* and wood chips for aerated pile composting. The rolling action of the mixer can form balls from the sludge at low-speed revolutions. At high-speed revolutions the sludge sticks to the drum walls. No information is available regarding its performance with manure or other farm materials.

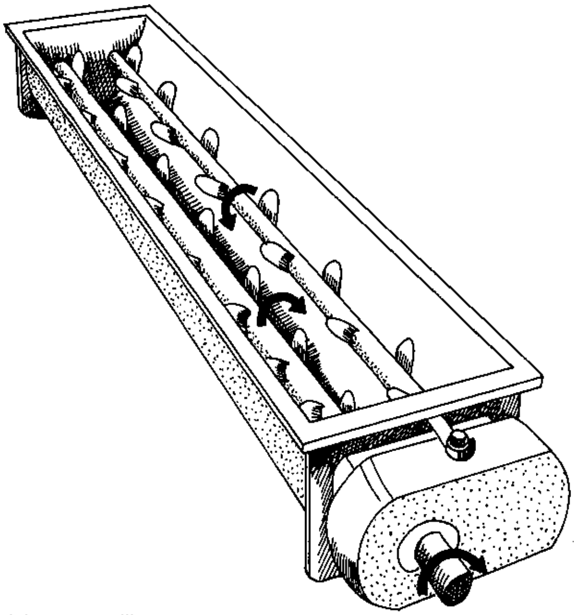


Figure 5.10
Continuous mixing pug mill.
Source: Rapin Machinery Company.

Mixing Liquid Materials

Liquid ingredients pose special handling problems because they need to be incorporated into the composting mix without making it soggy. Also, many liquids present a potential odor problem. Examples of liquid raw materials include manure slurries, fish processing wastes, dairy wastes, and small volumes of wash water. These materials might be the primary waste or a secondary material that the composting system is able to absorb, or they may be added for their nitrogen value. Occasionally, liquid is added to windrows that actually lack adequate moisture. This creates a good opportunity to dispose of certain dilute liquid wastes, like milk room wash water or site runoff collected in *holding ponds.* In any case, the other raw materials must be absorbent enough to hold the added liquid without sacrificing porosity. Usually large amounts of sawdust, *peat* moss, paper, or recycled compost are required.

If the volume of the liquid ingredient is small, it can be added during the initial mixing. However, where the amount of liquid to be composted would make the initial mix overly wet, the liquid must be added regularly to an existing windrow, pile, or vessel as it loses moisture. This can be done with *liquid-manure* handling equipment or a side-unloading manure spreader, or it can be sprayed out of tank trucks or wagons. Turning is necessary soon after the liquid is added to blend it into the windrow. To prevent liquid from running down the side, it may be necessary to create a furrow at the peak of the windrow and deposit liquid in the furrow (figure 5.11).

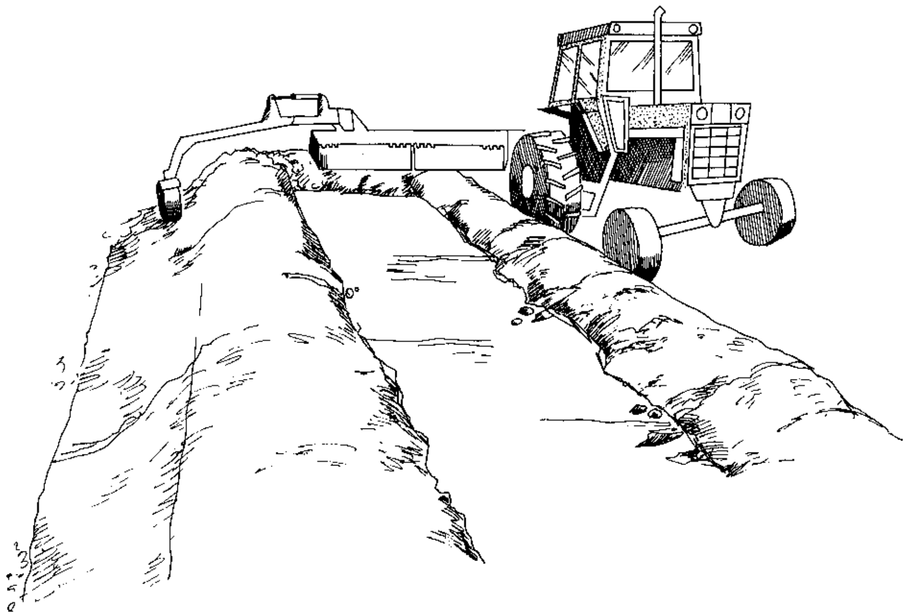


Figure 5.11
Adding liquid ingredients to a furrowed windrow.

When the liquid is odorous, it may be better to contain it within the windrow prior to turning. This has been successfully done with fish wastes by injecting it into the windrow with an apparatus mounted to the side of a tractor. In this case, a chisel plow creates a furrow in front of the hose which sprays in the liquid. A trailing disc then covers up the furrow. After the liquid is absorbed and begins to compost, the windrow is turned.

Curing, Storage, and Compost Handling

Following active composting, compost requires a curing period of at least one month to finish the process and allow the compost to develop the desired characteristics for its intended use. Usually, curing is practiced as a separate step and in a different area from the active composting stage. This frees space on the composting pad for the active windrows and piles which are more intensively managed. However, curing can certainly take place in the same piles and location in which active composting occurred.

Since curing piles are undergoing slow decomposition, *aerobic* conditions still need to be maintained. Anaerobic, or sour, curing piles develop odors and compounds toxic to plants. Although turning and *forced aeration* are unnecessary, curing piles should be small enough to permit adequate natural air exchange. A maximum pile height of 8 feet is often suggested. However, if the compost is intended for high-quality uses, such as potting soil, it is safer to limit curing piles to 6 feet in height and 15–20 feet in width. Since the piles are not turned, they can be placed close together to conserve space (figure 5.12).

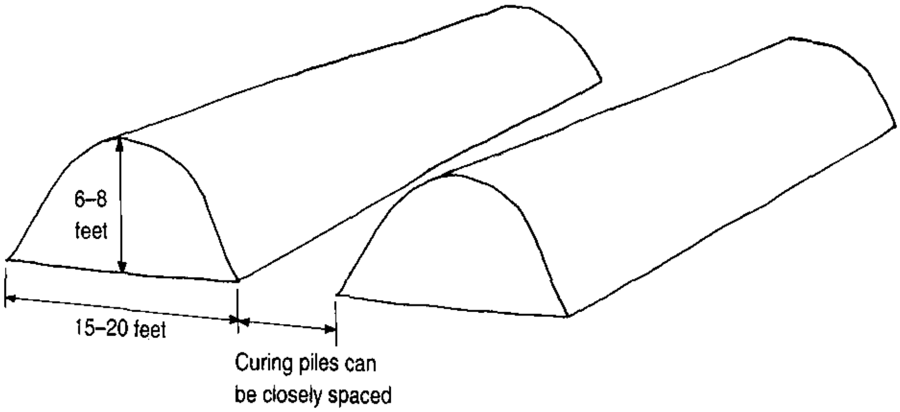


Figure 5.12
Curing pile dimensions.

Anaerobic conditions can also arise from excessive moisture or water that accumulates at the base of the pile. Curing compost does not generate enough heat to evaporate the moisture gained from heavy precipitation or runoff. The curing area should be well drained with surface runoff channeled away from the piles. The length of the piles should run parallel with the slope of the pad surface.

The most effective method of correcting wet or anaerobic conditions in a pile of compost is to remix the pile contents and spread the compost in an open area. This introduces oxygen throughout the mass and allows the anaerobic compounds to decompose aerobically or evaporate. Restacking the compost after one to two days of aeration will most likely cause the pile to reheat and actively compost for a short period. The pH will require several days to a week to adjust to its normal value.

The use and sale of compost are usually seasonal, with peak periods in the spring and fall. This creates the need for three to six months of storage for compost produced continuously.

Finished compost that has been properly composted and cured has a low but still ongoing rate of microbial activity. Although storage piles can be larger than curing piles, anaerobic conditions remain a threat. The pile height and width are generally determined by the reach of bucket loaders, conveyors, or other equipment. However, the height of the storage piles should not exceed 12 feet. As the pile size increases, the risks of *sour compost* and *spontaneous combustion* increase (see chapter 6). Piles greater than 8 feet high gain little moisture from precipitation, but poor drainage conditions can soak the bottom portion of storage piles.

If wet or anaerobic conditions develop in storage piles, the corrective measures recommended for curing piles should be followed. In general, it is a safe practice to restack the compost from large storage piles into smaller piles a few weeks prior to use or sale. This allows the stored compost to aerate naturally and dissipate *phytotoxic* compounds that may be present.

If the compost produced is to be applied to cropland, the curing and/or storage piles can be located near the appropriate fields, similar to a manure stack. Again, poorly drained sites and steep slopes should be avoided to minimize anaerobic conditions and the loss of compost and nutrients from surface runoff.

Screening

Screening separates materials of different sizes and/or shapes. In a composting system, screening serves one or more of the following purposes: removes a large number of unwanted objects from the raw materials including rocks, metal, bottles, and other trash; separates the portion of a raw material to be composted from the portion not to be composted; improves the quality of the compost for sale or use by removing unwanted objects, clumps of compost, and material that is not fully composted; and recovers *bulking agent* from the compost for reuse. When screening is used in farm composting systems, it is nearly always performed after composting either to improve compost quality or recover bulking agents. The primary exception is screening of manure to recover the solids for composting. (Screens used for this purpose are not considered here but are discussed by several references, particularly Moore).

When choosing screens, the important characteristics to consider are the screen opening size, capacity, effectiveness, cost, and susceptibility to blinding. Blinding refers to the condition when the screen openings become blocked with material. Most screens include some provision to reduce blinding, like brushes, vibration, or bouncing balls. For screening compost, the screen openings should be 1/4 to 1/2 inch, depending upon the material to be separated out and the end use for the compost. Smaller openings provide better separation but, for a given screen, reduce the capacity of the screen and increase the chances of blinding. Screen effectiveness relates to the success of separating the particles into the desired fractions. The effectiveness decreases when particles larger than desired pass through the screen or when particles of the desired size are retained by the screen. If the compost is to be sold, the priority should be placed on keeping the large particles from passing through the screen. Both effectiveness and capacity are influenced by the material feed rate as well as the screen opening size.

Screens perform better with dryer material. Usually, it is preferable to screen material after curing or drying. To screen compost without excessive blinding and lumping of material, the moisture content should generally be less than 50% and preferably less than 45%. In practice, the maximum moisture content depends on the specific screen used.

Some screen models have built-in shredding and mixing mechanisms, or these can be added as an option. Such shredders include abrasive belts or hammers which break up clumps of material prior to screening. The mixers can add fertilizer or blend together sand and compost to produce a topsoil.

Many different types of screens are available. Screens commonly used to separate compost and other soil-like materials are described below and listed in appendix B (table B.4, pages 135–139). Again, the costs and capacities listed in appendix B should be considered rough estimates. The actual capacities greatly depend on the materials and their moisture content.

Trommel Screens

A trommel screen is a rotating drum with holes (figure 5.13). It often includes a feed hopper and loading conveyor. The drum is inclined or contains internal flights to move the materials through as it rotates. The large particles are retained within the drum while the fine particles fall through the holes onto a conveyor. A trommel screen has a segment of its surface exposed at the top of its revolution. A rotary brush can be applied to the outside surface to clear the screen openings and overcome blinding.

Shaker Screens

Shaker screens create a reciprocating motion which bounces the material along the screen length. The motion helps to segregate the large and small particles, reduces blinding, and helps move the oversized particles off the screen. These screens are incorporated into a single unit consisting of a feed hopper, conveyor, and screen. The screens are wire mesh, perforated panels, or "piano wire" screens. Often several decks of screens are stacked to separate materials into several size ranges. The screens may include cleaning balls that dislodge material blinding the screen openings.

Vibrating Screens

Vibrating screens also use an oscillating motion to enhance separation. The vibration is much faster than the motion of a shaker screen. The vibration plus the slope of the screen move the oversized particles. These screens are used to separate fine materials, both wet and dry, in industrial processes; but some models have been adapted specifically for compost use. They also use wire mesh screens, multiple decks of screens, and cleaning balls or rings.

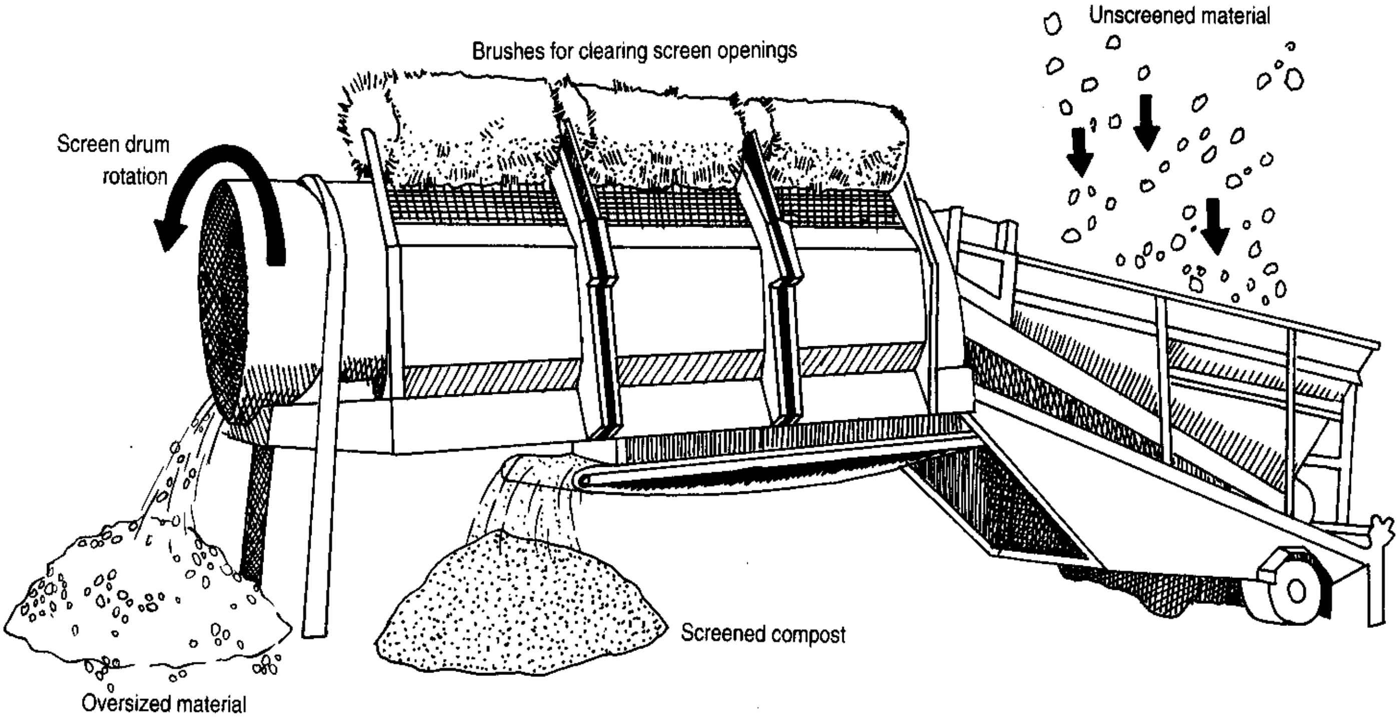


Figure 5.13
Trommel screen.

Flexing Belt Screens

One type of flexible-belt screen uses a slotted belt of a durable material. Sections of the belt are alternately flexed and snapped taut, throwing the material up and clearing the slots. Another flexible-belt screen uses a perforated belt which moves in a wave-like pattern. This motion bounces the material up and down as it travels along the screen.

Disc Screens (Scalping Discs)

This device uses banks of overlapping, scallop-edged rotating discs to move coarse items from one end of the screen to the other. Smaller pieces fall between the discs as they rotate. Scalping discs are designed to remove large items and may serve as the first stage in a screening system that includes several other screens and shredders.

Auger and Trough Screens

This screen consists of a perforated trough containing an auger that moves the materials from one end to the other. The fine material drops through the holes, and coarse materials pass on to the end. Multiple-auger screens can be combined to achieve multiple separation of sizes. This type of equipment is designed to remove soil and fine materials from wood chips.

Rotary Screens (Spinning Disc)

This type of screen has plates or discs with holes of selected size onto which a material is fed. Its spinning action throws oversize material to the outside. Rotary screens are often used in sawmills to separate sawdust from larger materials.

Drying

Drying obviously lowers the moisture content of the compost. If necessary at all, drying is most important where compost is used for bedding or potting soil or packaged in bags. A reasonable goal is to produce compost with a moisture content between 35% and 45%. Below 45%, compost handling and screening improve. Moisture contents above 35% minimize dust.

In composting systems, drying typically involves extra aeration or an extended composting period. If drying is necessary, windrows can be turned at least daily in the later stages of composting. Mature compost does not generate enough heat to drive off added rainwater. At this point, drying depends on solar evaporation. An alternative method during warm, dry weather is to spread the compost in a thin layer on the ground to dry naturally. Working the layer of compost with a rake or spring tooth harrow speeds the drying. The compost should be re-piled if rain is expected. Large, conical piles shed water and minimize the moisture absorbed from rain.

If the compost produced is consistently wetter than desired, drying may only be compensating for other problems in the system. Wet compost can result from a mix with a high initial moisture content; a lack of energy in the raw materials; infrequent turning/aeration; drainage problems at the composting site; or cold, wet weather.

Bagging

Bagged compost brings a higher price than compost sold in bulk and is practiced when the sales volume justifies the equipment and effort (see chapter 9). Bagging may also be justified as a way to expand the market clientele. For a small volume of bagged sales, special equipment is not necessary. Hand bagging with a shovel, though laborious, works well. Bag holders, bag ties or sealers, and simple hoppers with a hand or foot valve make the work faster and easier. Much of this equipment can be fabricated on the farm or salvaged from existing obsolete equipment.

For high-volume operations, bagging equipment includes hoppers with metered valves, scales, bag sealers, and one or more conveyors. Since many buyers require bags to be palletized and wrapped, a pallet wrapper may be necessary. The cost of a complete automated bagging line could easily exceed $50,000. This does not include labor and the cost to warehouse the product. As an alternative, the bagging operation could be contracted to an independent vendor.

Compost that is packaged in plastic bags should have a moisture content of 35% or less. Otherwise, the compost may become sour as it continues to decompose in the airtight bags.

6

Management

The manner in which a *composting* system is managed can make or break the operation. With a given composting system, proper management produces the desired quality of *compost* in the shortest possible time with a minimum of odors, environmental impacts, and other process-related problems. Good management also makes best use of the materials, equipment, and labor available. For *manure*-composting systems, this requires some integration between manure-handling and composting practices. On the other hand, poor management can lead to compost with poor or even detrimental qualities, odor problems, neighborhood complaints, and eventual shutdown by regulatory agencies.

In many situations, a key management task is public relations. In fact, this task should begin before the composting operation is established. Neighbors and local officials need to be informed, consulted, and educated about intended practices and changes at the site. Operations may need to be modified to accommodate specific local situations. In general, stay on good terms with neighbors, public officials, and the news media. They can become either your allies or your opponents.

Safety and Health

Proper attention to health and safety can prevent most occupational risks at compost facilities. While composting is not an inherently dangerous activity, precautions are necessary to protect against injury.

Safety concerns in composting relate primarily to equipment. If grinders, front-end loaders, or other standard farm equipment is used, eye and ear protection and normal safety precautions apply. Additional precautions must be followed when specialized *windrow-turning* equipment is used. Several turners contain mixing flails which rotate at a high rate of speed and should, therefore, be well-shielded from human or animal contact. As the flails rotate through the compost windrow, they will eject foreign matter which is in the windrow. Stones can become dangerous projectiles when thrown behind the turning equipment. Equipment operators and workers at the site must maintain a safe clearance both around and behind operating machinery.

Fires are rarely a problem in outdoor composting operations, as properly moist composting material does not readily burn. However, if the material does dry out and if windrows/piles are too large, *spontaneous combustion* becomes a possibility, just as it can with hay or silage. This phenomenon occurs at *moisture contents* approximately between 25% and 45%. In piles over 12 feet high, it is possible for the internal heat of the compost pile to initiate chemical reactions, which then lead to spontaneous combustion. Proper attention to moisture, temperature, and pile size is the best protection against this problem. An accessible water supply is a valuable safety precaution.

While many compost operations have run smoothly for years without unusual health or safety problems, workers should be aware of some unique concerns in composting. By understanding these concerns, it should be easier to recognize them early and seek an appropriate remedy before serious problems develop.

Human health concerns relating to compost depend both on the individual and on the material being composted. While few *pathogenic* organisms found in farm animal manures or vegetative wastes affect humans, normal sanitary measures are important (washing hands before touching food, eyes, and so on). These measures become more critical if human wastes are being handled. *Sewage sludge* or *septage* can contain disease-causing organisms. Pretreatment of these wastes through *aerobic* or *anaerobic* digestion, extended air drying, or lime stabilization will destroy most pathogens. Such treatments have been developed to reduce the level of pathogens in sludge to levels below an infectious dose. Nonetheless, anyone in regular contact with sludge or septage is at greater risk of contracting infections and should exercise caution.

Just as individuals vary in their resistance to disease, a few individuals may be particularly sensitive to some of the organisms in compost. The high populations of many different species of molds and *fungi* in an active compost process can cause allergic reactions in sensitive individuals, even though most people have no problems at all. Simple precautions, such as dust masks or even half-mask respirators with disposable cartridges, can help limit human exposure to this microbiological zoo. Conditions which may predispose individuals to an infection or allergic response include a weakened immune system, allergies, asthma, some medications such as antibiotics or adrenal cortical hormones, or a punctured eardrum. Workers with these conditions should not normally be assigned to a composting operation. If workers do develop an infection or have an allergic reaction to compost, it is important to recognize the problem promptly so that it does not develop into a chronic condition.

A specific concern which has been documented at composting facilities is caused by the fungus *Aspergillus fumigatus*. This fungus is naturally present in decaying *organic matter* and will colonize any waste material handled at a compost facility. *Aspergillus fumigatus* is probably present in considerable numbers on most farms, especially where moldy hay exists. Spores from this organism can cause problems for some compost workers, particularly if the compost drys out and dusts are inhaled. Approximately 5–10% of the population is sensitive to this fungus. A blood test identifies antigens in sensitive individuals. To minimize the risk of infection, disposable respirators (such as dust masks which filter particles down to 1 micron in size) should be worn, particularly under dry and dusty conditions.

Aspergillus fumigatus is also an opportunistic organism. Therefore, it can affect individuals with pre-existing health problems. Individuals with weakened immune systems or people taking medication which suppresses the immune system are most vulnerable. This point should be considered when staffing and locating the composting facility.

Season and Weather Management

Composting can continue year-round, even in cold climates. Seasonal and weather variations often call for operational adjustments that compensate for or take advantage of the changing conditions. This is primarily a concern with windrow composting. *Aerated static pile* and *in-vessel* methods are much less affected.

Cold weather can slow the composting process by increasing the heat loss from piles and windrows. The lower temperatures reduce the microbial activity at least near the surface of the pile/windrow. This, in turn, decreases the amount of heat generated. In extreme cases, the entire windrow could freeze, halting composting temporarily. For winter operation, windrows and piles should be combined or enlarged to retain more heat. To prevent freezing, windrows should be large enough to generate more heat than they lose to the environment—at least 3.5 feet high. Older windrows/piles generate less heat and, therefore, should be 5 feet high if composting is to continue through cold weather.

Warm weather enhances water loss by evaporation from the windrow/pile surface. In the case of windrow composting, increasing the number of turnings evaporates more moisture. This can be an advantage in achieving a drier compost. Water should be added if windrows/piles become too dry.

Precipitation is occasionally a problem to composting. Again, windrow composting is affected more than the other methods. Windrows usually absorb water from normal rainfall or snow without saturating the materials. If the windrows do become wetter than desired, more turnings are required to evaporate the added moisture. The biggest problems with precipitation are site conditions. Rain can produce muddy conditions and soft soil, making it difficult to operate equipment. Snow melts from windrow/pile surfaces but needs to be plowed from the path of equipment. Puddles and standing water can lead to anaerobic conditions at the base of a windrow/pile or nuisances from insects and odors. Good drainage at the site is important.

In addition to weather, seasonal changes can also influence the availability of raw materials and the use of compost. Leaves are a good example. Available primarily in the fall, they must be composted in large quantity at that time or stored in a safe manner and used gradually. Some crop residues and processing wastes have similar seasonal characteristics. Compost also has a seasonal use and usually requires storage.

Process Monitoring and Troubleshooting

Basically only two tools are essential to monitor the composting process—a temperature sensor and your nose. Temperature and odor are the most important indicators of how well composting is progressing.

Although some odor may continually be present at the site normally (depending on raw materials), strong putrid odors are a sign that something is wrong—that anaerobic conditions exist. A windrow/pile may require turning/*aeration;* or a problem which is inhibiting aeration may exist, such as a poor mix of raw materials. Odors could also come from mishandling of raw materials. In any case, operators should always be alert to odors and then quickly identify their source and correct the situation.

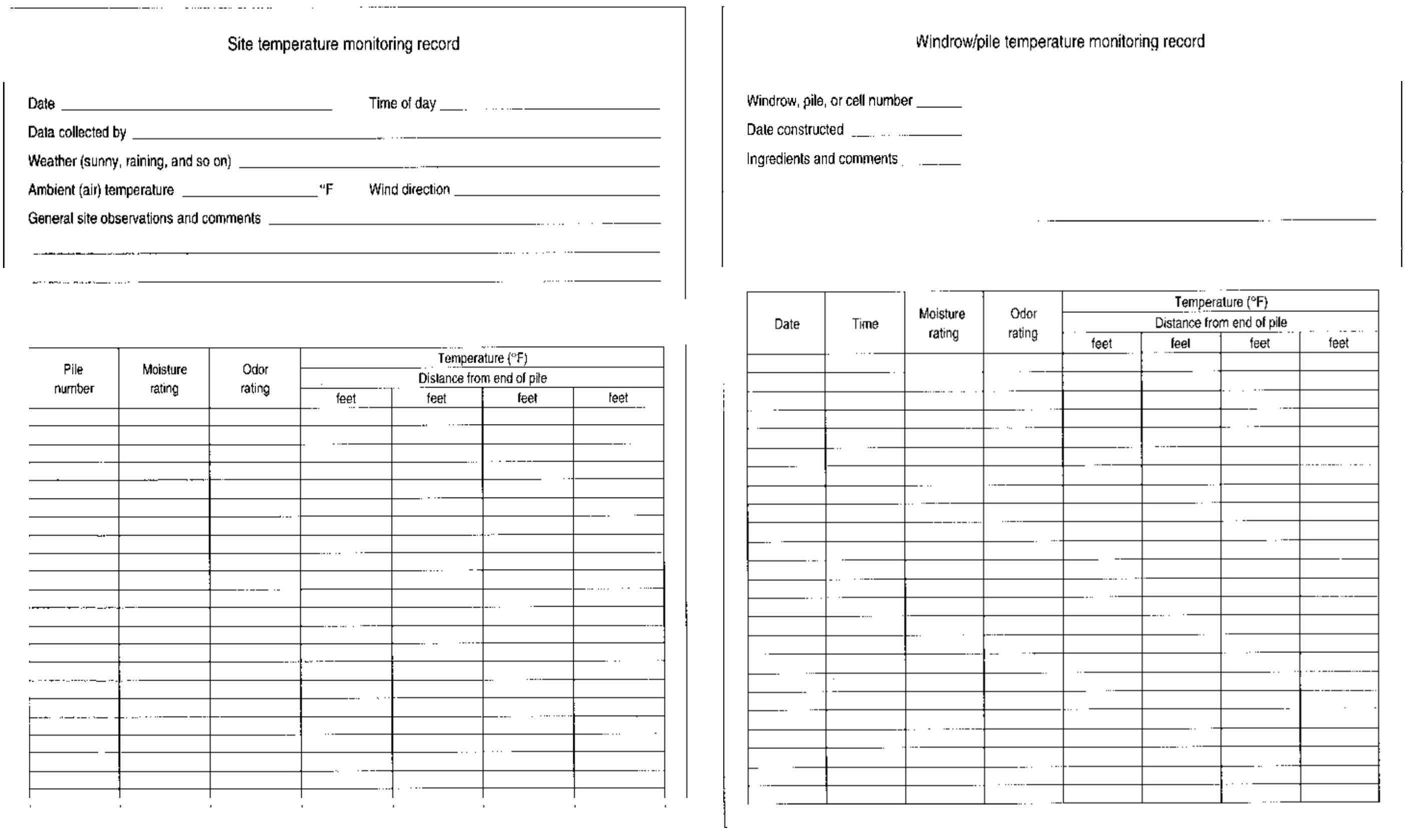
Because the heat produced during composting is directly related to the microbial activity, temperature is the primary gauge for the composting process. Abnormally low temperatures are a signal of reduced aerobic microbial activity. This could mean the process is lacking oxygen or is slowed because of low moisture or freezing conditions. In most cases, a lack of oxygen is the cause. Therefore, low temperatures usually call for aeration or turning. High temperatures (surpassing 140°F) also call for turning or aeration to cool the pile.

If the windrow/pile temperature does not recover after turning or aeration, either the process is nearing completion or a problem exists (see appendix C, table C.1, troubleshooting and management guide, pages 147–150). You should suspect a problem if this occurs before the normal composting time period is reached or if odors are detected. Low temperatures accompanied by odors point to a lack of oxygen, which can mean that the materials are too wet or poorly mixed. It is not unusual to find low temperatures in some sections of the pile while other sections are well-heated. Uneven mixing and short circuiting of air are common causes of this, but it can also occur if the differing sections have been composting for different lengths of time. Low temperatures can also reflect a need for moisture.

The temperature should be monitored and recorded daily at least until the operator acquires a strong feel for the process. Sample forms for recording temperatures are shown in figure 6.1 and are included in the appendix D (pages 152–153). The daily temperature measurements show trends in the temperature as the windrow/pile ages and suggest how often turning/aeration is required. A normal pattern should emerge after several batches of materials have been successfully composted. Deviations from the normal temperature pattern indicate changes have occurred which might need correcting, like poorly mixed materials.

A dial thermometer with a 3-foot stem is recommended for monitoring temperatures. The thermometer should have a temperature range of approximately 0–200°F. A pointed stem tip helps push the thermometer through dense clumps of material and lowers the chance of breaking the stem (figure 6.2). A list of thermometer suppliers is included in appendix B (page 146).

Oxygen-sensing equipment is occasionally used to monitor and troubleshoot composting operations. Oxygen measurements directly indicate the oxygen level within the composting materials and, therefore, provide a clue to the state of the composting process. A 5% oxygen con-



Site temperature monitoring record

Date ________________ Time of day ________________

Data collected by ________________

Weather (sunny, raining, and so on) ________________

Ambient (air) temperature ________ °F Wind direction ________________

General site observations and comments ________________

Pile number	Moisture rating	Odor rating	Temperature (°F) Distance from end of pile			
			feet	feet	feet	feet

Recorded by date

Windrow/pile temperature monitoring record

Windrow, pile, or cell number ______

Date constructed ______

Ingredients and comments ______

Date	Time	Moisture rating	Odor rating	Temperature (°F) Distance from end of pile			
				feet	feet	feet	feet

Recorded by windrow, pile, or cell

Figure 6.1
Two different approaches and record forms for monitoring temperature at a composting site (examples).
Note: Full-page copies are reproduced in appendix D, pages 152–153.

centration is generally considered the minimum for sustained aerobic composting. Although this is a useful guide, lower oxygen concentrations are sometimes measured during vigorous aerobic activity, and higher concentrations have been measured when conditions were clearly anaerobic. Oxygen-sensing instruments are more expensive and complex than temperature-measuring devices (figure 6.3). In almost all situations, temperature provides an adequate indication of the process conditions, and oxygen monitoring is not necessary. Oxygen-monitoring may be most useful in experimental situations.

Odor Control

Odor problems are the single biggest threat to a composting operation. Nothing is more persistent than an angry neighbor seeking to shut down the farm or composting operation because of odors. The best defense against odor complaints is a large distance between neighbors and the composting site. Since this is not always possible, odor control, or at least a sensitivity to odors, is necessary.

In theory, aerobic composting does not generate odorous compounds, as anaerobic processes do. However, objectionable odors can come from certain raw materials or the process itself if conditions are not right. There are three primary sources of odors at a composting facility: odorous raw materials, *ammonia* lost from high-nitrogen materials, and anaerobic conditions within windrows and piles.

Anaerobic conditions can be minimized by proper management at site. Use a good mix of raw materials, avoid overly wet mixes, monitor temperatures, and turn or aerate the materials regularly. Occasionally, equipment problems or unusually wet weather creates problems. In these instances, the odor correction measures discussed below can be followed. Pungent ammonia odors can be controlled by providing extra carbon in the mix and maintaining the *pH* below 8.5 (see following section).

The most common causes of odors at a

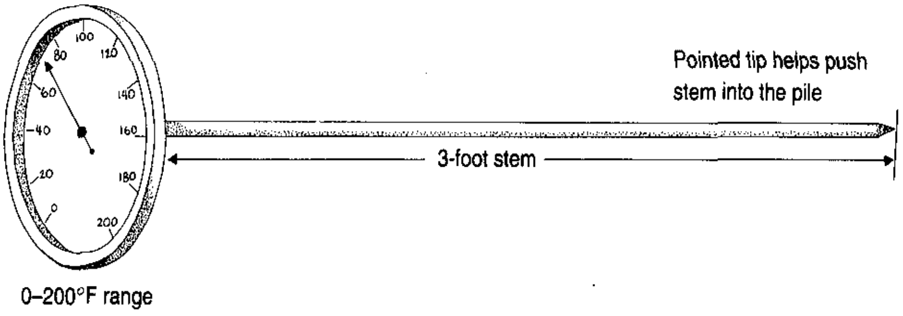


Figure 6.2
Dial thermometer for monitoring windrow/pile temperatures.

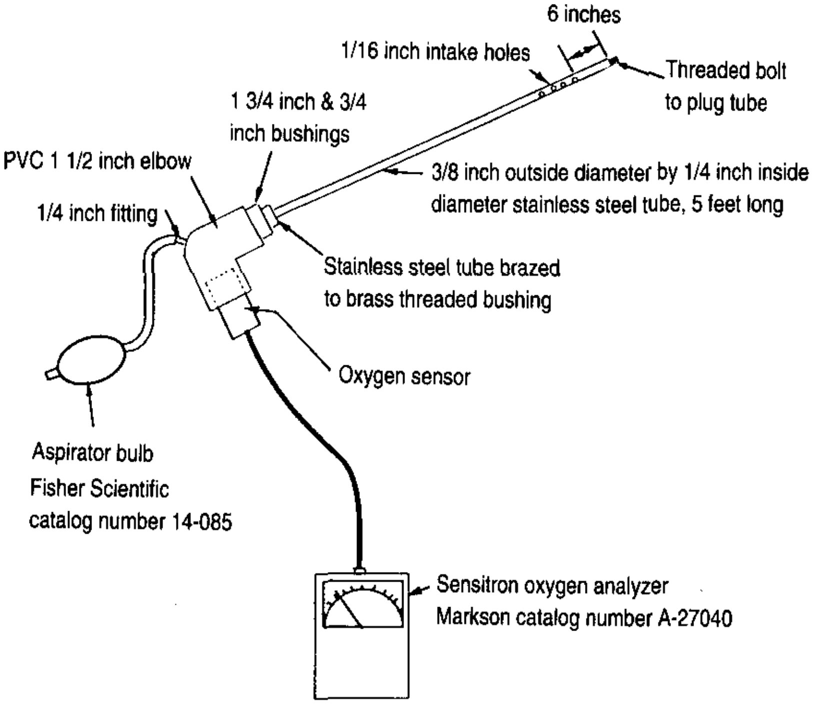


Figure 6.3
Oxygen-analyzing equipment.
Source: Richard, Dickson, and Rowland, *Yard Waste Management.*

composting site are strong-smelling raw materials. The odors come to the site with the materials and do not dissipate until the materials begin composting. This problem does not occur with many farm composting materials unless they have been stored for several weeks. Materials like sawdust, leaves, crop residues, and fresh-bedded manure present little or no odor problems. Sewage sludge, *liquid manure,* and fish wastes typically do.

The key to minimizing odors is to start the materials composting as soon as possible and then to keep them aerobic. This sometimes requires special provisions such as an extra porous mix, an odor absorbing cover material, and/or a separate windrow/pile with extra aeration. These provisions should be maintained until the process is well underway and the characteristic odor is eliminated. The *porosity* of the mix is particularly important for windrow composting since windrows aerate by passive air exchange. Materials with strong odors should be combined with *amendments* to obtain an especially porous mixture. After the odor decreases, this mix can be added to other materials at a more typical porosity.

To a limited extent, odors can also be controlled by the choice of raw materials. For example, a layer of finished compost or *peat* moss on the surface of an aerated pile traps odors. Also, mixes with a large proportion of sawdust, compost or peat moss tend to absorb odors coming from other ingredients.

Several odor-absorbing or odor-masking chemicals have been used to control composting odors. Generally these have met with limited success and are relatively expensive because large amounts of chemicals are required. Large amounts of lime are often used to raise the pH above 10, which limits odors by reducing the microbial activity. This is frequently done with sewage sludge. However, the effect is only temporary; and lime can aggravate the situation because the high pH causes greater ammonia loss and odor.

During windrow composting, odors tend to be contained within the windrow. When the windrow is turned, the odors are briefly released. Unfortunately, there is a temptation to reduce the turning frequency when the mix contains strong-smelling materials. Do not try to hold in odors by reducing the turning schedule! This will only compound the problem later. When the windrow is finally turned, the odors released will be even stronger and more persistent. It is better to turn more frequently early in the process and accept a minimum odor. If the odor is still too bothersome, then the *recipe* should be changed, the odorous raw materials should be avoided altogether, or another composting method should be used.

Odor control can be easier for composting facilities that use *forced aeration.* The exhaust air leaving the pile or vessel can be directed into an odor-absorbing filter. For aerated static pile composting, a pile of finished compost often serves as the filter. Since compost has an affinity for many odorous compounds, the filter pile removes odors from the air. Peat moss can also be used. The odor-filter piles must be changed regularly before they become wet, lose porosity, and generate odor themselves. Other odor-filtering systems pass the air into a system of drain pipes laid beneath the soil or into plywood filter boxes containing peat or compost (figure 6.4).

If the facility is enclosed within a building, there are two odor control options. The ventilation system for the building can collect the air and direct it to an odor treatment system. Alternatively, the ventilation system can dilute the odors by moving a large volume of fresh outside air through the building.

Concern for odors should extend to the scheduling of composting activities. Activities which tend to release odors include windrow turning, mixing, and movement of odorous raw materials. As much as possible, these activities should be scheduled to minimize the impact of the odors. For example, avoid turning windrows on hot still days or on holidays and weekends

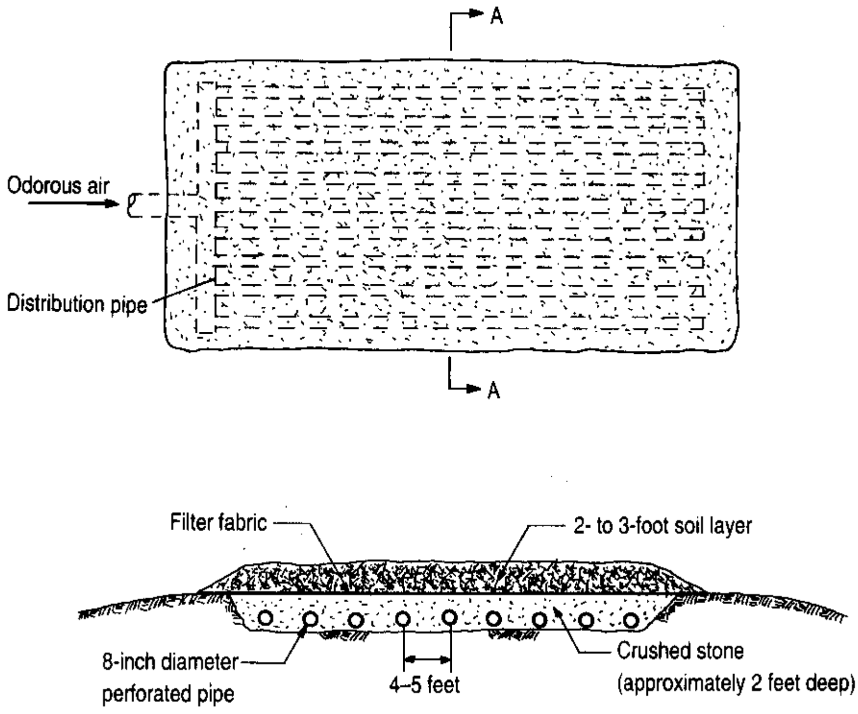


Figure 6.4
Odor treatment using a soil filter.

Adapted with permission from International Process Systems, Inc.

when neighbors are more likely to be affected. Windy conditions and early morning hours are generally better. Monitor the wind direction. Postpone activities that release odors when the wind is blowing toward the most sensitive neighbors. The same practices used to minimize odor complaints from other farming activities apply to composting as well.

Finally, control odors with proper housekeeping and management practices. Raw materials should be stored for as short a time as possible. Storage piles should be contained and kept dry. On the site, prevent puddles and standing water, which serve as pools of anaerobic activity. Dispose of runoff from the site using a grassed *infiltration* strip or other appropriate technique. Minimize dust, which carries odors. Practice good composting by ensuring adequate aeration, pH, and temperature control.

In general, odor-treatment measures should be used as a last resort. They tend to be expensive and only partially effective. Odor avoidance, via appropriate raw material selection and proper management, is the best approach and should be adequate for most farm composting situations.

Nitrogen Conservation

A fairly large loss of nitrogen occurs as raw materials are converted to compost. It is desirable to retain as much nitrogen as possible in the composting materials. A high nitrogen content adds value to the compost. A second reason to conserve nitrogen is to minimize the pungent odor of ammonia.

Almost all of the nitrogen lost during composting results from the release of ammonia, formed from organic nitrogen compounds. Additional nitrogen may be lost by *denitrification,* which produces nitrogen gas (N_2) under anaerobic conditions. Although nitrogen losses from denitrification are minor, it provides another reason to minimize anaerobic conditions.

Microorganisms break down organic sources of nitrogen into simple compounds to obtain nitrogen for new cell material. Some of the nitrogen is converted to ammonia (NH_3). If the nitrogen becomes available faster than it is used, ammonia accumulates. Eventually it escapes the windrow/pile because it is a gas, which is lighter than air.

The best way to retain ammonia is to match the rate of nitrogen availability to its rate of uptake by the microorganisms. The microorganisms use the nitrogen in proportion to the amount of carbon available. Therefore, high *C:N ratios* tend to limit ammonia loss.

High pH levels increase the loss of ammonia, especially with nitrogen-rich raw materials like poultry manure. Two forms of ammonia are in the composting materials—gaseous ammonia (NH_3) and the *ammonium* ion (NH_4^+), which stays dissolved within the compost pile. Both forms are present and can be converted from one to the other. Their proportions are determined by conditions in the pile. A higher pH (fewer H ions) favors the gaseous ammonia form which can escape from the pile. To avoid excessive ammonia loss, the initial pH of the mix should be as close to neutral as possible and no greater than 8.5.

Turning, forced aeration, and agitation accelerate the escape of ammonia from windrows/piles. Since proper aeration is critical, turning or aeration should not be reduced at the expense of the composting process just to conserve nitrogen. Only unnecessary disturbance of the materials should be eliminated if nitrogen conservation is important.

An outer layer of compost or peat moss, used with static and *passive* piles, helps to reduce ammonia loss. The particles in the layer retain ammonia as it passes out of the pile. Then the ammonia is converted to less mobile forms of nitrogen in the cooler and more stabile environment of the outer layer.

The addition of superphosphate to dairy manure has been found to conserve nitrogen during composting. Recommendations call for additions of superphosphate equal to 2–5% of the dry weight of manure (approximately equal concentrations of nitrogen and phosphorus).

Determining When Active Composting Is Finished

The point at which the active composting stage should be stopped depends on the ultimate use for the compost, on how soon it will be used, and also on the available space at the compost site. These factors determine how stable the compost must be before it is used or cured.

At a minimum, the decomposition must have slowed enough to allow the compost to store indefinitely without overheating or generating odors. A sustainable drop in temperature is perhaps the most reliable indication that active composting has been completed. In windrow composting, the failure of a cooled compost to reheat after turning indicates that decomposition has slowed enough for the compost to be cured. In the case of forced aeration, the compost is ready for *curing* when the temperature remains relatively low or falls gradually. However, the lower temperature must not result from other factors such as a lack of moisture. This can be checked by thoroughly wetting a small sample of the compost, sealing it in a plastic bag and storing the bag at room temperature. If the compost does not emit a foul smell after a week in the bag, it can be considered stable.

Characteristic dark brown color and earthy odors of composting materials are not adequate criteria to determine that composting is completed. These qualities develop relatively early in the process, long before *stability* is reached. Immature or unfinished composts may have detrimental or even *phytotoxic* effects if applied to cropping soils too soon. It seems prudent to accept a final temperature drop as a guide for measuring the end of active decomposition and then to cure the compost for one month or longer prior to use. Other criteria depend upon end use. The required characteristics of compost for various uses are discussed more thoroughly in chapter 8.

Compost continues to decompose slowly in the curing piles. Therefore, as the curing time increases, the point at which active composting is stopped becomes less critical. The primary concern is that high temperature and anaerobic conditions do not develop in the curing piles. If space is limited at the composting site, it is advantageous to shorten the active composting time as much as possible, making room for new windrows/piles. This might occur during peak periods only. In this situation, the composting period can be curtailed with the partially finished compost moved to curing piles or stacked in fields to finish composting. The curing piles should be small enough to permit natural aeration and should be monitored for temperature and odor. Compost should not be sold or used until it has properly cured.

Manure Management with Composting

Once composting is adopted, it becomes part of the overall manure management system. Composting changes the way manure is handled, and the way manure is handled affects the composting system. Ideally, composting and manure handling should be matched or adjusted to make the entire job easier, from removing manure from the barn to curing the compost. A large part of the labor in composting involves handling and mixing manure with amendments. This is where the manure handling and composting tasks overlap the most. Good materials-handling principles should be observed: combine or eliminate steps, lift materials as little as possible, store materials close to their point of use, minimize travel, and avoid crossing paths.

Composting does not lock the farm into composting all of the manure produced. Manure can and should be applied directly to cropland when the conditions are right. This avoids much of the labor involved in composting while still providing organic matter to the soil. It also reduces the amount of dry amendment required. How much manure should be composted depends primarily on the purposes for composting and on other outlets and uses for the raw manure. Usually the other outlet is direct *land application,* which in turn depends on the land area available, the soil and weather conditions, and the stage of crop growth. If the compost is destined for sale, then the amount of manure composted may depend on the size of the market. The availability of dry amendments may also limit the composting volume.

The consistency of manure is a particularly important factor in composting. With few exceptions, manure is too wet to be composted by itself. It needs to be mixed with some dry amendment. There are strong incentives for minimizing the moisture content of manure. Dry manure requires less amendment and, therefore, less materials-handling. The lower volume of amendment also reduces the size of the composting site.

The moisture content of manure, as it is removed from the barn, is primarily determined by the amount of *bedding* it contains. Using bedding and dry *litter* materials liberally is perhaps the best way to mix dry amendments with manure for composting. Additional amendment may still be required after the manure/bedding is removed, but the added bedding still reduces the effort in mixing materials. Although this approach narrows the choice of amendments, many common bedding materials—including sawdust, straw, and wood shavings—are also good *composting amendments.* Even dry compost and *shredded* newspaper can serve both purposes (see sidebar).

The use of bedding is a farm management decision which goes beyond manure handling and composting. The current trend favors less rather than more bedding, primarily because of the high cost and short supply of bedding materials and increasing use of liquid manure systems. Nevertheless, if composting is adopted, dry amendments must be added at some point. As long as bedding is compatible with the farm's management practices, amendments may be added in the barn as bedding.

Other factors can also play a role in determining the moisture content of manure. Leaking waterers contribute a surprisingly large volume of water to manure. This can be particularly troublesome in cage-managed hen houses because of the large number of waterers used. Rainwater from roof leaks, poor drainage in open lots, and drainage into *manure storages* also contribute water. These and other sources of water should be controlled, if not eliminated, to hold down the amount of amendment needed. Leaking waterers should be detected and controlled. Milk room wash water or other wet wastes should not be added to manure that is to be composted unless dry amendments are abundant.

Another approach to minimizing the moisture content of composted manure is to select only relatively dry manure for composting and handle the wet materials in another manner. Manure tends to be drier when it comes from dairy tie stall barns; bedded manure packs from youngstock barns; well-bedded sheep, beef, or goat barns; litter from floor-managed poultry operations (for example, *pullets,* broilers and turkeys); and horse stables. Free stall dairy barns, hog barns, and cage-managed poultry houses produce wet manure. Even within these operations differences can be exploited. In dairy free stall barns, for example, the manure collected from the alley between bedded free stalls is drier than manure in the feed alley. In some cases, the dry manure collected is dry enough to serve as an amendment. If wet material is also to be composted, the dry manure becomes a valuable ingredient in the mix (for example, bedded youngstock manure added to dairy free stall manure or pullet house litter added to caged layer manure).

It is also possible to take advantage of seasonal or weather conditions, such as composting manure collected from open yards during warm dry weather but avoiding it during wet weather. When the season strongly influences the consistency of manure, composting can be restricted to the dry season.

Manure storages are generally an advantage to a composting operation. Storages provide a flexibility that allows windrows/piles to be constructed at convenient intervals and in distinct batches. Storages also provide a backup system in case the composting operation is interrupted.

Using Compost for Livestock Bedding and Poultry Litter

One way to get extra value from compost is to use it for bedding livestock or as a litter ingredient for *floor-managed* poultry operations. Many of the same qualities that make compost a good soil amendment also make it a good bedding material—particularly its ease of handling, high moisture-holding capacity, and reduced pathogen level because of the high temperatures of the composting process. Using compost as bedding or litter offers some unique advantages for farmers who compost manure. The compost not only replaces increasingly scarce bedding materials but also preconditions the manure in the barn for later composting. One California farm found that 100 *cubic yards* of compost bedding per week lowered the moisture content of the manure from a ninety-cow free stall dairy barn from 85% down to 50–55%.

Moisture absorption is a key function of bedding and litter materials. Moisture-absorption capacities of common bedding/litter materials range from 1.5 for hardwood sawdust to 4.5 for chopped straw (pounds of water absorbed per pounds of bedding). In comparison, a pound of compost at a moisture content of about 40% absorbs 1.5–2.5 pounds of water (table 6.1).

When used for bedding, the compost must be stable and relatively dry, with a moisture content no greater than 50%. As the compost moisture content decreases, its water absorbancy increases, and the animals remain cleaner. This might dictate more frequent aeration during composting, extending the composting period, and/or providing a covered storage area. However, excessively dry compost (less than 35% moisture) is more likely to create dust problems. To minimize the risk of disease, temperature-time guidelines for pathogen destruction should be followed (see chapter 7 sidebar).

Research studies, as well as farm experience, have shown that good-quality compost performs as well as or better than traditional bedding and litter materials without animal health problems. One research project found no increase in mastitis among dairy cows using compost *manure solids* in bedded free stalls, even though the *bacteria* counts in the composted bedding were higher than those of straw and sawdust. In another project, broilers raised on litters of composted municipal garbage showed improved body weights with no adverse health or quality effects compared to birds raised on litters of wood shavings. The level of metals found in the tissue of broilers raised on compost litter did not differ from normal levels. However, these levels did change with the source of the compost. This highlights the importance of using compost made from uncontaminated materials.

Compost is probably best used as a supplement to existing bedding and litter materials rather than a replacement. First, there may not be enough compost available to meet the bedding/litter needs of the farm. Secondly, some conventional bedding materials may still be needed as a carbon source for the composting mix.

Table 6.1
Water-absorbing capacity of common bedding materials

Material [a]	Pounds of water absorbed per pound of bedding
Compost (30–50 % moisture)	1.5–2.5
Hardwood—sawdust, shavings, or chips	1.5
Leaves	1.0–2.0
Peanut hulls	2.0–2.5
Pine—sawdust, chips	2.5–3.0
Pine—shavings	1.7–2.9
Straw or hay (chopped)	3.0–4.5
Straw or hay (long)	2.1–3.8

[a] At typical moisture contents for farm storage and use

For farms with short-term storages (four to thirty days), composting activities can be scheduled to suit the manure storage capacity. If windrows/piles are constructed with a manure spreader or dump truck, locating the amendment near the manure storage minimizes handling and equipment travel. Depending on the type of storage structure, the storage might serve as an area for mixing manure with the amendment.

With long-term manure storage (four to six months), most of the storage capacity is wasted, since the manure is removed frequently for composting. One option is to convert the manure storage structure to a *composting pad* or area for mixing. Earthen lagoons with a concrete floor or roofed storages work well but provide a limited area. Using the storage as a composting site forces the farmer to compost all the manure produced or find alternative outlets or locations for the manure that is not composted.

In deep-pit poultry barns, the composting process may be started in the storage itself. By periodically adding high-carbon *dry matter* to the fresh droppings and providing good pit ventilation, aerobic composting may be initiated and sustained, at least in the upper manure layers. Regular agitation and mixing could maintain the process but extra ventilation is needed to exhaust the water vapor, *CO_2*, and ammonia generated by the composting process. At a minimum, good ventilation in either deep- or shallow-pit manure storages encourages drying of the manure prior to composting.

7

Site and Environmental Considerations

A site for an agricultural *composting* facility must provide the required area and conditions for all-weather composting as well as limit environmental risk, odor, and noise. Site planning involves finding an acceptable location, adapting the composting method to the site (or vice versa), providing sufficient land area, and implementing surface runoff and *pollution* control measures as needed.

Before beginning the planning process, check for local and state requirements that may need to be addressed, such as a permit application (see sidebar, page 76, and appendix E, pages 160–165, for more information). The agencies involved may have guidelines, especially if non-agricultural materials will be composted. Certain documents may be required prior to the start of construction and/or operation of the *compost* facility. Materials generated off the farm may also require the approval of local government boards and committees.

The USDA Soil Conservation Service (SCS) offers assistance with site planning, including soils information and drainage control. Also contact the USDA Agricultural Stabilization and Conservation Service (ASCS) to determine which site modifications are eligible for cost-sharing programs.

In addition to the site regulatory requirements that may apply in your state, it is important to be aware that starting a composting facility will raise concerns among neighbors and local public officials. Educating these groups about composting and its advantages will be a critical part of getting started smoothly. Your local county Cooperative Extension agent may be able to assist with that educational process.

Site Selection

The location of the composting site should allow easy access, a minimum of travel and materials handling, and a firm surface to support vehicles under varying weather conditions. Usually the most convenient composting site on the farm is near the barn or *manure storage*—the point where *manure* is collected. However, the convenience of a particular site must be weighed against factors such as area, proximity to neighbors, visibility, drainage, and runoff control. The best site on the farm may not be the most convenient; or a convenient site may require modifications, such as grading or drainage.

Sites near sensitive locations, such as schools, hospitals, and nursing homes, should be avoided. The composting site should also be distant from neighboring residences and preferably out of their view. If not, public relations and odor control will be more time-consuming.

Make a preliminary sketch of the compost facility showing all key areas. Show the prevailing wind direction, traffic flow patterns, the land slope, runoff patterns, surrounding land uses, and pertinent environmental information such as location of wetlands or water bodies. A circle diagram, as shown in figure 7.1, is a simple technique for site layout and evaluation.

Separation Distances

The separation distance, or buffer zone, between the farm composting operation and streams, water sources, and nearby human housing is intended to address water quality concerns and the nuisance factors of odor and equipment noise (figure 7.2).

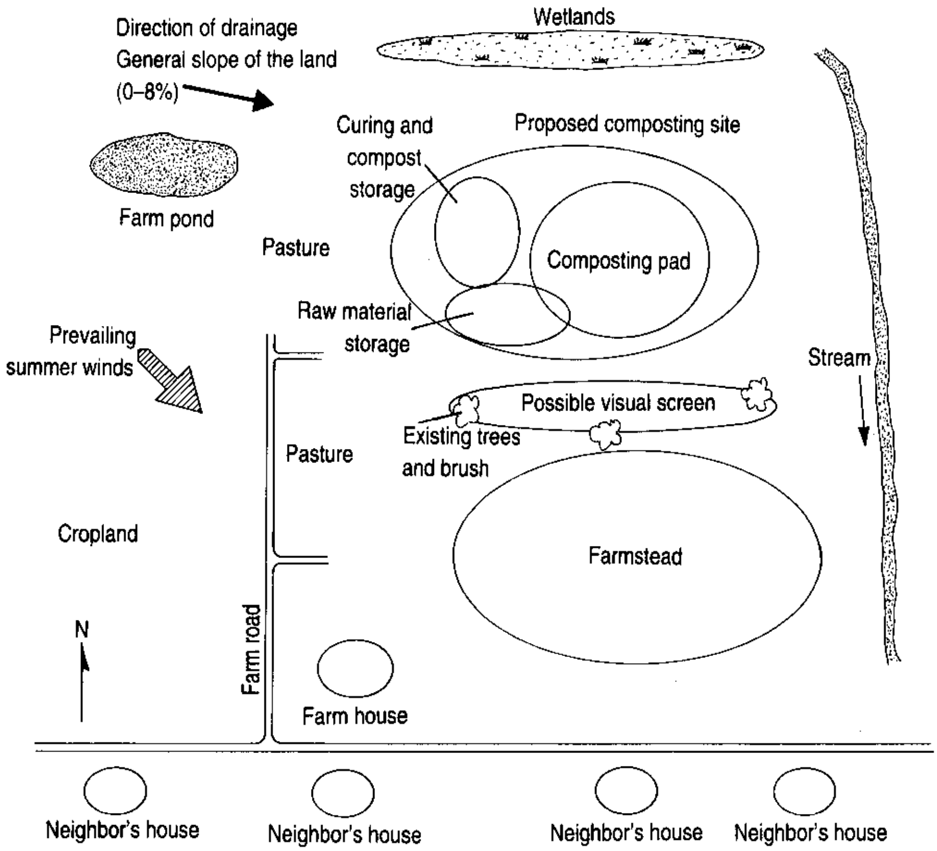


Figure 7.1
Site circle diagram (example).

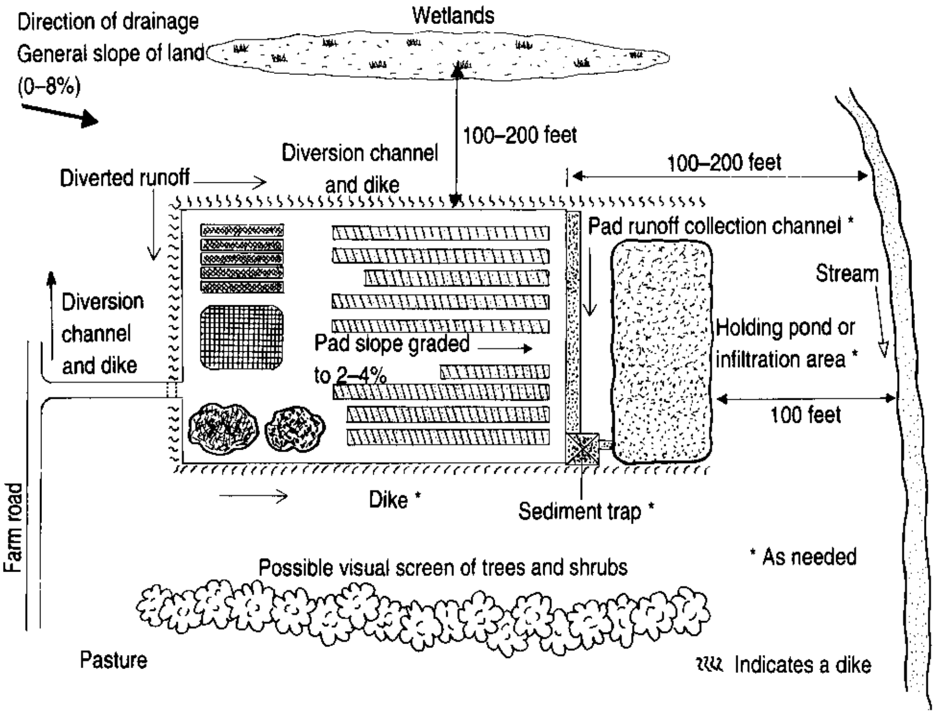


Figure 7.2
Site layout and drainage diagram (example).

For surface-water protection, the minimum horizontal separation distance is the distance between a compost facility and a surface-water body or wetland. For groundwater protection, it is the vertical distance from the *compost pad* surface to the seasonal high water table. In some instances, state regulatory agencies may have already established minimal horizontal and vertical separation distances.

Table 7.1 lists ranges of separation distances commonly recommended for composting sites and manure-handling facilities. The values listed in table 7.1 are based on information from current literature and existing environmental regulations which govern nuisances and water protection. Although separation distances can be somewhat arbitrary, they provide guidance for locating a composting site in relation to sensitive areas. In some states, required separation distances depend on the material being composted. Check with the appropriate environmental agency for state and local requirements.

Drainage Requirements

Good drainage at composting sites is a must! Poor site drainage leads to ponding of water, saturated composting materials, muddy site conditions, and excessive runoff and *leachate* from the site. A muddy composting pad is perhaps the most common site-related complaint of composting operators. Muddy site conditions limit access by equipment and can interrupt the composting operation for several weeks.

Locate the site on moderately to well drained soil. Ideally, the site should have few rocks, which can get mixed into the composting materials and damage machinery. If mud is a potential problem, consider resurfacing the composting pad with compacted gravel or sand.

To avoid standing pools of water, land slope at the composting site should be 1% at a minimum and ideally 2–4% (a 2- to 4-foot vertical drop over a horizontal distance of 100 feet). Sites with slopes up to 7% may be workable but require more attention to surface runoff and soil erosion control.

Windrows and piles should run parallel to the slope to prevent runoff from ponding on the uphill side of windrows/piles (figure 7.3).

The site should be graded for handling surface runoff without creating erosion. The runoff from the composting site can be directed to pasture, cropland, or an *infiltration area* or collected and stored in a *holding pond* for later use. Runoff or seepage from surrounding land that drains onto the site should be diverted away from the composting pad and storage areas. This can be accomplished by using diversion ditches, interceptor drains, or dikes (figure 7.4). Buildings should have roof gutters or perimeter drains if the roof runoff would otherwise empty onto the site.

A site soil investigation should be conducted by a soil scientist, possibly through the assistance of the SCS. Deep-hole checks should accompany a site soil investigation (figure 7.5). A backhoe is normally used for this purpose. Hole depths of 7–13 feet are common. The hole excavations are made at the compost-processing site location to determine the presence of bedrock or groundwater. If groundwater is not detected, then the soil profile is used to evaluate whether there is a seasonal fluctuating water table. Depending on the soils, proper precaution or safety measures should be taken before any individual is allowed to enter the excavation hole.

Environmental Considerations

The composting site will determine the risk associated with odors, noise, dust, leaching, and runoff. The materials being composted, composting method, and system management will also impact these environmental concerns.

Odor from the composting process is minimized through good management only if the composting system is properly designed and laid out (see chapter 6). In siting the facility, consider the direction of prevailing winds during warm weather periods. Normal odors from manure are often unacceptable to the suburban or rural dweller.

Table 7.1
Minimum separation distances commonly recommended for composting and manure-handling activities

Sensitive area	Minimum separation distance (feet)
Property line	50–100
Residence or place of business	200–500
Private well or other potable water source	100–200
Wetlands or surface water (streams, ponds, lakes)	100–200
Subsurface drainage pipe or drainage ditch discharging to a natural water course	25
Water table (seasonal high)	2–5
Bedrock	2–5

Note: Actual separation distances will depend on regulations and practices in specific states.

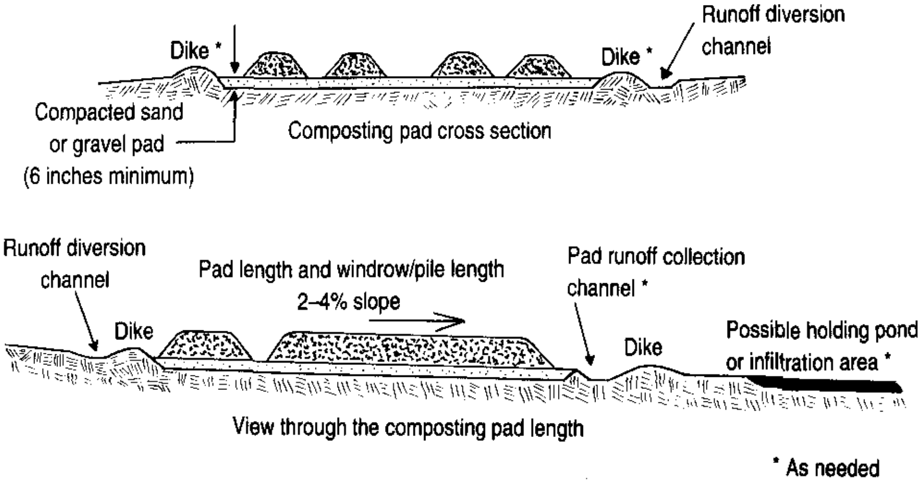


Figure 7.3
Composting pad construction and drainage (example).

Consideration must be given to the noise and dust resulting from the composting operations and from transport vehicles traveling to and from the site. This can be addressed somewhat by selective scheduling of activities during the day and by road use selection. *Grinding* is a particularly noisy operation and should be performed when noise will have the least impact. Noise from site operations will extend for longer periods as the size of the operation increases. Depending upon the material being composted or the type of compost enterprise, noise may be only a seasonal factor. It is of greater concern during mild and summer weather conditions when windows are open and neighbors are outside.

Site visibility and appearance influence human perceptions. Fewer neighborhood complaints will be received if the composting site is less visible. To shield

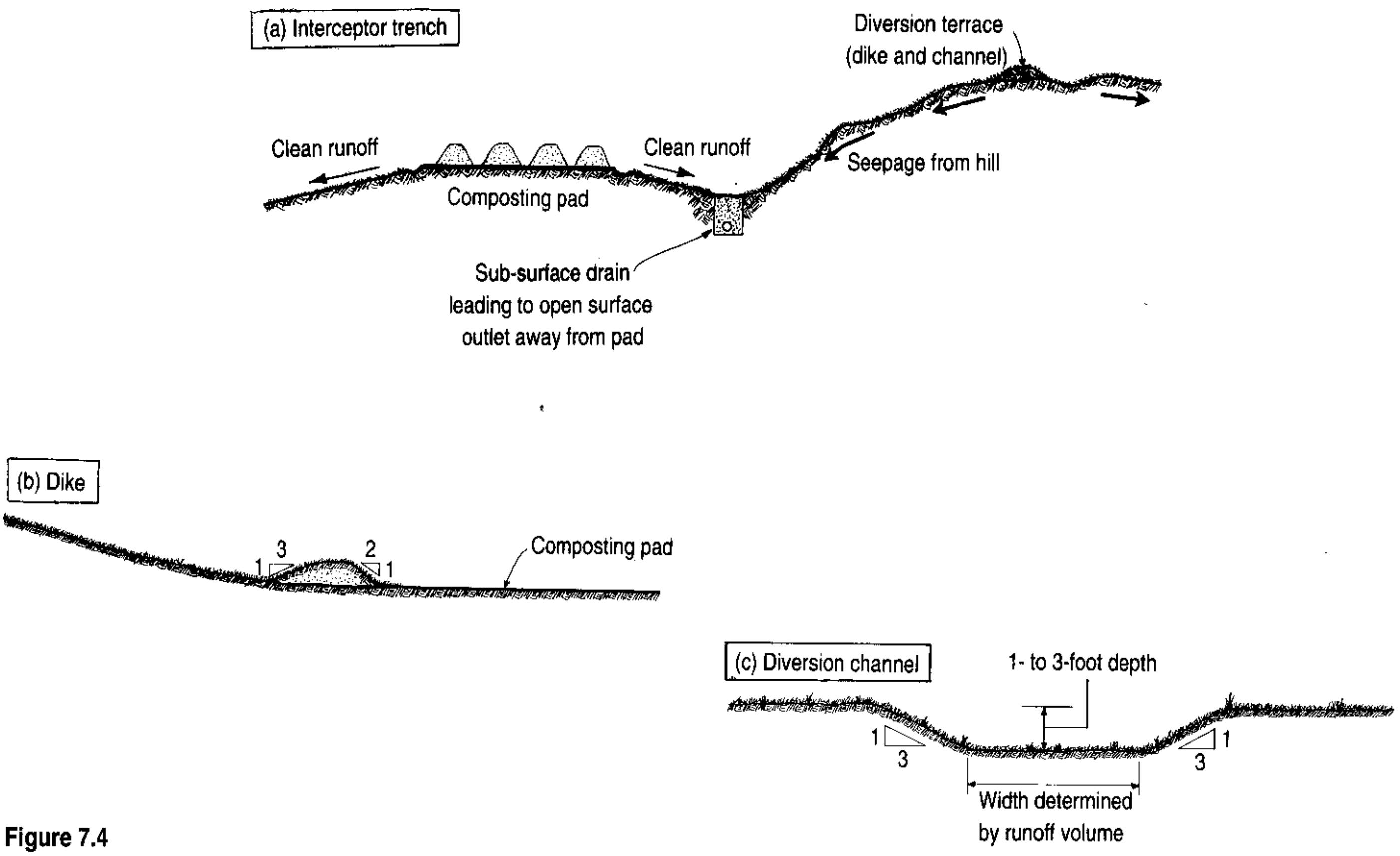


Figure 7.4
Methods of diverting surface runoff and seepage.

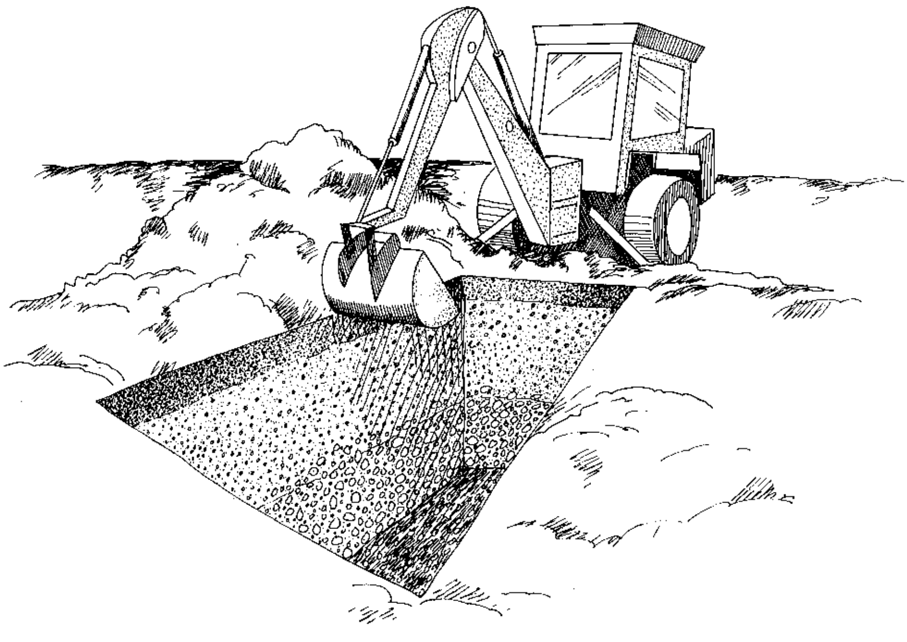


Figure 7.5
Backhoe used for a deep-hole check to determine the presence of ground water or bedrock.

the composting site from public view, take advantage of natural landscape features such as trees and shrubs; otherwise establish new plantings. If the site is visible to the public, it must be kept neat. Sloppy sites are perceived to have greater problems. Make use of the compost produced to landscape the site and make it attractive. Keep grass around the site mowed, control weeds, and maintain plantings in good condition.

Pollution control is a very important site consideration and is foremost on the minds of environmental regulators. Water serves as the vehicle for removing potential pollutants from the site. Rain and snow melt percolate through the materials and into the ground and/or create runoff, which can carry away pollutants. Since composting windrow/piles retain rain water, leaching is less of a concern than runoff. Therefore, emphasis at the site should be to minimize runoff and water entering the site and then handle site runoff in an environmentally safe manner.

Possible contaminants from an agricultural composting site include *nitrate-nitrogen, ammonia,* and organic compounds produced during decomposition. Although nitrate can be a threat to ground water, active composting piles normally contain relatively low concentrations of nitrate-nitrogen. These low concentrations result from the high carbon content of most composting mixes and from the high temperatures attained during composting (which inhibit nitrate-forming organisms). Piles of *curing* or stored compost may be greater potential sources of nitrate.

Organic matter and ammonia can create problems in surface waters because of their oxygen consumption, which is commonly referred to as *BOD* or *COD (biological or chemical oxygen demand).* The presence of pesticides on crop residues or *heavy metals* from off-farm wastes normally have a greater impact on the quality of the compost than on-site-related pollution. Other contaminants may be of concern when non-agricultural materials are composted. It is very important to know the nature of materials brought on to the farm for composting.

Pollution control should not be limited to the composting pad. Raw materials and finished compost stored on-site may present greater risks for pollution than the actively composting windrows/piles, particularly with regard to leaching.

At a minimum, the following pollution control measures should be observed:

1. Maintain windrows and piles below the maximum recommended *moisture content* (that is, 65%) to minimize leaching. Combine raw materials to the recommended *C:N ratios* to limit the loss of nitrogen. In general, follow good composting practices.

2. Do not allow runoff from the composting pad and storage areas to empty directly into surface water. Many of the potential contaminants that pose problems for streams, ponds, and lakes can be effectively treated by the soil. The runoff can be channeled to cropland or a vegetated infiltration area (figure 7.6). Runoff can also be collected in holding ponds (figure 7.7) and later used for irrigation or as a source of moisture for dry composting materials. A sedimentation device in the runoff collection system can be used to collect solids prior to a holding pond or infiltration area.

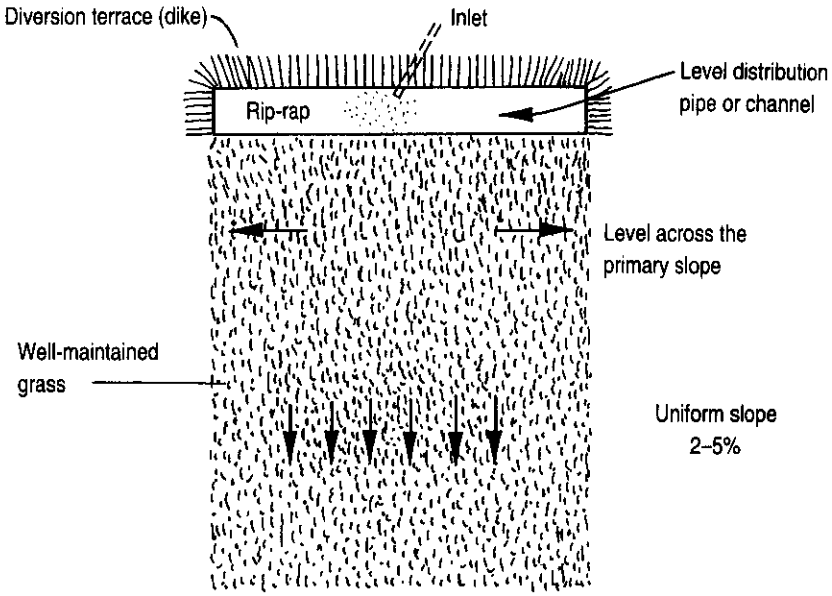


Figure 7.6
Grassed infiltration bed for treating compost pad runoff.
Source: Northeast Dairy Practices Council, "Handling Milk Center Wastes."

3. Divert water entering the site from uphill areas away from the composting pad and away from storage areas (see figure 7.2, page 64).

4. Observe the recommended separation distances to surface and ground water (see table 7.1, page 65, and figure 7.2, page 64).

5. Store raw materials and finished compost away from surface water and drainage paths. Wet raw materials that are prone to leaching should be stored under-cover or on an impervious surface with a method to collect and safely dispose of leachate (figure 7.8). Handle the leachate and runoff as suggested above.

Facilities

With the exception of *in-vessel* systems, composting sites require few facilities and utilities.

Composting Pad

The composting pad is the surface occupied by windrows and piles during the active composting period. Although a firm surface is necessary, it does not have to be paved. Moderate- to well-drained soils are satisfactory for most farm composting situations. A pad constructed of 6 inches of compacted and graded sand or gravel works well when the existing soil conditions are not acceptable. Paved pads of concrete or asphalt are generally a luxury. They reduce problems related to mud, equipment operation, and pad maintenance. They also minimize the amount of stones that get mixed into the compost. However, the cost is usually prohibitive and increased pad runoff must be managed. Usually, an impermeable surface is required only when both the soil is well-drained and the water table is high (for example, within 4–5 feet)

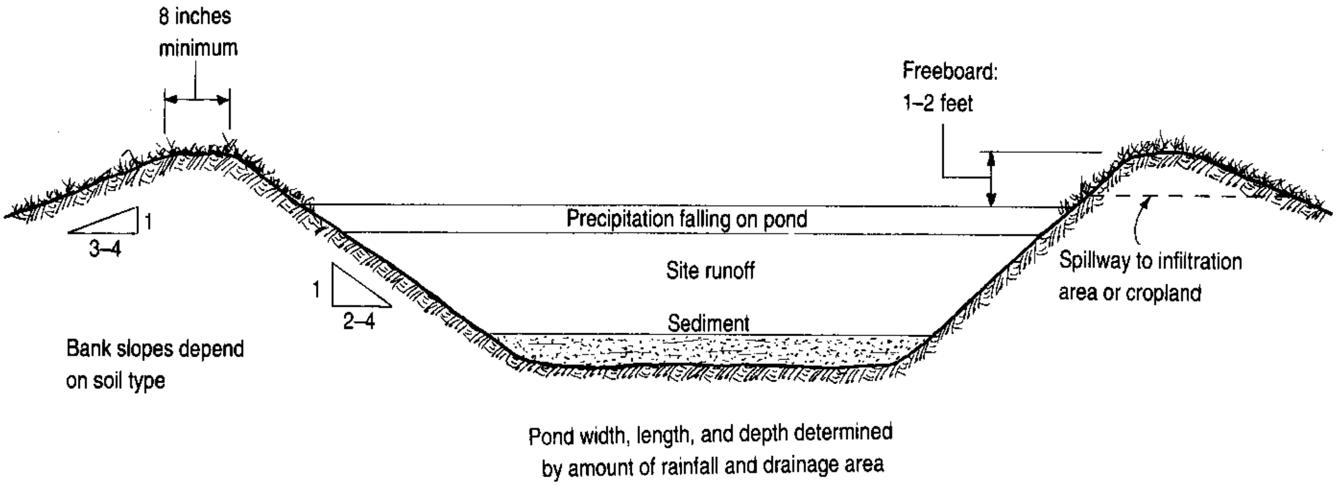


Figure 7.7
Typical characteristics of a holding pond.

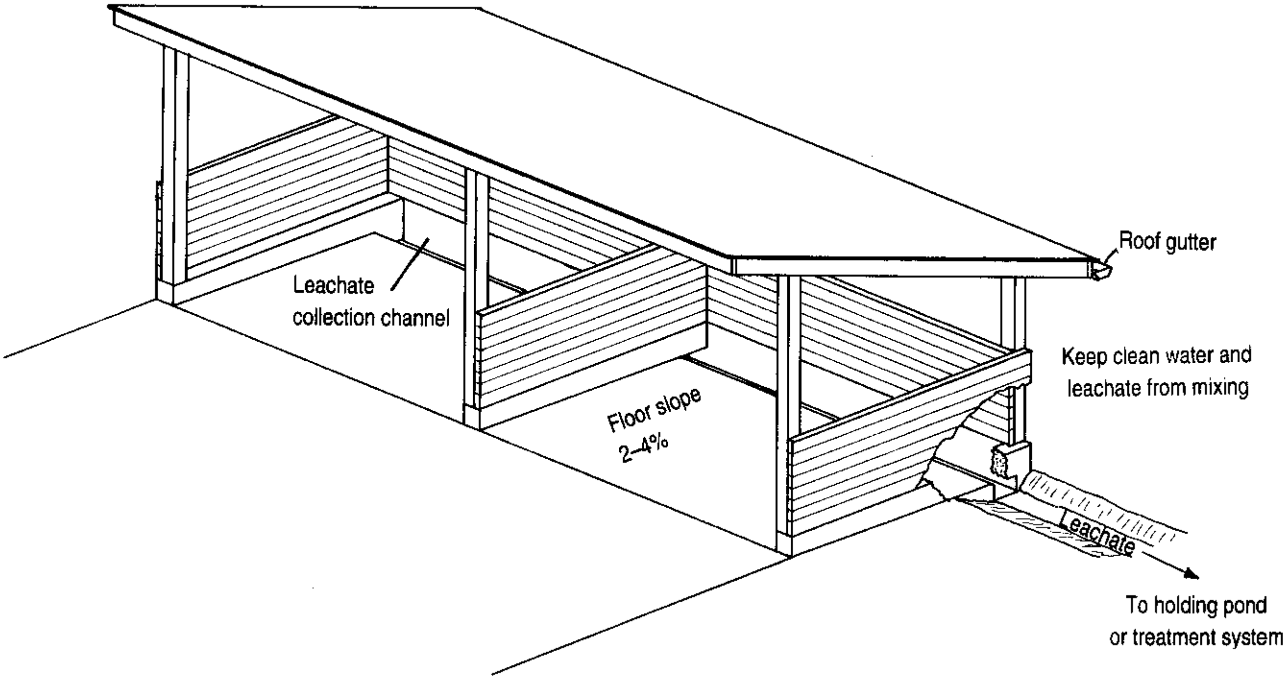


Figure 7.8
Covered storage with leachate collection for wet materials.

Other Working Surfaces

Concrete or asphalt surfaces are sometimes beneficial for special activity areas. Such areas include surfaces used to mix raw materials with a *bucket loader,* receive raw materials, and store wet raw materials. These areas are smaller than the composting pad, so the cost of installing concrete or asphalt may be acceptable. In the best case, existing farm facilities can be used.

Roads

The access roads should be functional for the entire composting season and capable of handling the anticipated vehicle loads.

Electricity

Electrical power is necessary to operate blowers for aerated piles and to run certain materials-handling equipment like augers and conveyors. If power is necessary, determine the energy availability and the cost to bring electrical power lines to the compost site. Electrical motors larger than 10 horsepower will require three-phase electrical service.

Water

The need for water depends on the raw materials and the climate. In most cases, water is not needed at the composting site. For dry mixes of raw materials, water may be needed initially and/or during dry, warm weather. Leaf composting, for example, may require up to 20 gallons of water per *cubic yard* of leaves. Good water sources include runoff collection basins and farm ponds. Tank trucks can be used for occasional water needs.

Fire Protection

For most raw materials, fire is not a significant hazard. However, when composting large quantities of leaves or other dry materials, provisions should be made for an adequate water supply and/or access to firefighting equipment. This may influence the road design and the spacing and location of windrows/piles to allow fire trucks access.

Buildings

Buildings are not necessary for most farm composting operations but can be advantageous in some instances, particularly for storage of equipment, raw materials, and finished compost. Buildings used for covering the composting system or for storing moist raw materials and compost should be ventilated and designed to withstand the high moisture. Typical farm structures, open-sided pole buildings, or greenhouses work well for composting conditions. Metal buildings must be corrosion-resistant or limited to storage of equipment and dry materials.

Area Requirements

Land area needs are based upon the composting method and equipment selected; vehicle traffic patterns; space requirements for storing raw materials, curing compost, and storing compost; and buffer areas for odor, noise, and pollution control. In-vessel composting requires less space. For in-vessel space requirements, check with the system supplier. Be sure to obtain recommendations about the method, time, and space for second-stage composting or curing.

Composting Pad

The area required for the composting pad depends on the volume of material handled, pile/windrow shape and length, and the space needed to maneuver equipment. The windrow/pile shape is determined by the composting method and equipment used to build and *turn* windrows/piles. Table 7.2 (page 70) and figure 7.9 (page 71) provide the basic information needed to estimate the composting pad area for a given volume of material. In addition, table 7.3 (page 72) gives the cross-sectional area of windrows and piles of typical shapes and sizes. The information in appendix B (table B.1, pages 115–119) provides dimensions for specific composting equipment.

The following procedure is one way to determine pad dimensions. A blank work sheet for performing the calculations is included in appendix D (pages 154–159).

1. Estimate the volume of material to be composted. Usually when composting materials are mixed together, the volume of the mixture is approximately 20% less than the combined volume of the individual ingredients. Therefore, the volume of material in newly formed piles/windrows can be estimated by adding together the volumes of the individual ingredients and multiplying this sum by 0.80 (80%). For a conservative estimate, just add together the individual volumes. For manure composting, the volume of *amendments* required is often two to three times the volume of manure. If the volume of manure to be handled is not known, refer to table 7.4 (page 73) for rough estimates of manure generation rates by livestock and poultry.

2. Multiply the daily volume of material available by the number of days the material will remain in the windrows or piles (see table 2.2, page 11, and chapter 4). This is the volume of material that the composting pad must hold.

   Because the materials lose volume during composting, windrows are often consolidated after a few weeks. Therefore, for windrow composting, the volume obtained from step 2 can be multiplied by a shrinkage factor if desired. As a general approximation, use a shrinkage factor of 0.75. The actual shrinkage depends on the raw materials, so use a more specific value if known.

3. Estimate the probable dimensions of the windrows or piles. Based on the proposed equipment and composting method, determine the pile shape and dimensions. Determine the available length at the site for windrows or piles. Account for space at ends for vehicle access (approximately 10 feet) and separation distances from property lines, wetlands, streams, and so on. Also account for space between separate piles/windrows lined up end-to-end.

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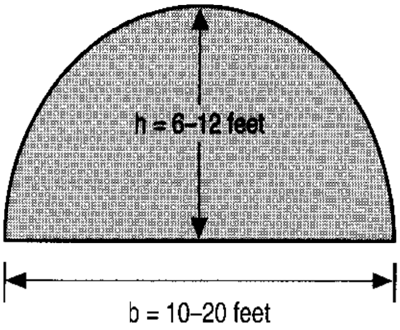
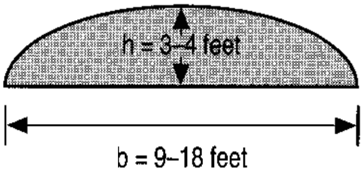
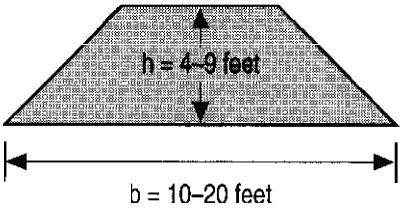
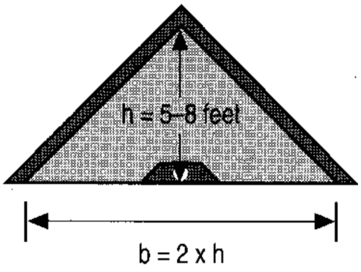
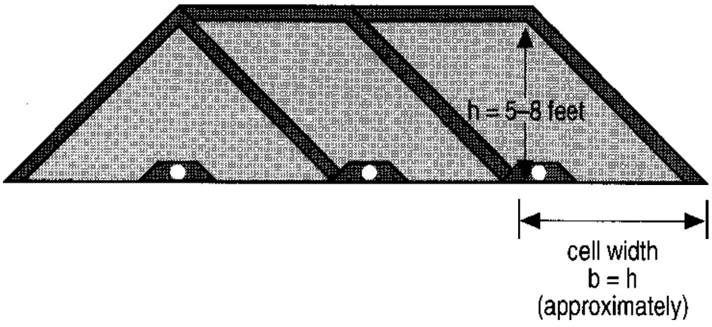
Table 7.2
Typical windrow and pile shapes and cross-sectional areas.

Method and equipment used	Approximate shape	Cross-sectional area
Windrows/piles turned with a bucket loader		$A = \frac{2}{3} \times b \times h$
Small tractor-drawn windrow turners or any turners with wet materials		$A = \frac{2}{3} \times b \times h$
Self-propelled and tractor-drawn windrow turners		$A = h \times (b - h)$ [a]
Individual aerated static piles and other piles with little or no turning		$A = \frac{1}{2} \times b \times h$
Extended aerated static piles		Cell area $A = b \times h$

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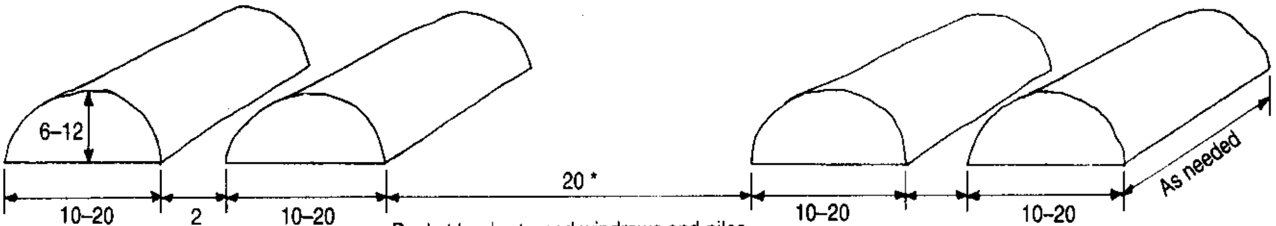
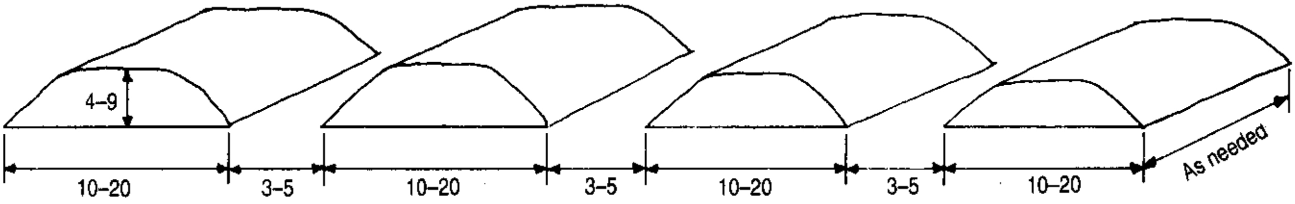
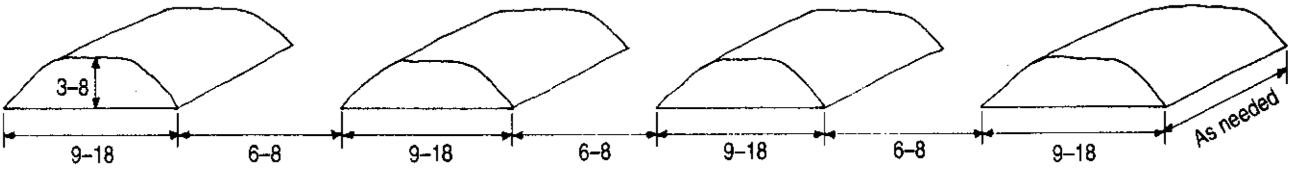
[a] This formula is an approximation and is valid only when the width is greater than or equal to twice the height.



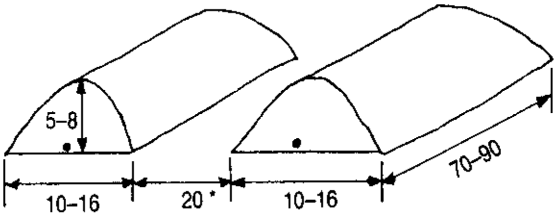
Bucket loader-turned windrows and piles



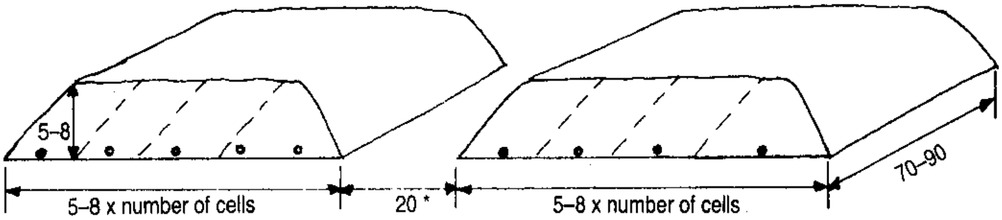
Self-propelled windrow turners



Tractor-assisted windrow turners (two-pass)



Individual aerated static piles



Extended aerated static piles

* Or enough space to maneuver loaders

Figure 7.9

Dimensions and spacings for windrows and piles.

Note: Dimensions are in feet. Refer to appendix B (table B.1, pages 115–119) for information on windrow size (width and height) for specific equipment.

Table 7.3
Approximate cross-sectional area of windrows/piles

High parabolic windrows/piles — turned with bucket loader [a]

Width (feet)	Area (square feet) Height (feet)						
	6	7	8	9	10	11	12
10	40	47	53	60	67	73	80
12	48	56	64	72	80	88	96
14	56	65	75	84	93	103	112
16	64	75	85	96	107	117	128
18	72	84	96	108	120	132	144
20	80	93	107	120	133	147	160

[a] Area = 2/3 width x height

Triangular-shaped static piles [b]

Width (feet)	Area (square feet) Height (feet)					
	5	6	7	8	9	10
10	25	30	35	40	45	50
12	30	36	42	48	54	60
14	35	42	49	56	63	70
16	40	48	56	64	72	80
18	45	54	63	72	81	90

[b] Area = 1/2 width x height

Cells — extended static piles [c]

Width (feet)	Area (square feet) Height (feet)					
	5	6	7	8	9	10
10	50	60	70	80	90	100
12	60	72	84	96	108	120
14	70	84	98	112	126	140
16	80	96	112	128	144	160
18	90	108	126	144	162	180

[c] Area = width x height

Trapezoidal shape — most windrow turners [d]

Width (feet)	Area (square feet) Height (feet)					
	4	5	6	7	8	9
10	24	25	—	—	—	—
11	28	30	—	—	—	—
12	32	35	36	—	—	—
13	36	40	42	—	—	—
14	40	45	48	49	—	—
15	44	50	54	56	—	—
16	48	55	60	63	64	—
17	52	60	66	70	72	—
18	56	65	72	77	80	81
19	60	70	78	84	88	90
20	64	75	84	91	96	99

[d] Formula: Area = height (width − height). This formula is an approximation and is valid only when the width is greater than or equal to twice the height.

Low parabolic windrows — passively aerated windrows, small windrow turners, or wet materials [e]

Width (feet)	Area (square feet) Height (feet)				
	3	3.5	4	4.5	5
9	18	21	24	27	30
10	20	23	27	30	33
11	22	26	29	33	37
12	24	28	32	36	40
13	26	30	35	39	43
14	28	33	37	42	47

[e] Formula: Area = 2/3 width x height

Note: Shapes are illustrated in table 7.2. Cross-sectional areas in this table are intended for use in calculating the volume of raw materials in a windrow or pile. The cover and base are not accounted for. If a base or insulating cover is used, consider it when estimating the space required for the pile.

Table 7.4
Production and characteristics of fresh manure (as produced with no bedding or water added)

Animal	Animal weight (pounds)	Total manure production per day: pounds	cubic feet	gallons	Water (%)	Density (pounds per cubic foot)
Beef cattle	500	30	0.50	3.8	88.4	60
Beef cattle	750	45	0.75	5.6	88.4	60
Beef cattle	1,000	60	1.00	7.5	88.4	60
Beef cattle	1,250	75	1.20	9.4	88.4	60
Cow	—	63	1.05	7.9	88.4	60
Dairy cattle	150	12	0.19	1.5	87.3	62
Dairy cattle	250	20	0.32	2.4	87.3	62
Dairy cattle	500	41	0.66	5.0	87.3	62
Dairy cattle	1,000	82	1.32	9.9	87.3	62
Dairy cattle	1,400	115	1.85	13.9	87.3	62
Veal	240 [a]	15	0.24	1.8	97.5	62
Horse	1,000	45	0.75	5.63	79.5	60
Poultry						
Broilers	2	0.14	0.0024	0.018	74.8	60
Layers	4	0.21	0.0035	0.027	74.8	60
Sheep	100	4.0	0.062	0.46	75.0	65
Swine						
Nursery pig	35	2.3	0.038	0.27	90.8	60
Growing pig	65	4.2	0.070	0.48	90.8	60
Finishing pig	150	9.8	0.16	1.13	90.8	60
Finishing pig	200	13.0	0.22	1.5	90.8	60
Gestating sow	275	8.9	0.15	1.1	90.8	60
Sow and litter	375	33.0	0.54	4.0	90.8	60
Boar	350	11.0	0.19	1.4	90.8	60

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Note: Values are approximate. The actual characteristics of a manure can easily have values 20% or more above or below the table values. The volume of waste that a waste-handling system has to handle can be much larger than the table values because of the addition of water, bedding, and so on. For example, liquid waste systems for swine farrowing and gestation units may have to handle twice as much waste volume as indicated; swine nurseries three to four times as much, because of large amounts of waste and wasted water.

[a] Average animal weight.

4. Determine the volume of a single windrow or pile. Calculate the cross-sectional area of a windrow/pile from the formulas in table 7.2, or use table 7.3. Multiply this area by the estimated windrow/pile length to determine the windrow/pile volume.

5. The number of windrows, piles, or cells required equals the total volume (from step 2) divided by the volume per windrow/pile/cell (step 4). Round off to a reasonable whole number.

6. Refer to figure 7.9 for spacing of windrows/piles. The width plus spacing times the number of windrows/piles gives the approximate pad width.

Curing and Storage

The space requirement for curing and compost storage is based upon the amount of organic material composted, the pile height and spacing, and the length of time the compost is cured and stored. The volume of compost produced is generally about half the original material being composted. However, it can be as low as 25% for loose, degradable raw materials like leaves. The storage period depends upon the end use of the compost. Most compost is used or sold in the spring and summer.

Compost curing and storage areas can be determined by dividing the estimated compost volume in cubic feet by the average pile height in feet. Within the limits imposed by preventing *anaerobic* conditions, the pile height is determined by the reach of loaders, conveyors, or other materials-handling equipment (see chapter 5). In the total area, allowance for movement and loading of vehicles must be included.

General estimates of area required for curing and storage vary considerably, from 25% of the composting pad area (for leaf composting) to twice the pad area (for *sewage sludge* composting by using *aerated static piles*).

Sample Calculation: Determining the Required Area and Layout of the Composting Pad

Manure from sixty thousand laying hens is to be composted with green sawdust. The farmer will use the windrow composting method and turn the windrows with a bucket loader. The estimated composting period is sixty days. The compost will be cured for one month (thirty days) and then may be stored for up to three months (ninety days) before being land applied. Assume that the compost volume is 50% of the volume of the raw materials.

Estimated composting pad area

1. Estimate the daily volume of material to be composted:

   a. Manure. From table 7.4 (page 73), one laying hen produces approximately 0.0035 cubic feet of manure per day

$$60{,}000 \text{ birds} \times \frac{\frac{0.0035 \text{ cubic feet manure}}{\text{day}}}{\text{bird}} = \frac{210 \text{ cubic feet manure}}{\text{day}}$$

   b. Sawdust. Assume that the composting *recipe* calls for 3 volumes of sawdust per volume of manure (equal parts by weight).

$$\frac{3 \text{ cubic feet sawdust}}{\text{cubic feet manure}} \times \frac{210 \text{ cubic feet manure}}{\text{day}} = \frac{630 \text{ cubic feet sawdust}}{\text{day}}$$

   Total daily volume of ingredients = 210 + 630
   = 840 cubic feet per day

   Account for a 20% volume reduction in combining the materials (that is, multiply by 0.80)

   Estimated daily volume of mix = 840 x 0.80 = 672
   = approximately 700 cubic feet per day

2. Determine the volume of material on the composting pad:

   Total material volume = 60 days x 700 cubic feet per day
   = 42,000 cubic feet

   The windrows will be combined as they shrink in volume, freeing space on the pad for new windrows. Assume a shrinkage factor of 0.75.

   Adjusted total material volume = 42,000 cubic feet x 0.75
   = 31,500 cubic feet

3. Determine windrow dimensions:

   Assume that the site allows 150-foot long windrows and that the bucket loader can build windrows 8 feet high and 14 feet wide. Assume that these dimensions allow adequate air movement through the windrows.

4. Calculate the estimated windrow volume:

   From table 7.2 (page 70), the windrow cross-sectional area is:
   A = 2/3 x b x h = 2/3 x 8 x 14 = approximately 75 square feet

OR From table 7.3 (page 72), the area of a 8 feet high by 14 feet wide windrow is 75 square feet

Windrow volume = A x length = 75 square feet x 150 feet
= 11,250 cubic feet

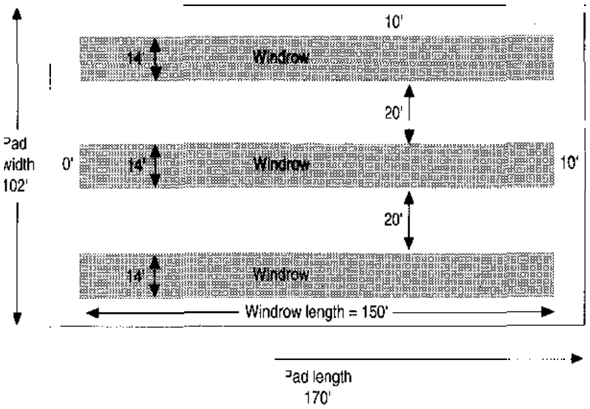
5. Determine the number of windrows required:

$$\# \text{ Windrows} = \frac{\text{Total material volume}}{\text{Single windrow volume}} = \frac{31{,}500 \text{ cubic feet}}{11{,}250 \text{ cubic feet}} = 2.8$$

Use 3 windrows

6. Lay out the windrow spacing, and determine estimated pad width.

Note: The windrows will require several *turnings* before they can be combined, so they must be spaced to allow equipment movement on both sides. From figure 7.9 (page 71):



Overall pad dimensions:
102 feet wide x 170 feet long = 17,340 square feet

Estimated curing area

Assume that the curing piles are 6 feet high and 18 feet wide with an average height of 4 feet and that they are stacked toe-to-toe (no space between piles).

1. Estimate the volume of compost in curing area:
700 cubic feet per day x 30 days x 0.50 shrinkage factor = 10,500 cubic feet

2. Determine the area occupied by the curing piles:

$$\text{Curing area} = \frac{\text{Curing volume}}{\text{Average pile height}} = \frac{10{,}500 \text{ cubic feet}}{4 \text{ feet}}$$

= 2,625 = approximately 2,700 square feet

3. Lay out the area accounting for pile spacing and equipment access (see below).

Estimated compost storage area

Assume that the compost is stored in adjacent piles at an average height of 8 feet.

1. Estimate the volume in the storage area:

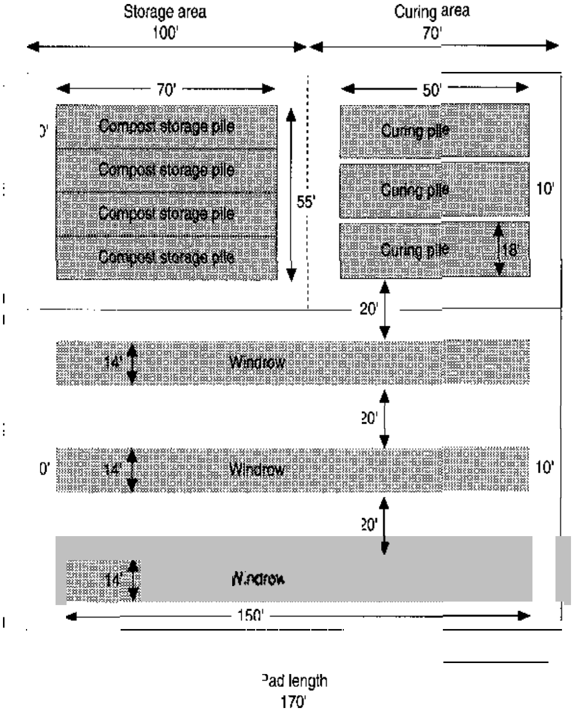
700 cubic feet per day x 90 days x 0.50 shrinkage
= 31,500 cubic feet

2. Determine the area occupied by the storage piles:

$$\text{Storage area} = \frac{\text{Storage volume}}{\text{Average pile height}} = \frac{31{,}500 \text{ cubic feet}}{8 \text{ feet}}$$

= 3,938 = approximately 4,000 square feet

3. Lay out the area accounting for pile spacing and equipment access (see below)



Note

This layout shows the minimum area required for the situation given by this example. In an actual operation, additional space might be needed for piles/windrows that are being constructed or removed plus areas for raw material storage, grinding, screening, and so on.

General Environmental Regulations

Regulations governing solid waste and composting vary from state to state. State environmental regulatory agencies in the United States are listed in appendix E (pages 160–164). Regional offices of the U.S. Environmental Protection Agency are also listed in appendix E (page 165).

Regulations relating to composting differ depending on the materials composted. Farm manures, *yard waste* (leaves, grass clippings, and so on) and other vegetative waste (such as fruit and vegetable processing waste) typically are the least regulated and may be exempt from regulation in some states. Concerns for these materials relate to site development and operational management provisions required to prevent odor complaints or other off-site negative impacts. Regulations may require *setbacks* from neighbors and bodies of water, grading to prevent runoff or ponding of water, regular turning, and so on. Additional regulations may apply to processed food and animal wastes, which have greater attraction for pests and a higher potential for odor and disease.

In many states, farms are exempt from permit requirements if they handle only farm-generated waste. Wastes brought in from outside the farm may require a permit or special approval. Contact the appropriate authority. Your state may allow exemptions for specific off-farm wastes that are generally considered safe—for example, sawdust, leaves, certain food wastes, or manures from other farms.

The strictest regulations relate to sewage sludge composting. To destroy *pathogens* in sewage sludge, current federal regulations require temperatures to be held at 131°F or higher for three consecutive days in the coldest section of an aerated pile or composting vessel. In windrows, uniform temperatures are difficult to achieve. Therefore the regulations for windrow composting dictate fifteen consecutive days at 131°F.

Regulations specifically governing the use of compost do not yet exist in most states. However, in their absence, most environmental agencies look to the rules for *land application* of sewage sludge as a guide for regulating the use of compost. The U.S. Environmental Protection Agency (EPA) has established minimum land application standards for sludge/compost which apply nationally, though some states have adopted stricter regulations. EPA standards are presently in the process of being revised, and the revised standards are expected to take effect in 1992.

Although the specifics of land application regulations differ among the states, the general approach is to classify a sludge or compost according to its concentrations of certain pollutants—in particular *PCBs (polychlorinated biphenyls)* and heavy metals (for example, lead, cadmium, zinc, copper, and nickel). In addition, the pathogen level and attractiveness to vectors can be a factor. Compost with low concentrations of contaminants have unrestricted use. Nearly all farm-produced compost falls into this category. As the levels of contaminants surpass established limits, the regulations limit the application rates and/or the cumulative amount applied. Written records of the applications may be required. Regulations may also call for specific management practices such as soil incorporation or a waiting period prior to grazing. Composts with contaminant concentrations above the established limits may, in some cases, be restricted to crops that are not used for food or animal feed.

8

Using Compost

Compost has numerous agronomic, horticultural, and forestry uses. It can be used for the production of agronomic and horticultural field crops, forest and wildlife seedlings, potted greenhouse crops, field- and container-grown nursery plants, cut flowers, and herbs growing in beds. It can be used to maintain the *organic matter,* tilth, and fertility of agricultural soils; to support urban landscapes; to reclaim disturbed land such as abandoned strip mines; to establish landscapes; and to cover landfills (figure 8.1).

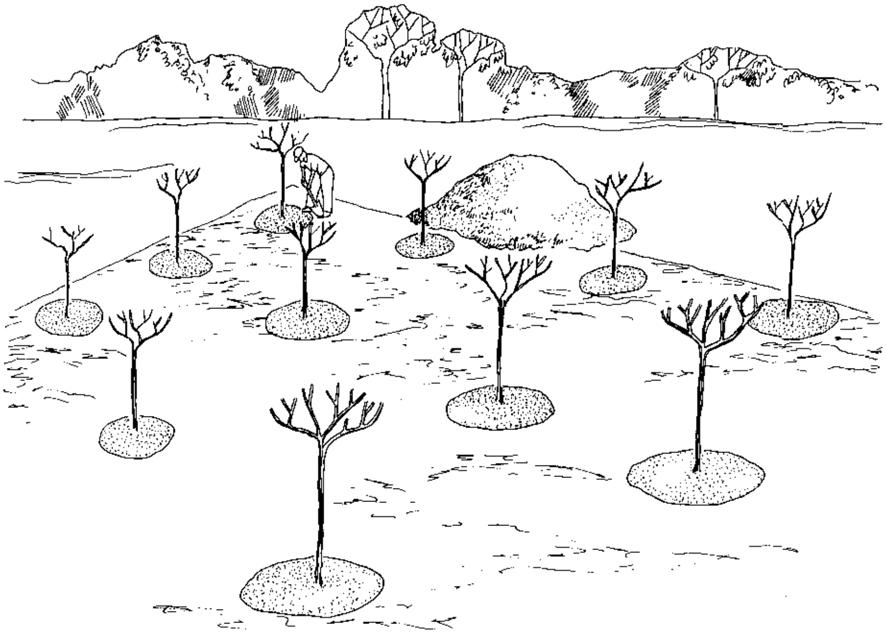


Figure 8.1
The application of compost, as mulch, around trees.

How each producer allocates the available compost should depend on the amount generated, on-farm needs, and off-farm markets. Often the most cost-effective use of compost is as a substitute for other inputs presently being used on the farm. By using the compost on the farm, costs and additional management associated with marketing can be avoided. Thus, the first step in planning for compost use is to determine the extent to which compost can be used effectively where it is produced. Once on-farm needs are satisfied, there may well be some compost left over which can be marketed.

Benefits of Compost

The addition of compost improves the physical, chemical, and biological properties of soils and potting mixes. Compost is a relatively stable form of organic matter. The addition of compost to soils reduces its *bulk density*. Compost improves the *aeration* and drainage of dense soils and the water-holding capacity and aggregation of sandy soils. Compost also increases the soil's *exchange capacity*—that is, its ability to absorb nutrients. In potting mixes, compost provides essential bulking material through which roots can easily grow, and it will not shrink rapidly. When used in combination with other materials, compost provides the water- and *nutrient-holding capacity,* plus the air space needed, to promote good root growth. Its *pH* is usually near neutral, which is preferred for most agricultural crops.

Most plant nutrients in compost are in an organic form. They are released slowly over a long period of time as a result of microbial activity. The nutrients become available to the roots of plants as needed and are, therefore, resistant to leaching. During late fall, winter, and early spring, when soils are cool, soil microbial activity decreases. This further reduces the *availability* of nutrients that might otherwise be leached.

Compost made from plant and animal residues contains all of the nutrients essential for plant growth, including trace elements. Compost also includes *humic acids,* which aid in making certain plant nutrients available. However, some of the major plant nutrients such as nitrogen, phosphorus, and potassium may not be present in adequate amounts for accelerated plant growth, unless the compost is supplied in large quantities.

The annual nitrogen mineralization rate, or availability, of compost is usually between 8% and 12% of the total nitrogen in the compost, depending on soil temperature, aeration, and moisture. The availability of phosphorus in compost may be only 25–40% of that of commercial fertilizers. Therefore, only a fraction of the nitrogen, phosphorus, and potassium applied as compost is usable by the crop the first year. However, when applied at the recommended rates, there is generally an adequate supply of plant nutrients from compost to keep most plants healthy for several years. Studies on the residual properties of compost on agricultural soils have reported measurable benefits for eight years or more after the initial application.

The biological properties of compost are not fully appreciated or thoroughly understood. Compost is known to contain naturally occurring fungicides and beneficial organisms that help suppress disease-causing organisms. The use of compost in potting mixes and in seedling beds has helped to reduce the need to apply soil fungicides in the production of certain horticultural crops. In the production of trees and shrubs, compost has been shown to be beneficial by promoting the growth of mycorrhizae-associated *fungi.* These fungi are essential for the growth of certain species. They are particularly important in establishing vegetative cover on disturbed soils such as abandoned strip mines and landfill covers or on soils that have been excessively sterilized to control disease-causing organisms, insects, weeds, and nematodes.

Compost Quality

There are two approaches to managing compost quality. Either the quality of compost determines its end use, or the intended end use determines the quality of the compost produced. The approach taken depends on the objectives and priorities of the *composting* operation and on the raw materials available. In either case, the quality and use of the compost are closely linked.

Producing a consistently high-quality compost is especially important when the compost will be marketed and not just used on the farm. The importance of quality increases further if the compost will be used for high-value crops such as potted plants; used on food crops; applied to sensitive plants, such as young seedlings; used soon after composting; or used alone without soil or other additives. On the other hand, if you plan to use the compost only for farm use as a *soil amendment* for field crops and apply it well before planting, the quality of the compost produced is less of a concern. Some quality criteria, such as particle size, may not be important for certain farm uses. The soil also buffers many potentially adverse effects of a low-quality compost.

Compost quality is generally based on particle size; pH; soluble salts; *stability;* and the presence of such undesirable components as weed seeds, *heavy metals, phytotoxic* compounds, and foreign objects. Quality is also judged by the uniformity of the product from batch to batch. Some users may consider the raw materials used as a basis for quality, favoring compost made from clean farm materials instead of waste materials with potential contaminants.

A compost with particle sizes less than 1/2 inch in diameter, a pH between 6.0 and 7.8, a soluble salt level less than 2.5 *mmhos* per centimeter, a low respiration rate, no weed seeds, and contaminant concentrations below EPA and state standards will have almost unlimited use (see chapter 7 sidebar). Respiration rate is measured by the rate of oxygen consumption and is related to stability. As compost characteristics vary from these levels, the uses become more restrictive. For instance, compost with a soluble salt level above 2.5 mmhos per centimeter would have to be diluted with other materials before it could be used for certain plants. Composts with a pH above 7.8 would be limited to acidic soils or to crops with a high pH requirement.

Table 8.1 provides an example of compost quality guidelines based on end uses. Although there is a great deal of interest in establishing quality standards for compost, no standards are generally accepted as yet. The guidelines suggested in table 8.1 have received support from producers of horticultural crops.

The physical and chemical properties of compost are influenced by the raw materials. For example, compost made from *yard waste* generally contains lower levels of nutrients than compost made from *sewage*

Table 8.1
Example of compost quality guidelines based on end use

	Quality guidelines			
	End use of compost			
Characteristic	Potting grade	Potting media amendment grade [a]	Top dressing grade	Soil amendment grade [a]
Recommended uses	As a growing medium without additional blending	For formulating growing media for potted crops with a pH below 7.2	Primarily for top-dressing turf	Improvement of agricultural soils, restoration of disturbed soils, establishment and maintenance of landscape plantings with pH requirements below 7.2
Color	Dark brown to black	Dark brown to black	Dark brown to black	Dark brown to black
Odor	Should have good, earthy odor	Should have no objectionable odor	Should have no objectionable odor	Should have no objectionable odor
Particle size	Less than 1/2 inch (13 millimeters)	Less than 1/2 inch (13 millimeters)	Less than 1/4 inch (7 millimeters)	Less than 1/2 inch (13 millimeters)
pH	5.0–7.6	Range should be identified	Range should be identified	Range should be identified
Soluble salt concentration (mmhos per centimeter)	Less than 2.5	Less than 6	Less than 5	Less than 20
Foreign materials	Should not contain more than 1% by dry weight of combined glass, plastic, and other foreign particles 1/8–1/2 inch (3–13 centimeters)	Should not contain more than 1% by dry weight of combined glass, plastic, and other foreign particles 1/8–1/2 inch (3–13 centimeters)	Should not contain more than 1% by dry weight of combined glass, plastic, and other foreign particles 1/8–1/2 inch (3–13 centimeters)	Should not contain more than 5% by dry weight of combined glass, plastic, and other foreign particles
Heavy metals	Should not exceed EPA standards for unrestricted use	Should not exceed EPA standards for unrestricted use	Should not exceed EPA standards for unrestricted use	Should not exceed EPA standards for unrestricted use
Respiration rate (milligrams per kilogram per hour) [b]	Less than 200	Less than 200	Less than 200	Less than 400

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[a] For crops requiring a pH of 6.5 or greater, use lime-fortified product. Lime-fortified soil amendment grade should have a soluble salt concentration less than 30 mmhos per centimeter.

[b] Respiration rate is measured by the rate of oxygen consumed. It is an indication of compost stability.

sludge or animal *manures.* Even composts made from different animal manures vary in nutrient content. The processing of raw materials prior to composting can affect the pH, soluble-salt concentration, and other characteristics of the compost.

Aging also influences the quality of compost. Compost that has aged three to four months tends to have a lower pH, a finer *texture,* and a higher concentration of *nitrate-nitrogen* (instead of *ammonium*-nitrogen). However, the change in pH occurs only if lime was not added to the initial ingredients. In time, larger particles decompose, and finer particles accumulate.

The quality of finished compost is highly dependent on its storage conditions. Although initial activity of *microorganisms* may have subsided and temperatures have dropped, composting is not necessarily complete. Composting slowly continues until all sources of available carbon have been exhausted. This means that even after the initial composting period, compost must be kept dry or stored in piles sufficiently small to allow *aerobic* respiration throughout the pile. Compost that becomes *anaerobic,* or *sour,* is likely to develop odors and contain alcohols and organic acids. These anaerobic by-products are detrimental to plants. The application of anaerobic compost to sensitive plants or overshallow roots will kill them almost instantly. If compost is stored in an anaerobic condition over an extended period of time, the pH will drop to near 3.0. The low pH is temporary, but it may be used to identify a sour compost.

Measuring the Quality of Compost

If compost will be marketed for high-quality uses, it is necessary to establish a quality control laboratory and/or have the compost tested by an independent laboratory.

Regular testing is required when compost is sold with claims of a specific nutrient analysis or when environmental regulations require specific analysis for *land application.* Occasional analysis of the compost nutrients is necessary to determine land application rates. Composts are also tested for suspected contaminants. The contaminants to test for depends on the source of the materials and on environmental regulations. For materials with land application restrictions, like municipal and industrial sludges and some processing wastes, heavy metals are most commonly analyzed. The presence of suspected phytotoxic compounds, *herbicides,* or other pesticides can also be of interest where the compost is used on sensitive crops. For example, compost made from a mix which includes a large amount of cardboard should be tested for boron concentration because boron is found in the cardboard adhesives. It is important to know the nature and chemical components of the raw materials obtained from off-farm sources. Literature can supply some of this information, but the best source is the supplier of the raw material.

Frequent testing is especially important if the intent is to produce a quality product consistently. For lab analysis, you need to make sure that the sample represents the average material. Pint samples should be taken at fifteen- to thirty-minute intervals during the screening of each lot. The samples from each lot are then combined to form a composite sample from which a quart sample is taken for laboratory analysis. This information should be recorded along with the lot number and date. When marketing any product, it is important to maintain accurate records. The records will also provide the necessary information to evaluate the consistency of the product.

Characteristics such as *moisture content, density,* pH, soluble salts, and particle size distribution can be conducted with limited laboratory facilities (see chapter 3). If you are going to guarantee that particles in your product do not exceed 1/2 inch in size, then all you will need is a 1/2-inch sieve. The sample is placed on the sieve; and if at least 95% of it passes through, your product has passed that standard.

Tests such as respiration rate, nutrient concentration, heavy metals, and chemical contaminants will most likely have to be conducted by an independent laboratory. The primary characteristics analyzed for composting materials are also routinely included in soil, manure, and fertilizer tests conducted by commercial and state-operated laboratories. Therefore, most agricultural laboratories should be able to provide an analysis of composts with little difficulty. In general, it is best to use a laboratory familiar with composting. A few labs offer tests specifically for composts, such as maturity or phytotoxicity evaluations.

When Is Compost Ready to Use?

Compost is ready for use after temperatures within the composting mass subside to near-ambient levels, and the oxygen concentration in the middle of the mass remains over 5% for several days. These measurements must be made when the compost mass has at least a 50% moisture content and sufficient volume for heating to occur. Although analytical methods are being developed to determine compost maturity, no single method is consistently reliable.

Compost should be adequately decomposed when applied to crops during the growing season. Organic matter with a high *C:N ratio* competes with plant roots for the available nitrogen in the soil. The microorganisms digesting the carbon in the organic matter have a greater affinity for nitrogen than the roots of plants. This can be most damaging when used around young plants, plants that have recently been transplanted, or seeds that have recently germinated. Plants growing in soils or potting media amended with improperly composted material stop growing, and the bottom leaves generally turn yellow and die. Although the problem can sometimes be corrected by applying additional nitrogen fertilizer at the time of compost application, the symptoms often go unnoticed until the plants becomes stunted. Treating the problem after the symptoms appear is generally too little, too late.

Just after the active composting period, most of the available nitrogen of compost is in the form of ammonium. Although many horticultural plants absorb ammonium-nitrogen, many can be damaged by concentrated amounts. It takes approximately three months for most of the ammonium to be converted to nitrate-nitrogen. Generally the roots of young plants can absorb ammonium more efficiently than mature plants. Therefore, it is important to be selective. Compost of different levels of maturity can be used only for certain plant species and at certain stages of growth. *Ericaceous* species such as blueberries, azaleas, rhododendrons, mountain laurel, andromeda, and leucothoe absorb all of their nitrogen in the ammonium form. However, most grasses, flowering annuals, herbaceous perennials, and vegetable plants absorb most of the nitrogen as nitrates, although in their juvenile state they will absorb ammonium-nitrogen. Most woody perennial plants not mentioned are capable of absorbing nitrogen as either ammonium or nitrates, depending on their stage of maturity and on the time of year. Ammonium is more easily absorbed by roots in the spring when soils are cool; but in the fall, as these plants mature, nitrate-nitrogen appears to be the preferred source.

Applying compost with a high concentration of ammonium will often cause temporary stunting and burning of the foliage of sensitive species. However, effects are seldom noticeable from applying mature compost high in nitrate to species of plants that absorb only ammonium, probably because these species grow at a low pH where a slow conversion of nitrate to ammonium occurs naturally.

Using Compost for Container Crops and Potting Mixes

All container-grown plants and landscape plants are high-value crops. Any variation in the quality of the compost between lots is likely to be noticed by the user and can ultimately create problems. Therefore, it is of utmost importance that high-quality standards be established and maintained. This means testing all lots for pH, soluble salts, respiration rates, and particle size as well as adhering to proper storage practices (see chapter 5).

In formulating potting mixes, the amount of compost used should range from 20% to 33%, depending on species being grown and other materials used. Compost is seldom used alone as a potting medium because it is too porous and frequently the soluble salt levels are too high. A common blend used for growing vegetable transplants includes equal parts by volume of compost; *peat* moss; and *perlite,* ground Styrofoam, or *vermiculite.* A popular blend used for growing a wide variety of *bedding* plants includes 25% compost; 50% peat moss; and 25% perlite, ground Styrofoam, or vermiculite. The basic blend used for growing herbaceous and woody ornamental plants in containers is equal parts by volume of compost, coarse sand, and either peat moss or milled pine bark. To increase the water-holding capacity of blends containing milled pine bark, growers often add 10% by volume of peat moss. Growers of ericaceous container crops prefer a high organic blend of equal parts by volume of compost, peat moss, and milled pine bark.

When using compost in formulating potting mixes, there is no need to add trace elements to the blend. Most composts will supply all of the trace elements needed by plants during their growth in the container.

Plants growing in potting mixes containing compost should not receive any liquid fertilizer during their first two to three weeks of growth. There is an adequate amount of nitrogen, phosphorus, and potassium in the compost to supply the needs of the plants during that period of time. The plants should receive only water as needed during this time period. A liquid fertilizer program, either as constant-feed or intermittent applications, should begin between the second and third week after potting. Resin-coated slow-release fertilizers can be blended with any compost-amended potting mix. They have a delayed release period (of two to three weeks) that coincides with nutrient reserve in the compost.

Soil testing is a frequent practice when growing plants in containers. However, to obtain a true measure of pH and soluble salts in potting media containing compost, delay testing at least two weeks after blending. This waiting period is necessary to allow the chemical properties of all the *amendments* to balance. After blending, moisten the media to approximately "pot capacity" and stored at room temperature in a sealed polyethylene bag. Although an approximate value of pH and soluble salts can be measured after one week of storage, an additional week is generally needed to obtain a true value. The same testing procedures recommended for measuring pH and soluble salts in compost should be used for measuring pH and soluble salts in the potting mix (see chapter 3).

The amount of lime or sulfur needed to adjust the pH to the desired level is dependent on the compost and other amendments. Therefore, it is best to make small test batches well in advance in order to make the final determination.

Using Compost As a Soil Amendment for Gardens and Field Crops

Compost applications to land should be based on soil test results and crop needs. Soil test results help determine which type of compost would be most advantageous and how much should be used. Soil testing is recommended when using compost initially and when making repeated applications. This is to prevent a nutrient imbalance from occurring and to make efficient use of compost.

It is important to know the soil nutrient levels, pH levels, and the needs of the crop to be grown. Some composted materials are rich in phosphorus, while other composted products contain low levels of phosphorus but are rich in potassium. The amount of nitrogen contained in compost does not vary as greatly as do phosphorus and potassium. Since compost tends to have a near-neutral pH, it will raise the pH of acidic soils but will contribute little to lowering the pH of alkaline soils. Lime-fortified compost would be beneficial for acid soils but could create problems in soils where the pH is above 6.0. In such instances, a compost that does not contain lime is more desirable.

In determining compost application rates based on crop needs, it is important to remember that only 8–12% of the nitrogen in the compost is available for plant growth in the first year. For a crop that requires a large amount of nitrogen, supplemental feeding with mineral fertilizers may be necessary. Compost application levels should not exceed 50 dry tons per acre or 4 *cubic yards* per 1,000 square feet. Upper limits of compost applications have been established to avoid creating environmental risk when the composted raw materials include toxic substances (for example, sewage sludge and solid waste).

When used at the maximum allowable rate, compost supplies most of the nutrient needs of plants through the first growing season. With time, less nitrogen becomes available; so, generally, supplemental nitrogen and potassium fertilizers are necessary during the two to three years following the initial application. However, this varies depending on soil type and crops to be grown. Although the crops do not usually exhibit nitrogen-deficiency symptoms during the second and third years after the initial application, the plants may not be growing at their optimum rate.

Compost may be applied using conventional rear-delivery or side-delivery manure spreaders for covering large acreage (figure 8.2). For the application of compost as a *top-dressing,* broadcast cyclone-type applicators or modified rear-delivery manure spreaders with brushes are being used. To obtain maximum uniformity of application of top-dressing compost, it should contain less than 40% moisture. Compost can also be spread on level ground using front-end loaders and land-levelers or road graders. For small areas, compost can be uniformly spread using shovels and rakes. In general, a 1-inch thick layer of compost, containing 50% water, is equivalent to 50 dry tons per acre.

Specific Applications

Home Gardens. Only high-quality compost with low soluble salt concentrations should be used for home gardens. The compost should consistently have a good earthy color and odor and be free of clods. Consistency of the product is the key to maintaining customers. As a soil amendment for gardens, rates of application should be based on soil test results but should not exceed 4 cubic yards per 1,000 square feet. To obtain maximum benefits, the compost should be applied and incorporated just prior to seeding or transplanting.

Agronomic and Horticultural Crops and General Landscaping Uses. Compost with qualities similar to the soil amendment grade (table 8.1, page 79) should be used for the production of agronomic and horticultural food crops and in the manufacturing of top-soil for landscaping. Because this compost will be mixed mostly with soil, the consistency, pH, and soluble salt levels are not as critical. However, heavy metal and contaminant levels of the compost should not exceed environmental standards for unrestricted use in case food crops are grown on compost-amended land. Application rates should be based on soil test results, and levels of application should not exceed 50 dry tons per acre. In the manufacturing of top-soil, the proportion of compost should not exceed one-third by volume of existing soil. It can be limed to achieve a desirable pH.

Non-Food Crops. Compost which does not meet minimum environmental standards for food crop production can be used for growing nursery stock and forest seedlings, field- and bed-grown ornamental plants, and sod; for highway and golf course construction; for establishment and maintenance of public gardens and landscapes; and for the reclamation of disturbed lands. The harvesting of nursery-grown plants by balling the roots with soil removes in excess of 250 tons per acre of top soil with the harvest of each crop. The harvesting of sod removes 20–25 tons of soil per acre per crop. Amending the soil with 50 dry tons of compost per acre between crops is an effective means of maintaining soil productivity. The use of compost in establishing and maintaining landscapes reduces our dependency on imported peat moss and commercial fertilizers while providing organic matter rich in plant nutrients.

Dedicated Land. Compost with excessive levels of heavy metals can only be used for landfill cover or for other uses on land dedicated to the disposal of waste materials. The application rates would be based on soil test, loading limits, and regulations developed for such uses. Application of highly contaminated compost or repeated applications of moderately contaminated composts severely restricts the future use of the land.

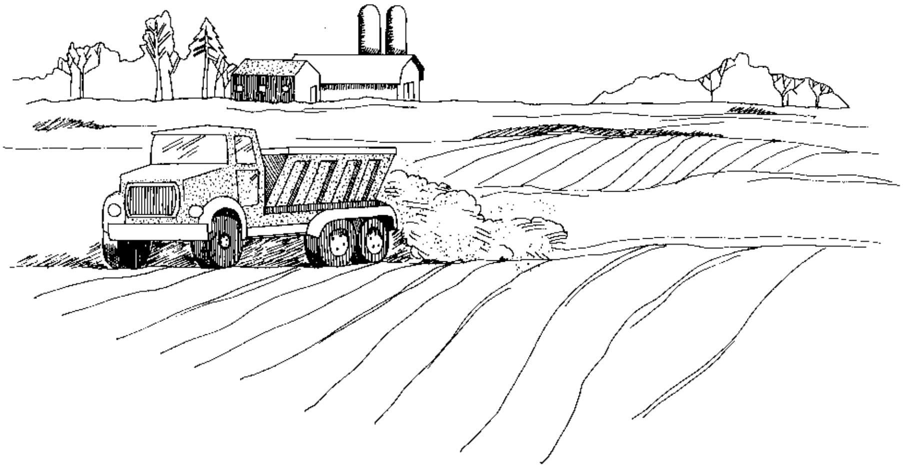

Figure 8.2
Field application of compost.

Using Compost for Plant Disease Control

Composts have been used for several thousand years to control diseases caused by soilborne plant *pathogens*. This approach to disease control was practiced long before pathogens were identified. In Oriental agriculture, complex *recipes* for the production of composts were prepared to improve soil health. Today, mostly because of research performed in the past twenty years on biological control of such diseases, we have a fairly clear concept of the many mechanisms responsible for this form of disease control.

The disease-controlling qualities of compost result mainly from the presence of beneficial microorganisms which are antagonists of plant pathogens. However, the substantial reduction of plant pathogens that occurs during composting also plays a large role. In addition, certain physical and chemical factors of compost contribute to disease control.

Composting results in the production of heat by microorganisms active in the process. Temperatures of 100–150°F (45–65°C) occur during composting. With time, these high temperatures kill pathogens and weed seeds. Frequent *turning* of *windrows* and insulating layers of compost on static piles ensure uniform high temperature exposure and thus uniform pathogen kill.

After the organic matter begins to stabilize and temperatures decline to below 100°F (40°C), the normal soil microorganisms recolonize the compost. These microorganisms include many types of beneficial organisms that kill, inhibit, or simply compete with pathogens in soil. Micro-arthropods, such as spring tails and mites, also devour pathogens in soils amended with compost.

The activity of the beneficial *microflora* and *microfauna* is supported by the available energy reserves in the compost. This property of compost determines its impact on the microbial carrying capacity of treated soil. Science has not yet progressed to a point where it can predict this phenomenon for soils as accurately as we can for animal feeds or human diets.

Procedures have been developed to measure microbial activity in compost-amended substrates and predict the potential for the development of *Pythium root rots*. Essentially, the procedures provide information on the nutritional status or health of the soil microflora. For example, a soil in which organic matter is highly decomposed and mineralized is also a soil that has low microbial activity and, thus, conducive to the development of soilborne diseases. Organic matter in the appropriate form should be applied to such "worn-out" soils to replenish the energy reserves for the beneficial microflora. Manure applied in the fall or compost applied weeks ahead of planting has such effects. Appropriate management of crop residues also has such impacts.

It is important for the organic matter in the compost to be stabilized (decomposed) well enough so that it cannot serve as a food base to plant pathogens. Fresh crop residues enhance the activity of many pathogens, even in the presence of large numbers of beneficial microorganisms. Therefore, proper composting and *curing* are necessary to obtain the full benefit of the compost's disease-controlling effects.

Chemical and physical properties of composts may enhance or negate the beneficial effects of composts. For example, composts high in salinity, applied just ahead of planting, increase *Phytophthora root rot* of soybean. If the compost is applied months ahead of planting, salts leach out, biological control is induced, and a positive crop response is obtained. Some composts, particularly those prepared from tree barks, release chemicals which inhibit some plant pathogens. Other factors like particle size, pH, and nitrogen content also influence disease suppression.

Some leaf and stem diseases may be controlled by spraying plants with water extracts from composts. This treatment is said to induce protection in plants against some foliar pathogens. Research on this topic is still in the exploratory stage, however.

Because nursery operators use compost for its disease-control advantages, the ornamentals industry has developed a great deal of knowledge about compost quality and how it affects plant productivity. Equivalent knowledge for vegetable and agronomic crops is lacking. The growing awareness of possible environmental impacts of soil pesticide use and high direct costs associated with fumigation or soil sterilization promise to remedy this situation. More rational procedures for using farm manures should also improve chances for reaping the beneficial effects associated with compost.

For more information of soilborne disease suppression, see the suggested readings section (page 178).

9

Marketing Agricultural Compost

Before you get excited over the prospect of selling agricultural *compost* as a cash crop, ask yourself, "Where am I going to sell it?" Can you imagine buying fifty thousand laying hens before you know where you'll sell the eggs? Compost marketing is little different from marketing eggs or any other agricultural commodity. The markets you establish will determine your success or failure; establish your likely customers before you have your product in-hand. You must know how much product your customers can use, what price they are willing to pay, and what qualities they want in the product. You must also know your projected cost per ton.

Farm Compost's Market Position

As more communities turn to *composting* to treat *sewage sludge, yard waste,* and solid wastes, the supply of compost is expected to grow. Fortunately, demand is also on the rise. Nevertheless, the increasing supply makes your marketing effort all the more important.

One of the main tasks in marketing farm-produced compost is to carve out a niche which separates your agricultural compost from the waste-derived composts. It does not matter if these other compost products are of good quality and perform well. Consumers perceive them as lower quality, something less than pure. On the other hand, composts made from food, plant, and animal by-products have an old and respected reputation. Promotional efforts and consumer education can effectively build on this sentiment. In addition, regulations may restrict the use of some sludge or solid waste composts. This leaves an opening in the market for agricultural composts to fill.

Farm-produced compost occupies a high-quality position in the market. Your marketing efforts should take advantage of this position and help to maintain it. This means that the highest priority must be placed on quality control, in both the production system and in your choice of raw materials.

Evaluating and Developing the End User Market

Potential buyers of compost include landscapers; commercial nurseries; home and garden centers; greenhouses; homeowners; farmers (fruit, vegetable, field crops, organic); golf courses and cemeteries; public works departments; road and highway contractors; schools; parks departments; turf growers; and developers (table 9.1). All of these groups use compost or some other product that compost can replace, including *peat* moss, topsoil, and chemical fertilizer. Public works departments, schools, landfills and other municipal and county users are likely to obtain compost from their own sludge or yard waste composting facilities. In this case, commercial high-value users, such as landscapers, greenhouses, garden centers, and nurseries, become the primary prospects.

Once you know the potential buyers, the next step is to determine how large the market for compost actually is. In most cases, the market for compost is very local, within 25–50 miles of the composting facility, because the cost of transportation is high compared to other production costs. Although transportation restricts the market area, it also limits competition. Within the local area, the potential buyers of compost products should be contacted to determine if they would purchase compost, how they would use it, and what

Table 9.1
Potential users of and uses for compost

User group	Primary uses for compost products	Compost products[a]	Packaging
Agricultural and residential			
Forage and field-crop growers	Soil amendment, fertilizer supplement, top dressing for pasture and hay crop maintenance	Unscreened and screened compost	Bulk
Fruit and vegetable farmers	Soil amendment, fertilizer supplement, mulch for fruit trees	Unscreened and screened compost	Bulk
Homeowners	Soil amendment, mulch, fertilizer supplement, and fertilizer replacement for home gardens and lawns	Screened compost, high-nutrient compost, mulch	Primarily bags, small-volume bulk
Organic farmers	Fertilizer substitute, soil amendment	Unscreened and screened compost, high-nutrient compost	Primarily bulk
Turf growers	Soil amendment for turf establishment, top dressing	Screened compost, topsoil blend	Bulk
Commercial			
Cemeteries	Top dressing for turf, soil amendment for turf establishment and landscape plantings	Screened compost	Bulk
Discount stores, supermarkets	Resale to homeowners	General screened compost product	Bags
Garden centers, hardware/lumber outlets	Resale to homeowners and small-volume users	Screened compost, mulch	Primarily bags, small-volume bulk
Golf courses	Top dressing for turf, soil amendment for greens and tee construction, landscape plantings	Screened compost, topsoil blend	Bulk
Greenhouses	Potting mix component, peat substitute, soil amendment for beds	High-quality, dry, screened compost	Bulk and bag
Land-reclamation contractors	Topsoil and soil amendment for disturbed landscapes (mines, urban renovation)	Unscreened compost, topsoil blend	Bulk
Landscapers and land developers	Topsoil substitute, mulch, soil amendment, fertilizer supplement	Screened compost, topsoil blend, mulch	Bulk
Nurseries	Soil amendment and soil replacement for field-grown stock, mulch, container mix component, resale to retail and landscape clients	Unscreened and screened compost, composted bark, mulch	Primarily bulk, some bags

Note: Unscreened compost with a consistent texture and few large particles may be used in place of screened compost.

[a] Topsoil blend is a mixture of compost, soil, or sand to make a product with qualities similar to topsoil or loam. Mulch includes unscreened, coarse-textured compost such as composted wood chips or bark.

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Table 9.1
Potential users of and uses for compost (continued)

User group	Primary uses for compost products	Compost products [a]	Packaging
Municipal			
Landfills	Landfill cover material, primarily final cover	Unscreened low-quality compost	Bulk
Public works departments	Topsoil for road and construction work, soil amendment and mulch for landscape plantings	Unscreened and screened compost, topsoil blend	Bulk
Schools, park and recreation departments	Topsoil, top dressing for turf and ball fields, soil amendment and mulch for landscape plantings	Screened compost, topsoil blend, mulch	Bulk

Note: Unscreened compost with a consistent texture and few large particles may be used in place of screened compost.

[a] Topsoil blend is a mixture of compost, soil, or sand to make a product with qualities similar to topsoil or loam. Mulch includes unscreened, coarse-textured compost such as composted wood chips or bark.

quality characteristics they expect in the compost. A simple survey conducted by mail, by phone, or in person can be helpful (figure 9.1).

After you know who and where your potential customers are and what they are looking for, a target market can be developed. The compost you produce must meet the needs of the target market. For example, many commercial nurseries want compost primarily for its soil-building qualities but not necessarily for its nutrients. On the other hand, organic farmers prefer compost products with high nutrient concentrations. Many home gardeners want a compost that is uniform, clean, and free of contaminants. Meeting the needs of the target market may dictate a change in the production system—adding a screen for example. If you find that you cannot produce the kind of compost demanded by the target market, then a different market must be developed.

Offering a variety of compost products may increase your success at developing a target market. For instance, in addition to compost, you might provide a composted *mulch* material and topsoil made from a blend of compost and soil. You might offer different grades of compost such as *soil amendment* grade, a nutrient-rich fertilizer grade, or a potting media grade.

Although the characteristics that users require of compost vary with the specific use, compost users generally share several common expectations. These are listed below, roughly in their order of importance.

- Quality. Quality compost is probably the number one requirement from the user's standpoint. It is not enough just to make compost. You have to make quality compost—not the kind of compost product you are capable of producing but the kind that the customer wants. A user's judge of quality depends on the ultimate use. But common criteria include moisture; odor; feel; particle size; *stability;* nutrient concentration; and a lack of weed seeds, *phytotoxic* compounds, and other contaminants. The product must also be consistent. The product must have nearly the same *moisture content,* particle size, and/or nutrient concentration from batch to batch. If not, the customer never gains confidence in using it. A consistently stable product is particularly important; just one bad lot of compost will turn away customers forever if it harms their plants.
- Price. The price must be generally competitive with other composts and compost substitutes (top soil, peat moss, and so on), though a higher price can be offset by high quality and performance.
- Color/texture/odor. Users expect compost to be uniform in *texture* and relatively dry (that is, less than 50% moisture) and to have an earthy color and odor.
- Information. Most potential customers are unfamiliar with compost's characteristics. At least initially, they want and need information about its benefits and how to use it. For some users, the most important information is an analy-

Company name ________________________________

Contact person ________________________________

Address ________________________________

Phone number ________________________________

Best time to call ________________________________

Type of business ________________________________

1. What are your annual purchases of the following?

	Tons	Amount Used	Amount Sold	Cost per Ton	Tons of Bulk Purchases
A. Composted manures	____	____	____	____	____
B. Fresh manures	____	____	____	____	____
C. Dried manures	____	____	____	____	____
D. Peat	____	____	____	____	____
E. Loam	____	____	____	____	____
F. Organic fertilizers	____	____	____	____	____

2. At what percentage are your annual needs for the above items increasing or decreasing? ____________
3. What are your current terms of purchase? ________________________________
4. If compost were available in quantity, on an ongoing basis, how much would your purchase? Would the purchase terms differ? ________________________________
5. Under what conditions would you be prepared to negotiate a purchase agreement for compost? ________

   ____
6. What are your major concerns when purchasing a compost product (such as odor, price, NPK, fineness, packaging, contract)? ________________________________

   Additional comments ________________________________

   ____

   ____

Please return to: J. Compost Farmer
100 Dairy Road
Poultryville, MA 00000
(123) 456-7890

Figure 9.1
Sample compost marketing survey.
Source: Massachusetts Department of Environmental Protection, Division of Solid Waste Management.

sis of the nitrogen-phosphorus-potassium *(N-P-K)* nutrient concentration and *pH*. Many users also desire information about application rates and application procedures.

- Reliable supply. Customers expect a reliable supply, especially if they have been given a commitment.

Bag versus Bulk Sales

One of the first marketing questions to consider is how to sell compost—in bulk, in bags, or in both. Bags accommodate customers who need compost in small quantities and are conveniently handled at retail outlets. Bagged products also sell at a considerably higher price than most bulk compost. The higher price justifies higher transportation costs and, therefore, a larger market area. In short, bagging expands the potential market. However, for this same reason, the bagged compost market is served by large-scale commercial composters. Farm composters selling bagged product must be able to compete with large-volume producers. In addition, they must recover the cost of equipment and labor for bagging and the cost of storage of the bagged product during the off-season. Quality control is also more critical since the compost remains in plastic bags for a relatively long time.

For small volumes of bagged product, you could consider offering bagged compost locally as a soil amendment to home gardeners. Customers could come to your farm and bag their own compost. You could also place bags at local stores. You would have to advertise the product locally, providing the names of the stores offering your product. If the volume of bagged sales is small, you can bag them by hand at the farm. Otherwise, consider subcontracting the bagging operation to a company that bags other products.

Most farm composters have found the bulk market a more favorable arena in which to participate. Transportation costs keep the bulk market at a very local level, so relatively small producers can compete. Compost could be offered in bulk right from your farm. Sell it by the *yard*, picked-up or delivered. The best market for this type of sale is the home gardener, local nursery, or landscaper. If you expect to produce a large volume of compost, you will need to spend more time developing firm markets that will be reliable customers year-after-year. Large wholesale nurseries, landscapers, public and private housing projects, municipalities, new home builders, greenhouse operators, and organic gardeners are all prospects for quantities of bulk compost.

Selling Your Product

Marketing your compost can be a minor or major task, depending on the amount, quality, appearance, and seasonal availability of your product. Most compost is used in the spring and early summer. Your product must be stable and suitably dry for delivery at that time. A consistently high-quality product is critical to the marketing effort. If a problem should occur with a customer using your product, you must remedy the situation immediately, both with the production process and with the dissatisfied customer.

Since you will be offering a product with some very unique characteristics, it is important that you know and stress those points when offering your product to customers. What are those characteristics?

- Compost is usually pH-neutral, which means it will neither add to nor detract from the acidity or alkalinity of soils.
- Compost is a soil amendment. Though it does contribute substantial nutrients to the soil, it should not be compared to chemical fertilizers.
- Compost is one of the best sources of *organic matter* available. When organic matter is added to soils, the water- and *nutrient-holding capacity* is increased, providing plants with superior growing conditions.
- As the organic matter of compost decomposes, it slowly releases its nutrients to plants. It will not burn plants the way chemical fertilizers can. The nutrients and other beneficial effects of compost last for several years.
- The organic matter in compost acts like a sponge, retarding the loss of moisture and nutrients from fertilizers, holding them available in the plant root zone.
- Properly made compost is nearly free of weed seeds—a big selling point. But it can also hurt your credibility if you cannot produce weed-free compost.
- Farm compost is made primarily from livestock *manures* and plant materials, not from sewage sludge or solid wastes. Customers may be concerned with what materials are used in making compost.
- Composting is an environmentally beneficial process, and compost is an ecologically sound product.

Emphasizing the positive benefits of compost will normally be sufficient to convince a prospective customer of its value. The fact that compost is made from recycled by-products is also helpful. To convince skeptical customers, use your products in demonstration plots and gardens. Although customers may gain satisfaction in participating in a recycling effort, offer compost as a valuable resource, not as a treated waste material.

10 Farm Composting Economics

Focus on Production Costs

Composters harness the agents of rot and decay to transform materials of little or even negative worth into a valued product. A few farm-produced composts are reportedly marketed at bulk prices exceeding $50 per *cubic yard.* However, most *compost* does not command such prices. Usually it is used directly by the composter or sold for prices under $10 per cubic yard in bulk.

Like most products, the price that can be charged for a given compost product depends on its consistency, overall quality, promotion, packaging, and associated services (for example, bulk delivery). These factors, in turn, depend upon the operational scale, skills, commitment, and resources of the compost maker. Only the most sophisticated producers meet the needs of the discriminating market for potting soils. Marketing packaged compost is unlikely to be economical for any but the largest compost producers. Most farm composters are best able to produce and distribute small to moderate quantities of bulk composts. Because bulk compost markets tend to be poorly developed and transport costs are relatively high, potential revenues vary with the compost's local competitiveness with substitute products.

The advantages of agricultural *composting* have been sufficient to convince a small but growing number of farmers to compost. These farmers have incorporated composting of a wide variety of organic wastes generated on- and off-farm into their normal operations. Some own large commercial enterprises. Others are small hobby farms. Some use all or most of the finished compost on-farm, while some market compost and soil mixes as an agricultural product. Many use existing on-farm technology to manage the compost piles. Others have invested in specialized compost production equipment.

The experiences of these pioneering composters demonstrate the practical potential for many different types of farms to compost successfully. However, a number of false starts and the limited number of farm composters balance this potential with caution. Despite escalating landfill fees, materials which bring *tipping fees* may be difficult to capture. In several cases, eager farmers have discovered that waste generators already have other local disposal options. Many farmers, particularly those distant from population centers, do not have the resources or location to take advantage of the potential for compost sales. Perhaps most importantly, each farmer must look closely at his or her own farm and financial resources to determine whether or not it would be advantageous to adapt and dedicate space, labor, and equipment to composting. Even the farmer that has a guarantee of revenues from waste disposers at the front door and from compost buyers at the back door must make sure that the costs of composting will not lead to long-term losses. This is particularly important when off-farm wastes are acquired in exchange for tipping fees. Unexpected costs, such as legal fees and odor control systems, can quickly eliminate the profit anticipated from tipping fees.

General Production Costs

Any farmer starting to assess the likely costs of a composting operation should ask a few basic questions. First, what quantity of appropriate organic materials are available and at what price? Many farmers have the potential to compost up to several thousand cubic yards of material each year without significant added costs. Larger volumes require greater commitments of land, labor, and/or capital investment.

Second, what kinds of on and off-farm materials are available? Preferable on-farm candidates are uncontaminated organic waste materials that have significant handling or disposal costs, whether composted or not. Preferable off-farm materials are those that come with a tipping fee and complement the important physical characteristics of on-farm compostables (*carbon to nitrogen ratio, moisture content*, particle size, and so on). Care must be taken to ensure that off-farm materials like municipal leaves or cardboard are free of contaminants (for example, metals, concrete, and chemicals) that can harm processing machinery or reduce the value of the final product. Usually, the farmer will not have to purchase any compost ingredients. However, even on-farm materials can impose significant costs because of additional handling.

Third, how much land can the farmer devote to composting? Composting can be land-hungry. Farmers serious about composting are likely to want at least an acre of land with suitable slope, drainage, and access. The amount of land available determines the composting technology adopted. Depending on the technology used, an acre can handle from two or three thousand cubic yards to tens of thousands of cubic yards of compostables per year. If land is scarce or costly, then farm composters need to invest in the capital equipment that allows them to minimize their land use.

Fourth, what are the expected markets or uses for the finished compost? The production of compost to meet the needs of a high-value market calls for rigorous quality control. Equipment for improving the final product through *shredding* or screening may be necessary. Marketing expertise is also required, along with associated marketing costs. Many farmers prefer to simplify their composting systems by taking advantage of the benefits of adding compost to their own soils. Much of the expensive extra processing adds little value to the compost for on-farm application.

In reality, the costs of a particular composting operation depend on a large number of variables which differ from farm to farm. Such variables include the local costs of labor and fuel, the value of land, and the cost of purchasing and maintaining equipment. Several location factors can have strong influences on costs. These include proximity to neighbors; the distance to off-farm sources of raw materials; and the distances on-farm materials must be moved, first to the composting site and later from the composting site to the point of final use. Other factors include the need for local or state permits, interest rates and credit terms, the quality of product desired by the end-user, and so forth.

Compost can be produced using different combinations of land, labor, and equipment. More expensive management systems can handle more material in a given land area, largely by decreasing the time required to produce finished compost. As the volume of material to be composted increases, the tendency is to first increase labor and then to purchase more sophisticated composting equipment.

Depending on the scale of operation and the technology adopted, initial outlays for site preparation, planning, permits, and equipment can range from a few hundred dollars to hundreds of thousands of dollars. The greater initial expense buys greater production capacity and/or a higher-quality final product. Existing municipal compost operations report total costs of production from several dollars per ton to more than a hundred dollars per ton of raw material. Farmers face a similar broad range of costs. The key to minimizing the cost per ton is to make full use of the production capacity. This is first accomplished by selecting equipment appropriate for the scale of operation.

Comparative Costs of Composting Methods

There are at least five basic approaches to composting. In roughly increasing order of capital investment, they are:

- the *passive* pile approach
- *windrow* composting using a loader for *turning*
- windrow composting using specialized windrow turners
- *aerated static pile* systems
- *in-vessel* systems

The Passive Pile Approach for Very Small to Moderate-Sized Operations

Farmers using this approach form piles of organic materials and then let them sit until the materials have degraded into a stabilized product. Overall costs of composting are minimized. They are likely to be dominated by the costs of the land used. This cost usually derives from the lost opportunity to put the land to other uses, not from out-of-pocket expenses. The costs of the labor and equipment used to form and mix the initial piles are the largest operational expenses. Farm loaders and *manure* spreaders are usually briefly diverted from other farm uses for this purpose. Reported costs of pile formation range from less than $1 per ton to more than $6 per ton of incoming material. These vary with the materials composted and amount of equipment used. In some cases there may be significant additional costs of transporting organic materials to and from the site.

The Loader-Turned Windrow Approach for Small to Moderate-Sized Operations

The loader-turned windrow approach is similar to the passive pile approach in that no additional equipment or investment is required. The key difference is that the piles are actively managed. Piles are turned with a tractor and *bucket loader* alone or with a manure spreader and tractor-loader combination. Volumes of material are likely to range from a few hundred to several thousand cubic yards per year.

Costs of composting by this approach are minimized by using the loader for other farm chores as well. The costs of turning and pile management can be added to the costs of initial pile formation and mixing discussed for the passive pile approach. Despite added costs, turning and mixing the piles even a few times per year hastens decomposition and improves the quality of the final product. It can take several days to turn moderately large piles of several thousand cubic yards. Turning piles three to five times during the year seems typical for yard-waste-based operations of this scale. However, the frequency of turning may need to be increased to control odors or speed up the process.

The experiences of municipal leaf-compost operations suggest that it costs about $5 per ton of raw material to turn piles with a front-end loader three to four times per year. Costs include municipal equipment, land, and labor. Costs directly associated with pile turning and formation usually account for at least 80% of this per ton cost.

What does it cost to turn and mix piles using standard farm equipment? The costs depend strongly on the character and *bulk density* of the materials being turned and also on the turning technique and the skill of the operator. The power and size of the equipment used obviously make a difference, as does the decision to use a manure spreader in addition to a farm loader. Municipal front-end loaders take roughly a minute to go through a simple cycle to load, dump, and maneuver. Farm loaders appear to be capable of similar performance. The amount of material loaders can process per hour is proportional to the size of their buckets. Thus, a farmer can increase the turning rate ninefold by using a 3-yard (cubic yard) loader in place of 1/3-yard loader. However, the capital cost of a 3-yard municipal loader is roughly nine times that of a skid loader or small tractor with a 1/3-yard bucket loader. Buying used equipment can reduce up-front capital outlays significantly.

The likely range of costs of turning and mixing with a loader is indicated by the data listed in table 10.1. The costs of turning windrows once are normally between $1 and $4 per ton.

Table 10.1

Reported costs of turning windrows with bucket or front-end loaders

Turning equipment/technique	Materials	Capacity (cubic yards per hour)	Turning cost per ton
100-horsepower tractor with 1-cubic-yard bucket loader	Leaves	70	$1.50–2.00 [a]
100-horsepower tractor with 1-cubic-yard bucket loader plus manure spreader and second 100-horsepower tractor	Leaves	70	$3.00–4.00 [a]
Front-end loader (22.5 cubic feet) plus manure spreader and tractor	Poultry litter	42	$1.12 [a]
Front-end loader (22.5 cubic feet) plus manure spreader and tractor	Poultry litter and leaves (1:1)	37	$1.25 [a]
Front-end loader (22.5 cubic feet) plus manure spreader and tractor	Poultry litter and newspaper (1:4)	15	$3.75 [a]
40-horsepower tractor with 1/3-cubic-yard bucket loader	Bull manure and sawdust bedding	20	$2.25 [b]

Sources: Dreyfus, Gresham et al, Richard.

[a] Assumes equipment owning and operating costs of $30 per hour (1988).
[b] Assumes equipment owning and operating costs of $15 per hour (1990).

An important factor to keep in mind is that the volume and weight of most incoming material decrease rapidly when composted, particularly in the first months after initial mixing. Eventual reductions in volume depend on the materials involved, but 50–80% reductions are normal. This means that second and subsequent turnings should be substantially less expensive and time consuming than the initial turning. One farm composter estimated that the sum of three subsequent passes (at three-month intervals) through well bedded bull manure only took 1 1/2 times as many hours as the first turning. This corresponds to a total turning costs of about $6 per ton of incoming manure. While there may be good reasons to turn a pile frequently after initial formation, the composter can reduce costs by waiting to turn piles that are shrinking rapidly anyway.

Turning piles using a loader adds several hundred dollars to the cost of a small composting operation and several thousand dollars to larger farm operations handling about 500 tons of material a year. However, most of this cost will be paid not in cash but in hours the farmer is not devoting to other tasks and in the accelerated depreciation or repair of farm equipment.

The Specialized-Equipment Approach for Moderate to Large Windrow Operations

As the volume of material increases, composting tends to become a central rather than an add-on farm activity. As the demand for land, labor, and equipment begins to interfere with other farm activities, most farmers purchase additional equipment dedicated to the composting operation. Additional farm labor will also be needed.

Many farmers facing this choice invest in specialized windrow turners. Municipalities using windrow turners for large volumes of *yard wastes* have reported total costs of producing compost (including full equipment, land, and labor charges) in the range of $15–30 per ton of incoming material. Calculations on the costs of composting 10,000 tons of *poultry litter* and sawdust annually suggest that lower costs may be achievable. These calculations estimate the total costs of composting to be about $5.50 per ton of incoming material (assuming no cost for raw materials) for both a system using a loader and a more intensively managed system using a windrow turner.

Windrow turners can substantially reduce the amount of time spent turning piles. Nevertheless, a loader will still be required for initial pile formation, pile maintenance, and other tasks such as feeding a compost screener or shredder. A small *PTO*-driven windrow turner can process roughly 200 tons of material per hour at a capital cost of around $10,000. Larger windrow-turning machines, including self-propelled models, can process over 2,000 tons per hour and cost $75,000–200,000 (see table B.1, pages 115–119).

Table 10.2 compares the overall costs and amount of time required to turn, based on the volume of incoming material. These hypothetical examples focus strictly on turning windrows. Volumes of incoming material range from a modest 1,000 cubic yards to a substantial 15,000 cubic yards per year. In these examples, the time required to turn the material four times a year ranges from fifteen hundred hours to less than an hour, depending on the amount of material and on the capacity of the turning equipment. All the windrow turners can handle up to 15,000 cubic yards of incoming material in about one hundred hours or less. The largest one would scarcely need to be warmed up to manage 15,000 cubic yards. In contrast, the smallest loader would need to work almost full time to manage that volume of material. Even the large front loader takes more than four weeks to turn the 15,000 cubic yard windrow four times. In reality, anyone who invested in a windrow turner would turn the piles more frequently than four times. Similarly, a small tractor or skid loader operator would not likely turn the 5,000 or 15,000 cubic yards even four times.

Turning becomes less costly on a per-unit-volume basis as the volume of material increases and equipment is used more efficiently. None of the specialized windrow turners are competitive if very small volumes of material are to be turned. As the amount of material turned increases (either through more incoming material or because of more frequent turning), the windrow turners become more competitive. At 15,000 cubic yards per year, the PTO-driven turner is the least costly, and the self-powered windrow turner is no longer the most costly approach. The economies of scale are not nearly as great for the loaders. The skid loader and tractor loader are the most cost effective turning approach at small volumes and remain relatively inexpensive even as volumes increase. This is because variable operating costs are low and the modest capital costs continue to be spread over other farm activities. The poor showing of the large front-end loader results from the assumption that it has few other farm uses, which may not be the case.

Farm Composting with Static Pile or In-Vessel Systems

There is little experience using aerated static piles with *agricultural wastes*. Municipal experiences with aerated static pile systems indicate costs in the range of $20–50 per wet ton of incoming material. The technology is commonly used for treatment of municipal *sewage sludges*. The capital costs of these systems range from about a hundred thousand dollars for a village of a few thousand people to millions of dollars for systems capable of handling the waste from a large city.

Costs for municipal in-vessel systems are typically $50–100 per ton, while some of the more expensive systems report costs as high as $150 per ton. Such high costs are justified where land is limited and/or maximum process control is needed.

Calculations based on a hypothetical poultry litter composting operation suggest lower costs may be achievable. The estimated total capital investment for a 40,000 ton per year aerated pile system is $1.1 million, compared to $1.4 million for an *agitated bed* in-vessel system of the same capacity. With annual variable costs of $79,000 and $67,000, respectively, total

Table 10.2

Time and costs of turning windrows four times annually

	Incoming material											
	1,000 cubic yards			5,000 cubic yards			15,000 cubic yards			Assumptions		
Equipment used	Total cost	Hours	Cost per cubic yard [a]	Total cost	Hours	Cost per cubic yard [a]	Total cost	Hours	Cost per cubic yard [a]	Capital costs	Hourly operating costs	Processing capacity (CYH) [b]
Small loader (40 horsepower); 1/3-yard bucket	$1,423	100	$1.42	$6,398	500	$1.28	$17,276	1,500	$1.15	$15,000	$10	25
Tractor (85 horsepower) and $6,000 loader attachment; 1-yard bucket	$1,116	33	$1.12	$4,800	167	$0.96	$11,669	500	$0.78	$45,000	$13	75
Front loader (135 horsepower); 3-yard bucket	$3,062	11	$3.06	$11,365	56	$2.27	$21,135	167	$1.41	$130,000	$22	225
Windrow turner (small, PTO-driven) with 40-horsepower tractor	$2,326	6	$2.33	$2,885	31	$0.58	$4,205	94	$0.28	$28,000	$13	400
Windrow turner (large, PTO-driven) with 100-horsepower tractor	$4,383	2	$4.38	$4,551	10	$0.91	$4,996	31	$0.33	$65,000	$19	1,200
Windrow turner (medium size, self-powered) with 80-horsepower tractor tow	$17,360	1	$17.36	$17,491	3	$3.50	$17,797	9	$1.19	$115,000	$32	4,000

Note: Operating and ownership costs are included. Turnings are assumed to be timed such that 2.5 times the incoming volumes are turned after accounting for shrinkage. Total compost turning hours are calculated by dividing the total volume to be turned by the assumed hourly processing capacity of each machine and, therefore, assume maximum efficiency with no breaks. The proportion of total hours of farm use attributable to composting is calculated by dividing turning hours by the sum of turning hours and typical hours of farm equipment use reported for each type of equipment in New York farm survey data. Ownership costs are annualized over ten years assuming 11.5% interest rates and 40% salvage values. Insurance and storage are assumed to be 2% of the purchase price annually. Operating costs assume $6.50 per hour labor for tractors. Other hourly operating costs are based on long-term rental rates or derived from O&M data provided by equipment manufacturers or New York farm survey data.

[a] Multiply costs per cubic yard by 4 or 5 for per-ton costs for leaf composting; less for denser materials.

[b] CYH stands for cubic yards per hour.

costs per ton of raw material are $7.64 for the aerated pile and $8.40 for the agitated bed systems. These figures include the cost of land, structures, labor, and equipment (composting, screening, and bagging). They exclude the $410,000 estimated annual cost of raw materials.

Another project estimated ownership and operating costs of $2,661 per year for a small aerated static pile system, scaled to manage 200 tons of fish waste plus sawdust and other *amendments*. This cost includes use of a machine to mix materials, a loader to form piles, an electric blower (335 cubic feet per minute), and 4-inch perforated pipes. It excludes costs of transportation, purchase of *bulking agents*, land, and site preparation. The $2,661 translates into $13.31 per ton of fish wastes composted. Farmers might find a simple system like this to be cost-effective.

Case Studies

The following case studies are based on information provided by cooperating farm composters. The specific information is based partly on farm records and partly on personal recollections of prices paid, hours worked, and other variables. Some farmers reported on the time and money it took to perform specific tasks in a single compost cycle. Others reported monthly average uses of compost personnel and equipment. These kinds of information sources normally vary in completeness and precision and are meant to be illustrative rather than definitive.

Farm Composter #1

Farm Composter #1 is a certified organic vegetable producer that has composted a variety of materials using the passive pile method. Approximately half of the 60-acre farm is devoted to pasture or small fruit and vegetable production. A wide variety of crops is grown, though the farm specializes in asparagus, garlic, greens, and root crops.

The compost operation occupies about a one-acre site on a corner of the farm. The nearest neighbors are thousands of feet away. The site is very near a locally maintained paved road, but a short roadbed of crushed limestone had to be built into the site to allow delivery truck access. Approximately four hours of farm labor were required to grade the access road. In exchange for composting certain county wastes, free limestone was delivered by the county government. The site had an estimated land value of $500–600 in 1991. The farm as a whole is in a state agricultural district, and the site is part of a small parcel currently enrolled in a USDA conservation easement program. Hence, the land is utilized at no cost attributable to composting (an effective opportunity cost of zero).

The prospect of composting lake weed from the county harvesting program was the major stimulus to begin composting on this farm. However, a variety of materials generated on and off the farm are composted each year (see table 10.3 for 1990), reflecting the farmer's interest to add both nutrients and *organic matter* to farm soils. Lake weed, which has a 90% water content and low nutrient concentrations, in 1990 constituted the bulk of the material composted, though its volume reduces dramatically and quickly. No tipping fees were received for any of the materials brought onto the farm. The farm paid $25 for delivery of a single 30-ton load of nutrient-rich *liquid* chicken *manure* and paid a nominal 3¢ per bale for a neighbor's spoiled hay.

The lake weed, like most of the other composted materials, is delivered to the site at no cost to the farm. Only a couple of hours of farm labor were required during the year to meet the delivery trucks. Other collection/delivery costs to the farm were associated with sheep and horse manures collected from two neighbors. About eighteen hours of farm labor in 1990 were required to collect and move 125 tons of manure about 1/2 mile to the farm. While the farm used its own manure spreader for collection of the horse manure, it borrowed a spreader for delivery of the sheep manure. In addition, a couple of hours were required to run the flail chopper and transport the green chop (timothy and alfalfa) a short distance to the compost site.

The main compost task for passive pile composting is formation of the compost piles. On this farm, formation of a 90-foot long pile required three or four half-day sessions in the months of July and September and amounted to about twenty-four hours of labor. This included time to lay down a length of perforated black pipe at the base of the pile and cover the pipe with wood chips. This modification is intended to improve the natural circulation of air through the pile without the expense of the blower and controls associated with an aerated static pile. A tractor bucket loader is used to fill the manure spreader, which forms the piles. A couple of hours in total were required to first grease and eventually clean this machinery when used for composting, plus about another hour or so to install manure tines on the loader. After forming the piles, an additional hour was required to grade the site in order to remove the ruts caused by equipment movement over the unsurfaced site.

Once formed, the piles were not disturbed. Samples were taken for lab analysis. Temperatures were monitored with a probe daily the first week and then less often, perhaps requiring an extra hour or two of work during the year.

After letting each pile compost undisturbed for a full year, all of the compost product was used on the farm. Very small amounts of compost were used to make a potting soil acceptable under organic growing standards. This potting soil was used to start plants and orchard trees, including fifteen thousand broccoli, bok choy, and cauliflower plants, as well as lettuce, pepper, eggplant, and tomato. The vast bulk of the finished compost has been land applied at a rate of 1.25–1.5 cubic yards per quarter acre of cropland. For the sake of convenience, rock phosphate was applied with the compost, and use of supplemental magnesium is planned for the future. Field spreading of the annual production of roughly 250 tons of finished compost required about three to four days of labor with an old, slightly modified 100-bushel manure spreader.

The composting activity, from materials

Table 10.3
Composting enterprise #1

Activities

Tasks	Farm expenses	Farm labor time (hours)	Farm machine time (hours)	Comments
Site preparation				
Land value	$550	—	—	Local land value estimated
Planning, build access road, prepare site	$0	8	5	Tractor/loader used
Materials collection and purchase	$34	20	6	Used farm manure spreader
Preprocessing of materials (green chop)	$0	2	2	Used tractor, chopper, wagon
Pile formation	$45	24	24	Used spreader, tractor, loader
Maintain, monitor (site repair, cover piles, and so on)	$0	8	1	Area disced to smooth ruts
Field spreading	$0	30	30	Used modified spreader

Materials

Compostable material	Estimated quantity	Farm labor time for delivery (hours)	Cash cost
On-farm			
Green chop (timothy, alfalfa)	6 cubic yards	2	0
Off-farm			
Wet hay	9 tons (dry)	0	$9
Wood chips	2 tons	0	$0
Chicken manure	30 tons	0	$25
Well-rotted horse manure	45 tons	6	$0
Race-track horse manures	10 tons	0	$0
Sheep manure, straw bedding	80 tons	12	$0
Lake weed	720 tons	0	$0
Waste vegetables (for example, squash)	Less than 1 ton	0	$0

Note: Total for 1990 materials was about 900 tons. However, an undetermined amount of some of these materials are in stockpiles not mixed into the windrow.

Table 10.3 continued on next page

collection to use of the final compost, required about two weeks of labor for the year, not counting the initial site preparation time (table 10.3). Of this, less than four days of time were devoted to the compost production tasks themselves. The remainder was devoted to collection of materials and final spreading of the compost. Out-of-pocket costs were kept below $150, not including several hundred dollars for lab testing. No specialized equipment other than a temperature probe was involved in the compost operation. The total capital expenditure on farm equipment involved in various parts of the composting cycle was under $25,000. (Almost all of the equipment was purchased as used equipment. Replacing this equipment with comparable new equipment would cost approximately $75,000.) The equipment ownership and operating costs attributable to the composting operation are under $1,500. Assigning a reasonable wage rate of $6.50 per hour, the rough estimates of

Table 10.3
Composting enterprise #1 (continued)

Farm compost equipment

Equipment	Model and features	Cost	Year purchased	Estimated hourly cost
Manure spreader	8-ton New Idea	\$75 [a]	1980s	\$10 [b]
Manure spreader	516 New Holland 5-ton series	— [c]	—	—
Dump bed	8-ton	\$3,000	1991	\$15 [b]
Tractor	Belarus, 60-horsepower	\$9,000	1986	\$25 [b]
Loader	Allied	\$3,100 [d]	1989	\$6 [b]
Tractor	50-horsepower JD 2010	\$7,500	1987	\$25 [b]
Flail	JD 520	\$7,500 [e]	1982	\$15
Self-unloading forage wagon	PAPEC	\$9,000 [e]	1970	\$12
Modified spreader	John Deere #33 100-bushel	\$100 [f]	—	\$5
Disc	10-foot transport KBA-JD	\$7,000 [e]	—	\$15
Temperature probe		\$75 [e]	—	—

[a] Plus trade and repairs.

[b] Very rough hourly owning and operating cost estimates are based on cost and use data in Dhillon and Palladino and in Snyder. They include \$6.50 per hour operator labor cost.

[c] Borrowed from sheep farm for delivery and spreading.

[d] Including manure tines.

[e] 1991 replacement value. Actual purchase price unknown.

[f] Current market value. Actual purchase price unknown.

making and applying the compost are less than \$5 per ton of incoming material. Almost two-thirds of that cost is devoted to collection and field spreading. Other experimental studies of the economics of municipal or agricultural composting report similar or somewhat higher costs.

Finally, the compost earned no off-farm revenues. The economic value of the compost is primarily its role in increasing soil productivity and fertility. This compost was made almost entirely of off-farm materials that the farm acquired specifically to be composted. Composting a variety of materials provided this farmer with an opportunity to pursue an interest in recycling and improve farm soils while limiting the potential for *pollution* from improper manure application.

While composting requires more processing time than direct manure spreading, the stabilized compost is perceived as a benefit on this farm. The use of raw manure on organic farms is restricted by standards which define organic practices. Nevertheless, because of time and labor constraints, most farms will continue to use raw manures instead of compost.

Farm Composter #2

Farm #2 is situated on more than 300 acres of hilly terrain in horse farm country (table 10.4). It pursues two primary activities: organic vegetable and compost production. A crew of four full-time and three part-time workers grow vegetables on 12 acres (as much as 40 acres in previous years) and in a 2,700-square-foot greenhouse. About three-fourths of the compost produced on the farm is used on-farm for vegetable production.

The compost production activity occupies a staff of 6 to 8 people. At full staffing, 1 position is secretarial, 2 1/2 positions are for site workers/equipment operators, and 2 1/2 positions are devoted to off-site collection of manures. The principals on the farm combine administrative and marketing responsibilities with site work. Total payroll is about \$200,000.

The composting activity occurs on six graded acres of converted cropland that include *composting pad, curing* area, runoff control areas, and structures (the greenhouse, a trailer/office, and a large steel storage building). Large areas at the margins of the main composting pad are occupied by slowly decomposing piles of well-bedded manure. These passive compost piles require only minimal management such as grooming and monitoring. The actively managed windrows are turned six to twelve times in a three to five month period, primarily with a large self-propelled windrow turner which straddles the windrow.

Between 30,000 and 40,000 cubic yards of organic materials are accepted each year. Of these, approximately 12,000–14,000

Table 10.4
Composting enterprise #2

Compost tasks and equipment usage for each task (1990)

Task		Farm labor hours	Farm labor costs	Equipment usage and comments
1.	Planning, permitting, administration	1,000	$16,286	Computer used
2.	Secretarial, bookkeeping, dispatching	2,340	$20,000	Computer used
3.	Off-site collection/trucking of materials 100% of truck and container use	5,840	$58,400	Trucks and containers used
4.	Materials receiving on-site 12% of front loader use	948	$11,409	Unload containers, stack material, maintain pile with front loader
5.	Day to day management	832	$14,086	No major equipment used
6.	Preprocessing of material 2% of front loader use	688	$6,409	Sort for trash, preblend piles with front loader
7.	Pile formation and mixing materials 33% of front loader use 29% of bulldozer use 7% of skid loader use	1,292	$13,867	Front loader forms windrow, skid loader maintains pile edges, bulldozer shapes and maintains passive piles
8.	Pile turning 4% of front loader use 21% of skid loader use 100% of windrow turner use	1,552	$16,467	Piles turned and shaped with windrow turner, secondarily with front loader and skid loader
9.	Site and machine maintenance 10% of front loader use 28% of bulldozer use (turning area) 43% of bulldozer use (other areas) 21% of skid loader use	1,850	$22,122	Bulldozer, skid and front loaders used to maintain site surface, ditches
10.	Shredding, screening of products 21% of skid loader use 100% of shredder/screener use 100% of power screen use 100% of large loader use	1,002	$9,345	Shredder and screener used with loader
11.	Market, blend, load, ship, bag product [a] 39% of front loader use 30% of skid loader use 100% of soil bagger use	850	$11,557	Bagger, trucks, skid, and front loaders used
12.	Miscellaneous	370	$5,643	No equipment
Total annual hours and wages [b]		18,564	$205,591	

Note: Total hours are likely to be more trustworthy than hours allocated to each task.

[a] Includes 120 hours for bagging labor at $1,200 labor cost.

[b] Sum of on-site pile management tasks (4–9) was 7,162 hours at $84,360. Sum of market related tasks (10–11) was 1,852 hours at $20,902.

Table 10.4 continued on next page

Table 10.4
Composting enterprise #2 (continued)

Compost equipment costs and total use

Equipment	Actual cost	Year purchased	Vintage	Annual hours	Approximate cost per hour [b]
Traditional earth moving					
Front-end loader (Michigan L90)	$120,000	1988	1987	980	$50
Larger front-end loader (Michigan L-120)	— [c]	—	—	800	$55
Bulldozer (John Deere 450)	$45,000	1987	1987	630	$35
Skid loader (Gehl 6625, 1 yard bucket)	$22,000	1989	1989	570	$10
Specialized for composting process					
Windrow turner, self-propelled (Scarab 14)	$50,000	1987	1976	425	$45
Screening and bagging					
Shredder/screener (Royer 300)	$42,000	1988	1988	270	—
Screener (Powerscreen MK II)	$50,000	1990	mid-1980s	650	—
Soil bagger (Bouldin and Lawson)	$150,000 [d]	1988	—	60	—
Collection [e]					
Collection truck 1	$90,000	1988	1988	—	—
Collection truck 2	$32,000	1987	1978	—	—
Collection truck 3	$25,000	1989	—	—	—
50 containers (30 cubic yard)	$3,000 [f]	—	—	—	—
On-farm compost use					
Tractor (Belarus 70-horsepower)	$14,000	1990	1990	—	—
Spin spreader (Stoltzfus 5-ton)	$100 [g]	—	—	—	—

[b] Approximate owning and operating costs excluding labor charges (estimated at $10 per hour).
[c] Temporary rental.
[d] Approximate.
[e] Fleet mileage of about 3,900 miles per month.
[f] Cost for each container. Rental fee of $125 per month charged to customer.
[g] Rental cost per day.

Table 10.4 continued on next page

are windrowed. The remaining material is composted passively. Well over four-fifths of the material is horse manure with wood chips and shavings. The other materials include small volumes of grass from the farm, dairy manures from other farms, and municipal leaves. A fleet of three trucks averages 3,900 miles per month collecting manure and delivering a small amount of compost. The manure is picked up in thirty-cubic-yard containers rented to customers for a fee of $125 per month. A tipping fee is charged according to distance and other factors and averages about $5 per cubic yard. The average collection round trip is approximately 50 miles.

The compost operation uses a great deal of equipment in addition to the windrow turner and collection trucks. The farm owns a 156-horsepower front-end loader used for sorting and blending raw materials and for forming and shaping windrows. Sometimes a windrow is first turned with a loader because the initial pile size is larger than the windrow turner can handle. A smaller skid loader is used to maintain the pile edges and the site and to screen, mix, and load final products. A bulldozer helps shape and maintain the site surface, access road, drainage ditches, and passive piles.

Other equipment is used to upgrade the quality of the compost. In 1990 an additional very large front-end loader was rented for almost half a year for a number of tasks, especially to assist with compost screening. In order to produce increased quantities of high-grade compost product, the farm also rented a high-capacity screen for much of 1990. The screen supplements a soil shredder/screener of lesser capacity owned

Table 10.4
Composting enterprise #2 (continued)

Materials composted and revenues

	Estimated quantity		Revenue	
Compostable materials	(cubic yards)	(bags)	(per cubic yard)	(per bag)
On-farm				
Grass	60	—	—	—
Off-farm				
Municipal leaves	350	—	$1.50	—
Wood chips/shavings as horse farm bedding	25,000	—	$5	—
Dairy cow manures	5,000	—	—	—
Total (per year)	30,410			
Products				
Compost	5,880 [h]	—	$18	—
Bagged compost	120	3,600	$72	$2.40
Potting soil	240 [i]	—	$52	—
Bagged potting soil	60	3,000	$103.50	$2.07
Topsoil (25% compost)	1,000	—	$18	—
Approximate total compost	6,500			

Revenues per year
30-yard container rentals: $5,000; Tipping fees and sales: $195,695
"Market value" of compost used on farm [j]
Compost: $81,000; Potting soil: $1,560

Note: Assuming volume reduction of 50% on average, the roughly 6,000–7,000 yards of compost used would have been derived from 12,000–14,000 yards of incoming material. Roughly 16,000–18,000 yards of the material that arrives on the farm is, therefore, not actively composted. Instead, it is piled in very large piles for slow passive composting.

[h] 4,500 cubic yards used on farm.
[i] 30 cubic yards used on farm.
[j] Volume times sales price.

Other fixed costs of composting

Land value—part of farm land (heavy clay soils) purchased at approximately $8,000 per acre (6 acres for $48,000) for compost area

Initial site preparation—grading, surfacing, drainage, and gate installation with rented bulldozer, excavator, and loader required approximately 800 hours of machine work in 1988. Rental cost was roughly $40,000.

Additional drainage work—new pond and ditches at $10,000 were cost-shared with ASCS.

Structures—trailer and large storage building. Cost not available.

by the farm. Finally, the compost operation owns a soil bagger which bagged almost seven thousand bags of compost and potting soil in 1990.

Well over $250,000 has been invested on equipment primarily used for composting itself (not including the rented machinery). An additional $200,000 is invested in screening and bagging equipment. Almost $300,000 has been invested in collection trucks and containers. Much of this equipment was purchased second hand, so new replacement values would be higher. Other fixed costs include land value of roughly $50,000; an investment of another $50,000 or more in initial site preparation, *holding ponds*, and a runoff management system; plus the value of the structures.

The compost-related revenues derived from tipping fees and container rentals totalled more than $130,000 in 1990. Additional revenues of slightly under $70,000 were earned from sales of bulk compost (at $18 per cubic yard), bagged compost ($2.40 per 40-pound bag or $72 per cubic yard), potting soil ($52 per cubic yard), bagged potting soil ($2.07 per 22-quart bag or $103.50 per cubic yard), and topsoil ($18 per cubic yard). Customers for the compost mainly included area landscapers, nurseries, and residents. Other farmers and local government parks departments purchased smaller amounts. The potting soil was purchased primarily by other farmers, followed by the landscapers, nurseries, parks departments, and local residents. Sixty percent of the topsoil was purchased by area landscapers, with the remainder split evenly between residents and parks departments.

Much of the collected manure and compost value is "invested" in the farm and waits to be fully realized. About 4,530 cubic yards of compost and potting soil have been used to improve farm fields or in the greenhouse. The compost was applied to fields at a light rate of about 5–10 tons per acre using a recently purchased tractor and rented spin spreader. Again, as an organic farm, the benefits of adding compost to the soil are of greatest concern. Finally, the residual 15,000 cubic yards of manures in the passive piles are being transformed into compost. While this slow and cheap approach to compost production has yet to prove itself, it will eventually add to the compost inventory.

Farm Composter #3

The daily four- to five-hour chore of manure spreading, an inability to obtain cost sharing for a *manure storage* system, and the prospect of earning tipping fees from local municipalities convinced the third farm to consider composting (table 10.5). After spending about six hundred fifty hours in planning over an eight-month period, the three-hundred-head dairy farm began a pilot composting operation in September, 1990. Initially, dairy manures and straw *bedding* were mixed for composting with a fine sawdust residue from pressboard manufacturing. Within a year, the farm had added four hundred pigs, cut the dairy herd size by one hundred cows, and added cardboard and shredded paper to the bedding and compost mix. Recently the farm applied for a permit to collect yard wastes and offered to accept yard wastes from municipalities for $25 per ton. After several months, no municipalities had yet accepted this deal. Purchase of a $150,000 tub grinder to process cardboard boxes, woody materials, and leaves for bedding was being considered. Planning was also underway for a 200-ton-per-day in-vessel composting system capable of handling manures and bedding from thousands of pigs and possibly sewage sludges or municipal solid wastes.

On-site preparations for the composting project began during three weeks of full-time work in August, 1990. A one acre site ($1,000–1,500 value) of underutilized land adjacent to the dairy barn was graded and surfaced with topsoil and gravel from small rises at the edge of the site. The slope was later regraded to improve drainage off the site. The acre of land is sufficient to manage the estimated 500 tons of manure and bedding per month generated by the six hundred animals currently on the farm. Wet manures and bedding are bulked with additional cardboard, paper, and sawdust. Paper and cardboard materials are delivered daily to the farm in county collection trucks. Sawdust is delivered every other month by the pressboard manufacturer. Each is charged a $30 per ton tipping fee.

As in the past, it takes about an hour of labor each day to clean out the barns and dump the manures in a pit with a 5-cubic-yard front-end loader. However, instead of spending another four to five hours on six or seven trips a day with a *slurry* spreader to spread the manures on a field 1.5 miles distant, an average of about three hours a day are devoted to compost-related chores, including chopping cardboard in a corn chopper for bedding, blending the bedded manures with additional amendments in the mixing pit with the loader, and forming windrows of the mixed material with the loader. Only mixing and windrow formation, which take about two hours of time every three days, are completely new tasks. Prior to beginning the composting operation, the farm was already putting a couple of tons of *mulch* hay per week through a bedding chopper. Now, cardboard is being chopped; but instead of paying $50 per ton for mulch hay, the farm receives the tipping fee for cardboard and shredded paper.

Unfortunately, the chopper is not well suited for the cardboard. Down time, machine wear, and labor time are costly. The farm is exempt from solid waste regulations because the cardboard is used for bedding purposes. Therefore, there is an incentive to continue chopping the cardboard rather than incorporating it into the windrow unchopped. However, plans to increase compost volumes in the future will help justify a tub grinder, which is better suited to the task of shredding cardboard.

Turning the piles with the windrow-turning machine adds four hours per week to the overall operation. The $56,000 windrow turner is self-powered but requires towing by a slow-moving tractor. In this case a rented track bulldozer is used for towing. The bulldozer costs $30 per hour of use but is kept permanently on the farm. The purchase of a used loader and rental of the bulldozer have reduced initial capital outlays. The cost to purchase all new equipment (loader, bulldozer, and windrow

Table 10.5
Composting enterprise #3

Tasks

Task	Monthly farm labor (hours)	Monthly farm machine time (hours)	Comments
Initial site preparation (one-time expense) [a]	360 [b]	360 [b]	Dozer, loader, truck used
Manure removal from barns	30	30	Used 5-yard bucket loader
Pile formation, chopping and mixing materials	90	90	Used chopper and loader
Mixing and pile formation only	25	25	Used loader
Cardboard chopping only	65	65	Used chopper
Pile turning	17	17	Used dozer and turner
Field spreading when not composting	150	150	Used slurry spreader
Field spreading of compost	2	2	Used loader, spread at 1 inch

[a] Estimated local land value is $1,500 per acre.
[b] One-time expense.

Materials

Compostable materials	Notes	Estimated quantity (tons per month)	Special handling	Farm labor involved (hours per day)	Revenue per ton
On-farm					
Dairy manure	No bedding, 200 cows	350 [c]	Manure removal	1	—
Pig manure	No bedding, 400 pigs	80 [c]	Manure removal	1	—
Off-farm					
Cardboard	Used for bedding	55	Chopping	2	$30
Shredded paper	Used for bedding	20	Use as is	—	$30
Cellulose powder	From pressboard	7	Use as is	—	$30
Total		512			

Note: Because of composting, mulch hay purchases of 8–10 tons per month at a cost of $50 per ton were avoided.

[c] Estimates based on data from the American Society of Agricultural Engineers.

Compost/manure-handling equipment

Equipment	Model and features	Cost	Year purchased	Notes
Front-end loader	Michigan 175B, 5-yard bucket	$15,000	1975	Replaced by loader below
Front-end loader	International H-90, 5-yard bucket	$30,000	1991	Vintage 1984
Windrow turner, tractor tow model	Scat 482B	$56,000	1990	Vintage 1990
Track dozer for turner tow	John Deere 450G	$30 [d]	—	—
Slurry type spreader	Gehl 7-ton capacity	$14,000 [e]	—	—
Corn chopper with hay head	Gehl 860	$16,000 [f]	—	—
Tractor (85-horsepower)	Case International 5130	$48,000 [f]	—	—

[d] Per hour rental.
[e] Estimated 1991 new value for 2,400-gallon capacity. Actual costs not available.
[f] Estimated 1991 new value. Actual costs not available.

turner) currently used for the compost operation would be approximately $250,000.

All of the finished compost is intended for use in building farm soils. After composting from fall to early spring, the first compost was spread in 1991 on several acres of corn fields to a depth of one inch. The farmer estimates that it took about two hours to spread the compost derived from about 1.5 months' accumulation of manures and added materials. In comparing the monthly hours devoted to slurry spreading (one hundred twenty to one hundred fifty hours) to the time for compost mixing, turning, and spreading (forty to fifty hours, including only part of the cardboard chopping time necessary to produce bedding), it appears that substantial labor time was saved.

Early plant growth in the field which received compost was visibly greater than in nearby fields, with few weeds. The farm hopes to eventually eliminate its *herbicide* use by using compost ($3,200 was spent on herbicide for 115 acres of corn in 1990).

Farm Composter #4

Farm #4 is one of the smaller farms that has chosen to compost in an agitated bed system. Prior to composting, the farm's poultry manures were sold seasonally as fertilizer. During the winter, the manure was spread three times per week, causing odor problems. Now, the manure from eighty thousand birds is mixed year-round with spent mushroom compost (red oak and cotton seed) from an exotic mushroom business. The mushroom compost is available for the cost of hauling. (Of other available inexpensive bulking materials, only rice hulls and apple pulp have also been found to have properties that complement the manure). Approximately 10 cubic yards of manure are mixed with 10 cubic yards of spent compost on a daily basis.

A tractor with a 1.5-cubic-yard bucket is used for mixing. The tractor rolls the mixture into the bays of the agitated bed system. This process takes about three hours per week. The two bays are 210 feet long and 10 feet wide, and the material is piled to a height of about 3 feet. Material stays in the bays for a thirty-day cycle and reduces in volume approximately 50%.

The compost structure is a greenhouse with partially open sides and ends. It is located in an area with neighbors who would notice problems. A misting system with a chemical odor-masking agent is used. The 1.5-acre site is on a hillside and required substantial grading work. Capital cost of the basic system was approximately $80,000. An additional $20,000 was required for the structure, grading, and landscaping.

The finished compost is marketed at a bulk price of $15 per cubic yard or $25 per pickup truck. This contrasts with the $3.50–4.00 per cubic yard price that the farm has received for fresh manure in the past. The farmer plans to begin a bagging operation. Other bagged poultry composts sell regionally in retail outlets for $1.50 for a 25-pound bag.

11

Other Options for Waste Management and Composting

Although the focus of this handbook is farm-scale *composting,* it is important to recognize that composting is just one of several approaches that can turn both on-farm and off-farm waste materials into a farm resource. Other alternative uses for waste materials or composting techniques not discussed in the previous chapters may be more appropriate for a given farm or raw material. Like composting, these options offer a farm several potential benefits including improved handling of the farm's own waste materials, a source of nutrients and *organic matter* for farm soils, and/or possible revenue from handling off-farm wastes.

This chapter briefly reviews several waste management options so that you can better evaluate whether composting is the best approach for your farm or situation. Titles of selected references about these options are listed in the suggested readings section on pages 178–179. Full reference listings are included in the references section beginning on page 181.

Direct Land Application and Other Land-Based Methods

Direct *land application* is the traditional method of recycling *manures* and other farm-generated wastes. It has long been used as a treatment method for off-farm wastes as well. Like composting, it provides possible *tipping fees* and improved soil quality; yet direct land application is often less costly than composting because it involves less materials handling.

Solid and *slurry*-like materials, such as manures and sludges, are normally applied to cropland by a manure spreader or tank truck with and without soil incorporation. Dilute liquids are irrigated onto the land or applied through *infiltration* basins or allowed to flow over the land surface in a controlled manner. Liquids are also treated in aquatic land-based treatment systems such as lagoons and constructed wetlands which could possibly be located on a farm.

A growing list of waste materials are being considered for land application including *sewage sludge,* food wastes, paper, and *yard wastes.* For example, pretreated fish-processing wastes are being applied as a fertilizer to cranberry bogs via sprinkler irrigation systems. A few farms are plowing leaves or grass clippings directly into the soil without prior composting. Farmland often receives clean sewage sludge as a fertilizer supplement and source of organic matter.

In applying waste materials to cropland, consideration must be given to the timing of the application, nutrient needs of the crop, *nutrient availability* of the waste, the waste's *C:N ratio,* the need for storage, weather, and *pollution* control. Depending on the specific material, pollution control can be a major concern. Special environmental protection practices and monitoring systems may be required. For a few waste materials, regulations restrict the crops grown and future land use.

Anaerobic Digestion/ Biogas Production

Anaerobic digestion of manure is currently practiced by several farms. Anaerobic digestion occurs in the absence of oxygen. The *microorganisms* involved decompose manure or other organic material, producing an effluent plus *biogas*—a mixture of methane, *carbon dioxide,* and other gases. The effluent has nearly the same consistency, weight, volume, and plant nutrient content as the material entering the digester; but it has a lower potential for odor.

The production of biogas is a primary incentive for adopting anaerobic digestion. The biogas is similar to natural gas. It can be used as a fuel for heating or for generating electricity. The need for heating is seasonal and does not match the continual production of manure and biogas. Therefore, biogas is more often used to generate electricity. The electricity generated is used on farm, as needed, and the surplus is sold to the electrical utility.

Anaerobic digesters are enclosed vessels constructed of concrete or corrosion-protected steel. Mixed digesters are usually vertical cylindrical tanks (like a short silo) containing mechanical agitation. Plug-flow digesters are long concrete vessels often built in the ground with a flexible plastic membrane as a cover. Both types require a means of heating to maintain favorable temperatures inside the digester.

Unlike composting, anaerobic digestion requires little deliberate manipulation of the digested material before or during the digestion process. Raw manures by themselves are good materials for anaerobic digestion. The manure is pumped or flows by gravity into and out of the digester. On average, the manure remains in the digester for three to five weeks.

Anaerobic digestion requires less operational labor than composting. However, the digester requires management of temperature, *pH,* and loading rate because the process can be easily upset. Overall costs include regular maintenance for the electrical generation equipment and the capital costs for the digester, heating, and generating equipment. The economics depend on cost of electricity being replaced on the farm and price that the farm receives for the surplus electricity.

Anaerobic digestion provides additional value because of the manure's reduced odor. The effluent can be used or stored in the same manner as raw manure with the advantages of low odor and the potential to reclaim *bedding* materials. Anaerobic digestion does little to solve manure-handling problems stemming from limited land for land application. The digester effluent can be composted if desired, though its carbon content and energy value are reduced.

Vermicomposting

In *vermicomposting,* or vermiculture, earthworms digest organic materials and produce castings. Worm castings are generally considered a good *soil amendment,* providing the same benefits as a high-quality *compost.* Worms are capable of breaking down a variety of organic materials including vegetated wastes, food processing wastes, sewage sludges, and manures. In addition to their value for waste management and compost production, the worms themselves have value as fish bait and potentially as a source of protein for animal feed.

Vermicomposting starts by adding the desired species of worms to a bed or pile of organic materials. The worms work their way through the bed. No physical *turning* of the bed is required. As the worms move through the bed, new material is added either to the end or in thin layer on top of the bed. The worms progressively move through the bed toward the new material, leaving behind castings which form the stable compost. As the worms vacate the decomposed sections, the composted material can be removed. Any worms remaining in the harvested compost can be screened-out and either returned to a composting bed or marketed.

The worms need a relatively moist and *aerobic* environment with low concentrations of *ammonia. Moisture contents* in the range of 60–90% are required. The earthworms also require mild temperatures, in the range of 60–85°F. To maintain aerobic conditions and limit the temperature rise (because of aerobic microbial decomposition), the bed or pile of material needs to be less than 3 feet high. In the winter, the beds must be contained in a building and perhaps heated to maintain favorable temperatures. Some degree of *porosity* is also required to allow air movement through the bed. Some raw materials may require *amendments.*

Farm-scale systems for vermicomposting have been developed. They tend to be simple systems using conventional materials-handling equipment. Little manipulation of the process is required. The worms do most of the processing work. However, labor and/or equipment is required to add material to the bed, remove composted material, separate the compost from the worms by screening, and process the compost and worms for their respective markets. Since this process occurs at low temperatures, flies are a potential problem. *Pathogen* destruction and drying are also reduced. A drying or heating step may be required to produce the desired compost.

Recycling Wastes as Livestock Bedding and Poultry Litter

Several materials which are normally considered solid waste can be used on farms as livestock bedding or as *litter* for poultry operations. Examples of materials that have been used for this purpose include leaves, newspaper, cardboard, waste-derived compost, mixed paper, and even telephone books. When removed from the barn, the manure/bedding mixture can be applied to cropland, sold, or composted. Using these materials for bedding/litter replaces conventional materials that may be scarce or expensive. In addition, the farm might collect fees for accepting certain materials.

Waste paper has generally been deemed to be a safe bedding material, though several researchers have stopped short of giving it their whole-hearted endorsement. No seriously adverse effects have yet been found from animals lying on or ingesting paper bedding, including those with printing inks. Nevertheless, the quality of the material and the presence of foreign materials should be strongly considered.

In most cases, paper, cardboard, and other waste bedding materials need to be *shredded* before use. Paper shredders, grinders, and forage choppers have all been used (see chapter 5). Possible problems to contend with include materials-handling, storage, dust, and waste paper littering the farmstead and neighboring area. Additional steps may be needed to sort and handle foreign materials, such as staples from cardboard boxes. If the manure/bedding mixture is to be directly land-applied, the bedding/litter material must be suitable as a soil amendment. The C:N ratio of the manure/bedding mixture should also be considered.

Home or Back Yard Composting

Home or back yard composting is composting on a small scale. Typically composting occurs in small free-standing piles or within small bins, although increasing varieties of commercial bins and rotating drums are also available. Turning is accomplished manually and, in many cases, infrequently. A pitch fork is the classic example of a turning device for home compost piles.

Home composting involves nearly the same processes and factors as those described in chapter 2. The primary exception is that home composting normally takes place at lower temperatures. In most cases, *thermophilic* temperatures are not sustained. Although sections of home compost piles may remain hot for long periods, much of the decomposition takes place at *mesophilic* temperatures. As a result, insects, worms, and other large organisms are more active participants in the home composting pile (compared to commercial or farm-scale composting).

Home composting is not an important concern to farmers, unless it is used for garden and residential wastes. However, for environmental officials and advocates, home composting represents a means to promote recycling at the source. It offers considerable potential to reduce the amount of wastes entering the landfill. Perhaps more importantly, home composting encourages citizens to think about recycling, gets them to understand and support larger composting projects, and gives them an appreciation of what farms must do to manage soils and wastes.

Leaf and Yard Waste Composting

Leaves and other yard wastes are a special class of composting materials, because of their seasonal availability, their high C:N ratio (except grass clippings), and the relatively few environmental risks they pose. Many of the techniques and practices discussed in previous chapters of this handbook are used for leaves and yard wastes. However, composting methods for these materials are unique in some ways and also tend to be similar from one facility to the next. In most cases, leaves and other yard wastes are composted in *passive* piles. They receive infrequent turnings and little management. Leaves may compost for nine months to three years depending on the level of management they receive.

A farm can be an ideal place for composting leaves and other yard wastes generated by municipalities and landscapers (for example, grass clippings, brush, and branches from tree pruning). Farms provide not only a large and often isolated land area to locate compost piles but also an outlet for the finished compost. Furthermore, the timing is right. On many farms, land begins to become available and chores begin to be less demanding in late autumn, just when the largest volume of leaves is collected. Composting of leaves offers farms an opportunity for tipping fees and/or a good source of organic matter for the farm's soils. It is not necessary for the farm to add its manure to these wastes or even produce manure. Leaves and yard waste materials compost well alone.

Guidelines for composting leaves and yard wastes are provided by several very good references (listed in the suggested readings section). Many of these are available from state environmental or solid waste agencies. You should contact these agencies in your particular state for both technical guidelines and regulations pertaining to leaf and yard waste composting.

A

Characteristics of Raw Materials

Table A.1
Typical characteristics of selected raw materials

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Crop residues and fruit/vegetable-processing wastes					
Apple filter cake	Typical	1.2	13	60	1,197
Apple pomace	Typical	1.1	48	88	1,559
Apple-processing sludge	Typical	2.8	7	59	1,411
Cocoa shells	Typical	2.3	22	8	798
Coffee grounds	Typical	—	20	—	—

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data.

[b] Mostly organic nitrogen.

Table A.1

Typical characteristics of selected raw materials (continued)

Crop residues and fruit/vegetable-processing wastes (continued)

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Corn cobs	Range	0.4–0.8	56–123	9–18	—
	Average	0.6	98	15	557
Corn stalks	Typical	0.6–0.8	60–73 [a]	12	32
Cottonseed meal	Typical	7.7	7	—	—
Cranberry filter cake	Typical	2.8	31	50	1,021
(with rice hulls)	Typical	1.2	42	71	1,298
Cranberry plant (stems, leaves)	Typical	0.9	61	61	—
Cull potatoes	Typical	—	18	78	1,540
Fruit wastes	Range	0.9–2.6	20–49	62–88	—
	Average	1.4	40	80	—
Olive husks	Typical	1.2–1.5	30–35	8–10	—
Potato-processing sludge	Typical	—	28	75	1,570
Potato tops	Typical	1.5	25	—	—
Rice hulls	Range	0–0.4	113–1120	7–12	185–219
	Average	0.3	121	14	202
Soybean meal	Typical	7.2–7.6	4–6	—	—
Tomato-processing waste	Typical	4.5	11 [a]	62	—
Vegetable produce	Typical	2.7	19	87	1,585
Vegetable wastes	Typical	2.5–4	11–13	—	—

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data.

[b] Mostly organic nitrogen.

Table A.1
Typical characteristics of selected raw materials (continued)

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Fish and meat processing					
Blood wastes (slaughterhouse waste and dried blood)	Typical	13–14	3–3.5	10–78	—
Crab and lobster wastes	Range Average	4.6–8.2 6.1	4.0–5.4 4.9	35–61 47	— 240
Fish-breading crumbs	Typical	2.0	28	10	—
Fish-processing sludge	Typical	6.8	5.2	94	—
Fish wastes (gurry, racks, and so on)	Range Average	6.5–14.2 10.6	2.6–5.0 3.6	50–81 76	— —
Mixed slaughterhouse waste	Typical	7–10	2–4	—	—
Mussel wastes	Typical	3.6	2.2	63	—
Poultry carcasses	Typical	2.4[b]	5	65	—
Paunch manure	Typical	1.8	20–30	80–85	1,460
Shrimp wastes	Typical	9.5	3.4	78	—

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data.

[b] Mostly organic nitrogen.

Table A.1
Typical characteristics of selected raw materials (continued)

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Manures					
Broiler litter	Range	1.6–3.9	12–15 [a]	22–46	756–1,026
	Average	2.7	14 [a]	37	864
Cattle	Range	1.5–4.2	11–30	67–87	1,323–1,674
	Average	2.4	19	81	1,458
Dairy tie stall	Typical	2.7	18	79	—
Dairy free stall	Typical	3.7	13	83	—
Horse—general	Range	1.4–2.3	22–50	59–79	1,215–1,620
	Average	1.6	30	72	1,379
Horse—race track	Range	0.8–1.7	29–56	52–67	—
	Average	1.2	41	63	—
Laying hens	Range	4–10	3–10	62–75	1,377–1,620
	Average	8.0	6	69	1,479
Sheep	Range	1.3–3.9	13–20	60–75	—
	Average	2.7	16	69	—
Swine	Range	1.9–4.3	9–19	65–91	—
	Average	3.1	14	80	—
Turkey litter	Average	2.6	16 [a]	26	783

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data

[b] Mostly organic nitrogen.

Table A.1
Typical characteristics of selected raw materials (continued)

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Municipal wastes					
Garbage (food waste)	Typical	1.9–2.9	14–16	69	—
Night soil	Typical	5.5–6.5	6–10	—	—
Paper from domestic refuse	Typical	0.2–0.25	127–178	18–20	—
Pharmaceutical wastes	Typical	2.6	19	—	—
Refuse (mixed food, paper, and so on)	Typical	0.6–1.3	34–80	—	—
Sewage sludge	Range	2–6.9	5–16	72–84	1,075–1,750
Activated sludge	Typical	5.6	6	—	—
Digested sludge	Typical	1.9	16	—	—

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data.

[b] Mostly organic nitrogen.

Table A.1

Typical characteristics of selected raw materials (continued)

[illegible]	Type of value	%N (dry weight)	C:N ratio (weight to weight)	Moisture content% (wet weight)	Bulk density (pounds per cubic yard)
Straw, hay, silage					
Corn silage	Typical	1.2–1.4	38–43 [a]	65–68	—
Hay—general	Range	0.7–3.6	15–32	8–10	—
	Average	2.10	—	—	—
Hay—legume	Range	1.8–3.6	15–19	—	—
	Average	2.5	16	—	—
Hay—non-legume	Range	0.7–2.5	—	—	—
	Average	1.3	32	—	—
Straw—general	Range	0.3–1.1	48–150	4–27	58–378
	Average	0.7	80	12	227
Straw—oat	Range	0.6–1.1	48–98	—	—
	Average	0.9	60	—	—
Straw—wheat	Range	0.3–0.5	100–150	—	—
	Average	0.4	127	—	—

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data.

[b] Mostly organic nitrogen.

Table A.1
Typical characteristics of selected raw materials (continued)

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Wood and paper					
Bark—hardwoods	Range	0.10–0.41	116–436	—	—
	Average	0.241	223	—	—
Bark—softwoods	Range	0.04–0.39	131–1,285	—	—
	Average	0.14	496	—	—
Corrugated cardboard	Typical	0.10	563	8	259
Lumbermill waste	Typical	0.13	170	—	—
Newsprint	Typical	0.06–0.14	398–852	3–8	195–242
Paper fiber sludge	Typical	—	250	66	1140
Paper mill sludge	Typical	0.56	54	81	—
Paper pulp	Typical	0.59	90	82	1403
Sawdust	Range	0.06–0.8	200–750	19–65	350–450
	Average	0.24	442	39	410
Telephone books	Typical	0.7	772	6	250
Wood chips	Typical	—	—	—	445–620
Wood—hardwoods (chips, shavings, and so on)	Range	0.06–0.11	451–819	—	—
	Average	0.09	560	—	—
Wood—softwoods (chips, shavings, and so on)	Range	0.04–0.23	212–1,313	—	—
	Average	0.09	641	—	—

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data

[b] Mostly organic nitrogen.

Table A.1
Typical characteristics of selected raw materials (continued)

Material	Type of value	% N (dry weight)	C:N ratio (weight to weight)	Moisture content % (wet weight)	Bulk density (pounds per cubic yard)
Yard wastes and other vegetation					
Grass clippings	Range	2.0–6.0	9–25	—	—
	Average	3.4	17	82	—
Loose	Typical	—	—	—	300–400
Compacted	Typical	—	—	—	500–800
Leaves	Range	0.5–1.3	40–80	—	—
	Average	0.9	54	38	—
Loose and dry	Typical	—	—	—	100–300
Compacted and moist	Typical	—	—	—	400–500
Seaweed	Range	1.2–3.0	5–27	—	—
	Average	1.9	17	53	—
Shrub trimmings	Typical	1.0	53	15	429
Tree trimmings	Typical	3.1	16	70	1,296
Water hyacinth—fresh	Typical	—	20–30	93	405

Note: Data was compiled from many references listed in the suggested readings section of this handbook (pages 179–180). Where several values are available, the range and average of the values found in the literature are listed. *These should not be considered as the true ranges or averages, just representative values.*

[a] Estimated from ash or volatile solids data.

[b] Mostly organic nitrogen.

B Equipment Tables

The information in this appendix was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned.

Costs are current to **September, 1991.** Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Current product information and updates to this appendix can be sent to NRAES, Cooperative Extension, 152 Riley-Robb Hall, Ithaca, NY 14853-5701. This information will be included in future reprints of the publication.

Table B.1
Windrow-turning equipment

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (hp)	Approximate cost
Brown Bear						
200	Auger-style turner	10 x 3	0	1,000–1,500	116	$118,000
300	Auger-style turner	12 x 3.5	0	1,200–1,700	177	$140,000
400	Auger-style turner	12 x 4	0	1,700–22,000	225	$180,600
500	Auger-style turner	14 x 5	0	2,500–4,000	300	$228,400

Note: All models are self-propelled and self-powered.

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (hp)	Approximate cost
Brown Bear attachments for other wheel loaders/tool carriers						
3110SC	to 16,000 pounds	10 x 3	0	to 1,000	76	$58,000
3610SC	to 20,000 pounds	10 x 3.5	0	to 1,400	116	$61,000
3912SC	to 25,000 pounds	12 x 4	0	to 2,000	152	$79,000
4812SC	to 35,000 pounds	12 x 5	0	to 3,000	177	$91,000
24SC	For skid steer loaders and loaders under 8,000 pounds	6 x 2.5	0	to 300	25	$15,000

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (hp)	Approximate cost
Centaur Walker						
510F	Rotary drum turner	10 x 5	6–8	800+	90	$7,400
510C	Rotary drum turner	11 x 6	6–8	950+	90	$10,600
1012F	Rotary drum turner	12 x 6	6–8	950+	120	$9,600
1012C	Rotary drum turner	12 x 6	6–8	1,200	120	$13,600

Note: "F" models have plywood shielding. "C" models have rubber shielding and a more open drum housing. All models are tractor-towed and PTO-powered and are single-pass turners which straddle the windrow. Aisle space required between every other windrow.

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.1
Windrow-turning equipment (continued)

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (horsepower)	Approximate cost
Eagle Crusher Company, Inc.						
Cobey Straddle Master 1400	Rotary drum turner	7 x 14	4	—	260	$130,000
Cobey Straddle Master 1600	Rotary drum turner	7 x 16	4	—	335	$160,000
Cobey Straddle Master 1800	Rotary drum turner	7 x 18	4	—	360	$170,000
Cobey Straddle Master 2000	Rotary drum turner	8 x 20	4	3,000–4,000	360	$180,000

Note: All models are reversible, self-propelled, self-powered, and fully hydrostatic; are operated by diesel engines; and are single-pass turners which straddle the windrow.

Finn Corporation						
Willibald TBU3000	PTO-driven. Vertical auger turns and shreds compost	10 (height)	—	—	PTO-driven	$68,000
Olathe Manufacturing						
868 CT	Elevating face turner Tractor-towed, self-powered Requires a 40-horsepower tractor	9 x 7 (single pass)	—	—[a]	87	—

[a] 3,000 cubic yards per hour.

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.1

Windrow-turning equipment (continued)

Resource Recovery Systems of Nebraska K-W

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (horsepower)	Approximate cost
K-W 510	Rotary drum turner	10 x 5	4	1,200	212	$90,000
K-W 512	Rotary drum turner	12 x 5	4	1,500	235	$99,000
K-W 614	Rotary drum turner	14 x 6	4–5	2,000 [b]	300	$105,000
K-W 616	Rotary drum turner	16 x 6	4–6	2,500 [c]	400	$130,000
K-W 718	Rotary drum turner	18 x 7	4–6	3,000 [d]	440	$175,000

Note: All models are self-propelled and self-powered single-pass turners which straddle the windrow.

[b] 5,000 cubic yards per hour.

[c] 6,000 cubic yards per hour.

[d] 7,500 cubic yards per hour.

Scarab Manufacturing

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (horsepower)	Approximate cost
Scarab 10	Rotary drum turner	10 x 5	3–4	1,250	155–177	$89,000
Scarab 12	Rotary drum turner	12 x 5	3–4	1,500	177–234	$98,000–112,000
Scarab 14	Rotary drum turner	14 x 6	3–4	2,000	234	$109,000–135,000
Scarab 16	Rotary drum turner	16 x 6	3–4	2,500	335–360	$113,000–173,000
Scarab 18	Rotary drum turner	18 x 7	3–4	3,000	360	$179,000
Scarab 20	Rotary drum turner	20 x 7	3–4	3,500	360	$183,000

Note: Turners are self-propelled and self-powered single-pass turners which straddle the windrow.

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.1
Windrow-turning equipment (continued)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Scat Engineering (also available from Waste Tech Equipment)

482B	2-pass elevating face turner Tractor-towed, self-powered Requires a 40-horsepower tractor	18 x 6	7–8	2,000 [e]	65	\$60,000–65,000
483B	2-pass elevating face turner Tractor-towed, self-powered Requires a 80- to 100-horsepower tractor	20 x 9	7–8	3,000 [f]	85	\$80,000–98,000
4831	2-pass elevating face turner Self-propelled, self-powered	20 x 9	2–3	3,000 [f]	107	\$190,000–210,000
4833	2-pass elevating face turner Self-propelled, self-powered Narrow machine for indoor use or tight conditions.	20 x 11	0	3,000 [f]	125	\$250,000

[e] 3,000 cubic yards per hour
[f] 4,000 cubic yards per hour

SimCorp, Inc. (also available from A1 Environmental)

Sims 2000	Rotary drum turner Self-propelled, self-powered Single-pass turner straddles the windrow	14 x 5	3	1,500–2,000	177	\$106,500

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.1
Windrow-turning equipment (continued)

Company and model	Type and description	Windrow size width x height (feet)	Windrow spacing (feet)	Approximate capacity (tons per hour)	Power (horsepower)	Approximate cost
Valoraction, Inc.						
510	Rotary drum turner	10 x 4.2	10	800	65	$7,650
1012	Rotary drum turner	12 x 4.7	10	1,200	90	$9,400
MM12	Rotary drum turner	12 x 4.7	10	1,200	127	$24,700

Note: All models are single-pass turners. Models 510 and 1012 are tractor-towed and PTO-powered. Model MM12 is powered by a diesel engine.

Wildcat Manufacturing						
FX700	Rotary drum turner Tractor-towed, PTO-powered, requires 60- to 120-horsepower tractor with hydrostatic drive or creeper gear transmission	14 x 4	7.5	300	PTO	$13,900
CX700	Rotary drum turner Tractor-towed, PTO-powered Requires 90- to 140-horsepower tractor with hydrostatic drive	14 x 4	7.5	400	PTO	$21,600
CX710 AMT-D	Rotary drum turner Tractor-towed, self-powered Requires a 70-horsepower tractor	17 x 5	7.5	1,000	103	$42,500–46,500
CX750 ME	Rotary drum turner Self-powered. Mounts on a 3-cubic-yard capacity front-end loader	17 x 5	7.5	1,100	177	$70,000
M700E Special	Rotary drum turner Self-powered. Mounts on a 4-cubic-yard capacity front-end loader	18 x 8	7.5	2,600	325	$100,000

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Allegheny				
16-Series	Paper shredder	2–5	0.375–0.675 TPH	$7,995–9,995
18-Series	Paper shredder	7.5–10	0.75–1.5 TPH	$19,995–21,995
20-Series	Paper shredder	15–20	1.5–3.5 TPH	$27,995–29,995
1000-Series	Paper shredder	30–100	3.5–15 TPH	$55,000–170,000
Amadas				
430 & 431	Hammer mill	150	60 CYH	$17,500
450	Hammer mill	350	100 CYH	$53,000
American Pulverizer				
HWC-24	Hammer mill	60	20 CYH	$20,000
WS-40	Hammer mill	200	60 CYH	$32,500
WBH-42x60	Hammer mill	400	80 CYH	$42,000
TG-10	Tub grinder	400	80–100 CYH [a]	$110,000–125,000
TRS 50x35	Rotary shear shredder	100–125	50–70 CYH	$85,000

Note: Capacities estimated for yard waste at a density of 250 pounds per cubic yard

[a] 180–240 pallets per hour.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Bandit Chippers				
Mighty Bandit	Disc-type, hand-fed chipper	20–30 [b]	6 inches	$5,200–7,500
Mighty BDT II	Disc-type, hand-fed chipper	24–30 [b]	5 inches	$5,800–10,000
90	Disc-type, hand-fed chipper	37–45 [b]	9 inches	$7,000–12,000
150, 200, & 250	Disc-type, hand-fed chipper	65–120	12 inches	$9,000–19,000
1250	Disc-type, whole tree chopper; towed or self-propelled	170–200	12 inches	$26,000–30,000
1400	Disc-type, whole tree chopper; towed or self-propelled	200	12 inches	$45,000–90,000
1700	Disc-type, whole tree chopper; towed or self-propelled	250	17 inches	$85,000–170,000
1900	Disc-type, whole tree chopper; towed or self-propelled	400–500	19 inches	$145,000–235,000

Note: Capacities are given in maximum diameter of materials.

[b] Size is for engine. Can also be PTO-driven.

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
DK Recycling Systems				
Jenz AZ 30	Hammer mill	175	100–150 CYH	$145,800
Jenz AZ 50	Hammer mill	300	300–450 CYH	$274,200

Note: Models are mobile yard waste shredders. Adjustable discharge chute can form windrows directly.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost	[illegible]
Eidal					
52-32/40	Low speed, high torque rotary shear shredder	75–200	5–10 TPH	$130,000	
62-41	Low speed, high torque rotary shear shredder	200–300	15–25 TPH	$195,000	
72-58	Low speed, high torque rotary shear shredder	300–400	40–50 TPH	$265,000	
96-58	Low speed, high torque rotary shear shredder	300–400	50–70 TPH	$295,000	
120-58	Low speed, high torque rotary shear shredder	300–400	70–100 TPH	$330,000	
120-60	Low speed, high torque rotary shear shredder	400–600	80–110 TPH	$360,000	
100	Vertical grinder	100	4–6 TPH	$138,500	
200	Vertical grinder	200	6–12 TPH	$169,500	
400	Vertical grinder	400	12–25 TPH	$299,750	
1000	Vertical grinder	1,000	50–100 TPH	$595,000	
2000	Vertical grinder	2,000	150–225 TPH	$725,000	

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2

Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Farmhand				
HG 3000	Tub grinder	80–150 [c]	15–30 TPH [d]	$20,000
CG7000 PTO	Tub grinder	150–200 [e]	25–50 TPH [f]	$35,000
CG7000 Engine	Tub grinder	210	25–50 TPH [f]	$65,000
Finn Corporation				
Willibald MZA 1500	Hammer mill	160	35 TPH	$140,000–150,000
Willibald MZA 2500	Hammer mill	245	50 TPH	$180,000–200,000
Fuel Harvesters Equipment				
Wood waste tub grinder	Tub grinder	503	10–40 TPH [g]	$95,000–125,000

[c] PTO-driven

[d] 50–80 cubic yards per hour

[e] Size is for PTO-driven. Diesel size is 200 horsepower. Electric motor size is 100 or 125 horsepower.

[f] 100–150 cubic yards per hour

Note: Models listed are mobile yard waste shredders with horizontal positive feed.

[g] Capacity is for wood waste. 50–125 cubic yards per hour.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Haybuster				
IG-8	Tub grinder	110	5–10 TPH	$28,600–34,000
IG-10	Tub grinder	260	10–15 TPH	$56,000–72,000
IG-11	Tub grinder	300 [h]	10–15 TPH	$28,000–64,800
IG-12	Tub grinder	503	25–35 TPH	$103,000–141,000

Note: Model IG-12 tub lifts for hammer maintenance. Optional grapple loader is available.

[h] Size of engine. Can be PTO-driven.

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Iggesund Recycling				
Malin 250	Rotary auger with counterknife	22	1–5 TPH	$48,000
Malin 300	Rotary auger with counterknife	90	8–18 TPH	$95,000
Malin 400	Rotary auger with counterknife	211	25–40 TPH	$190,000
Malin 500	Rotary auger with counterknife	335	40–65 TPH	$357,000

Note: Capacities are estimated for wood and yard waste and are two to three times listed values for asphalt/concrete

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Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Industrial Paper Shredder Inc.				
Model 16	Reel-type paper shredder	3	to 1 TPH	$9,000
Model 16B	Reel-type paper shredder	3	to 1 TPH	$9,500
Model 20	Reel-type paper shredder	10	3/4–1 TPH	$14,500
Model 20B	Reel-type paper shredder	10	3/4–1 TPH	$14,900
Note: B Models include rollers to flatten bulky materials				
Innovator				
Series 20000	Tub grinders	177, 234, 300	—	$80,000–120,000
Note: Discharge screens are not used. All models are engine-, motor-, or PTO-driven.				
Jeffery Division - Dresser Industries				
34WB-SS	Wood/bark hog and shredder (hammer mill)	100	4 TPH	$19,000
45WB-SS	Wood/bark hog and shredder (hammer mill)	200	8 TPH	$36,000
56WB-SS	Wood/bark hog and shredder (hammer mill)	300	12 TPH	$59,000
66WB	Wood/bark hog and shredder (hammer mill)	500	18 TPH	$81,000

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Jones				
PTO Model	Tub grinder	to 200	10 TPH	$39,000
PU1 (Power Unit #1)	Tub grinder	360–425	30 TPH	$80,000
PU2 (Power Unit #2)	Tub grinder	425–503	40 TPH	$105,000
Hydrofork-SN	Tub grinder (includes loader)	425–503	40 TPH	$150,000
JWC Environmental				
Muffin monster 30,000	Low-speed, high-torque rotary sheer shredder	3–5	—	—
Muffin monster 40,000	Low-speed, high-torque rotary sheer shredder	5–10	—	—
Norcia				
Municipal	Tub grinder	300–525	—	$90,000–175,000
Industrial	Tub grinder	525	—	$185,000

Note: Industrial model includes loader. Loader is optional for commercial model.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Northeast Implement				
Valby CH150 wood chipper	Cutting disc chipper	20 (minimum) [i]	6 inches [j]	$4,390
Valby CH231 wood chipper	Cutting disc chipper	40 (minimum) [i]	9 inches [j]	$6,345
Valby SH232 shredder	Cutting disc chipper	50 (minimum)	3–8 TPH [k]	$7,160

Note: SH232 model can be driven by PTO, diesel engine, or electric motor. Others are PTO-driven.

[i] PTO-driven.
[j] Maximum diameter of materials.
[k] Capacities are for paper and wood.

Olathe				
864	Wood/debris chipper	177 (diesel) 125 (electric)	—	—
818TG	Tub grinder	120 (gas) [l]	—	—
866TG	Tub grinder	300 (diesel) [m]	—	—

[l] Optional: 110 horsepower (gas) and 100 horsepower (diesel).
[m] Optional: 177, 234, or 250 horsepower (diesel).

PCR Inc.				
RotoChopper	Shredder with knives fixed to a set of rotating disks	30 (motor) 60 (PTO)	4 TPH	$11,000

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Recycling Systems Inc.				
Model 360 Mulch Maker	Hammer mill	250–300	to 40 TPH	$98,750–108,500
Model 480 Mulch Maker	Hammer mill	300–400	to 60 TPH	$116,000–123,000
Commercial	Tub grinder	250–325	to 40 TPH	$90,950
Industrial	Tub grinder	400 or 525	to 50 TPH	$191,400
Waste Recycler	Grinder/chipper	650	—	$300,000

Note: Capacities are estimated for wood and yard waste. Tub grinders have optional loaders available. Tub lifts for hammer maintenance. Waste Recycler grinds by fixed knives on the face of rotating discs. Cab and loader included.

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Royer				
182	Belt-type shear shredder and shredder-mixer unit	12–18	to 25 CYH	Depends on customer specifications
262	Belt-type shear shredder and shredder-mixer unit	22–25	to 45 CYH	Depends on customer specifications
300	Belt-type shear shredder and shredder-mixer unit	45–55	to 75 CYH	Depends on customer specifications
365	Belt-type shear shredder and shredder-mixer unit	72–89	to 125 CYH	Depends on customer specifications
401	Belt-type shear shredders and shredder-mixer unit	90–110	to 250 CYH	Depends on customer specifications

Note: Model 401 is programmable for automatic operation. Models 300, 365, and 401 are also available from Waste Tech Equipment.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Shred Tech				
ST-10	Low-speed rotary shear shredder	7 1/2	.4 TPH	$13,700
ST-10L	Low-speed rotary shear shredder	7 1/2	.5 TPH	$14,500
ST-20	Low-speed rotary shear shredder	15	1.5 TPH	$23,500
ST-20L	Low-speed rotary shear shredder	15	2 TPH	$28,000
ST-50S	Low-speed rotary shear shredder	40	3 TPH	$45,700
ST-50	Low-speed rotary shear shredder	40	3.5 TPH	$49,000
ST-50L	Low-speed rotary shear shredder	50	4 TPH	$55,000
ST-100	Low-speed rotary shear shredder	100	8 TPH	$102,000
ST-200	Low-speed rotary shear shredder	300	20 TPH	$300,000
SSI Shredding Systems				
600-E	Low-speed high-torque rotary shear shredder	25	1 TPH	$35,000
5000-H	Low-speed high-torque rotary shear shredder	500	50 TPH	$340,000

Note: Numerous models are available at sizes, costs, and capacities between those shown above and varying with specific materials and applications. Electric or hydraulic drives are available.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Sundance				
RAM Grinder	Reciprocating action hammer mill	360	75 TPH	$138,000
KID Grinder/chipper	Push feed hammer mill	63	8–10 TPH	$24,000
KID Grinder/chipper	Push feed hammer mill	—[n]	8–10 TPH	$14,000

[n] PTO, 50+ horsepower tractor.

Triple/S Dynamics				
Rotagator II Model 6576	Low-speed rotary shear shredder	200, 250 or 300 (hydraulic drive)	to 75 TPH	Price varies with options application

Note: Capacity is for solid waste.

Universal Engineering				
4260 Shredder	Hammer mill	250	10–15 TPH	$125,000
6060 portable shredder	Hammer mill	750	to 70 TPH	$450,000

Note: Model 6060 is portable shredder including hoppers, conveyors, and truck frame. Designed for shredding large stumps, pallets, yard waste, ties, refuse, demolition, and more.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.2
Grinding/shredding equipment (continued)

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
Waste Tech				
Norkot Maxigrind 9100	Drum grinder °	330	75± TPH	$135,000

° Rotating drum with carbide-tipped cutting bits and positive horizontal feed. Mobile unit. Designed to handle construction and demolition wastes including asphalt and masonry.

Company and model	Equipment type	Power requirement (horsepower)	Approximate capacity	Approximate cost
West Salem Machinery				
2412B	Wood and bark hog (hammer mill)	30–50	—	Prices vary with options
3240B	Wood and bark hog (hammer mill)	150–200	—	Prices vary with options
4864B	Wood and bark hog (hammer mill)	600–900	—	Prices vary with options
2412H	Horizontal-feed wood and bark hog (hammer mill)	25–75	—	Prices vary with options
4032H	Horizontal-feed wood and bark hog (hammer mill)	150–300	—	Prices vary with options
4864H	Horizontal-feed wood and bark hog (hammer mill)	600–900	—	Prices vary with options

Note: Numerous models are available at sizes between those shown above. Capacities range from 1 to 150 TPH. Capacities and costs vary with specific materials and applications.

Note: (1) TPH stands for tons per hour. CYH stands for cubic yards per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.3
Commercial mixing equipment

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
Davis Pugmill, Inc.				
300 B/LS	Pug mill	—	24–150 TPH	$30,000
500 B/LS	Pug mill	—	35–300 TPH	$33,000
750 B/LS	Pug mill	—	50–400 TPH	$36,000
1000 B/LS	Pug mill	—	75–500 TPH	$41,000
1500 B/LS	Pug mill	—	200–800 TPH	$55,000
500 HW	Mixing system [a]	—	35–300 TPH	$100,000–500,000
1000 HW	Mixing system [a]	—	50–500 TPH	$100,000–500,000

Note: Pug mills have twin-shaft twin-drive continuous mixers. Stationary or portable units

[a] Includes pug mill, conveyors, screw feeder, surge hopper, silo, control system.

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
Knight				
2120	Reel-type batch mixer	10	4.0 CY	$12,000
2170	Reel-type batch mixer	15	5.4 CY	$13,000
2250	Reel-type batch mixer	20	8.0 CY	$14,000-$19,000
2300	Reel-type batch mixer	30	9.6 CY	$16,000-$21,000
2375	Reel-type batch mixer	40	12.0 CY	$22,000-$42,000
2450	Reel-type batch mixer	50	14.4 CY	$24,000-$44,000
2550	Reel-type batch mixer	—	18.0 CY	$26,000-$50,000

Note: Models are truck-mounted, trailer (tow) or stationary units and are PTO-, electric-motor- or engine-driven. Capacities listed are struck capacities (volume held by mixing wagon while mixing).

Note: (1) CY stands for cubic yards. CYH stands for cubic yards per hour. TPH stands for tons per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.3
Commercial mixing equipment (continued)

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
Littleford Bros.				
KM-300D	Continuous compost mixer	—	6 TPH	—
KM-4200D	Continuous compost mixer	—	80 TPH	—

Note: Wide range of models, sizes, capacities, and costs between those listed above. Mixing elements on rotating shaft mix and move materials through a cylindrical vessel.

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
Mclanahan				
Blendmaster				
18-inch x 10-foot	Pug mill	10	36 TPH	—
24-inch x 12-foot	Pug mill	20	80 TPH	—
30-inch x 15-foot	Pug mill	30	150 TPH	—
36-inch x 18-foot	Pug mill	40	230 TPH	—
44-inch x 20-foot	Pug mill	50	305 TPH	—
Batch mixer	Paddle-type batch mixer	—[b]	405 cubic feet	—

Note: Pug mill sizes are based on two motors, each operating at the indicated horsepower.

[b] PTO-, motor-, or engine-driven.

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
Processall				
300HC	Continuous mix mill	—	1 TPH	—
8000HC	Continuous mix mill	—	148 TPH	—

Note: Wide range of models, sizes, capacities, and costs between those listed above. Mixing elements on rotating shaft mix and move materials through a cylindrical vessel. A general range of prices is $70,000–140,000.

Note: (1) CY stands for cubic yards. CYH stands for cubic yards per hour. TPH stands for tons per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.3
Commercial mixing equipment (continued)

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
Rapin Machinery				
Pug mills, other mixers and materials-handling equipment		—	—	—
Sludge Systems Inc.				
285	Auger-type batch mixer	75	10.5 CY and 38 CYH	$50,000–60,000
335	Auger-type batch mixer	75	12.4 CY and 46 CYH	$52,000–62,000
435	Auger-type batch mixer	75–165	16.0 CY and 60 CYH	$55,000–112,000
500	Auger-type batch mixer	—	18.5 CY and 70 CYH	$57,000–115,000
810	Auger-type batch mixer	75–165	30 CY and 100 CYH	$75,000–150,000

Note: Capacities are in cubic yards struck and cubic yards per hour mixing, respectively. Mixing capacities are based on a sixteen-minute cycle time. Models are truck-mounted, trailer (tow), or stationary units and are PTO-, electric-motor- or engine-driven.

Company and model	Equipment type	Size (horsepower)	Approximate capacity	Approximate cost
J.C Steele & Sons				
25A	Single-shaft pug mill	15–30	5–20 CYH	—
200E	Single-shaft pug mill	30–40	10–40 CYH	—
300F	Single-shaft pug mill	40–75	15–60 CYH	—
2030E	Double-shaft pug mill	50–60	12–50 CYH	—
5075F	Double-shaft pug mill	75–100	20–80 CYH	—

Note: A general range of prices is $20,000–80,000, depending on model and features

Note: (1) CY stands for cubic yards. CYH stands for cubic yards per hour. TPH stands for tons per hour.

(2) The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.4
Commercial screening equipment

Company and model	Type of screen	Approximate capacity (cubic yards per hour, except where noted)	Approximate cost	Comments
Amadas				
T72X 16	Trommel	70+	$75,000	
Magnum 72 x 20	Trommel	100	$135,000	
Models 440 and 442	Disc	Varies with disc spacing, material	$18,500	
DK Recycling				
Farwick Super	Trommel	30–60	$74,450	
Farwick Max	Trommel	70–120	$139,350	
Fuel Harvesters				
650	Trommel	10–40 tons per hour	$100,000–150,000	
750	Disc	10–40 tons per hour	$95,000–125,000	
Note: Price depends on optional components such as bins, conveyors, and so on				
Innovator				
20400	Trommel	10 tons per hour	—	Capacity is for wood waste

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.4
Commercial screening equipment (continued)

Company and model	Type of screen	Approximate capacity (cubic yards per hour, except where noted)	Approximate cost	Comments
McLanahan				
Rotary Screen	Trommel-type	Variable	—	
Mogensen Sizer	Vibrating	Varies with mesh size, screen width, material	—	3–5 vertical screen decks
Multitek				
Multi-Screen	Trommel	Varies with mesh size and material	$38,500–67,500	Includes hammers for size reduction
Ohio Central Steel Company (The Screen Machine®)				
Pulverizer II	Vibrating (two screen decks)	50	$50,000	Screening systems include shredder, conveyors and hoppers
2 in 1 Shredder	Vibrating (two screen decks)	80–125	$78,000	Screening systems include shredder, conveyors and hoppers
Multi-Blend I	Vibrating (two screen decks)	80–125	$100,000	Includes mixing-blending device via dual hoppers

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.4
Commercial screening equipment (continued)

Company and model	Type of screen	Approximate capacity (cubic yards per hour, except where noted)	Approximate cost	Comments
Powerscreen				
Mark II Belt Feeder	Vibrating	50–70	$70,000–80,000	Screening systems include optional hoppers, conveyors, and shredder
Mark III Shredder	Vibrating	120–150	$115,000–130,000	Screening systems include hoppers, conveyors, and shredder
Mark II Powergrid	Vibrating	Unlimited	$85,000–100,000	Heavy-duty, direct-loading unit
Rader				
Rader-Wave Compost Screen	Flexible belt	30–200	$20,000 (base price)	Wave-like flexing motion Multiple sizes and models are available
Recovery Systems Technology				
T550-D	Trommel	30–70 80–100	$89,950 (base price)	Lower capacity range is estimated for sticky materials; higher capacity range is estimated for topsoil

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.4

Commercial screening equipment (continued)

Company and model	Type of screen	Approximate capacity (cubic yards per hour except where noted)	Approximate cost	Comments
Recycling Systems Inc.				
Model 100	Trommel	—	$67,150	
Model 200	Trommel	—	$98,500	
Royer				
616 MP Mobile Unit	Trommel	Variable	—	Price depends on customer specifications
Note: Custom-designed systems using trommel-based screens are also available.				
Triple/S Dynamics				
Rotascreen	Trommel	Variable	—	
Texas	Shaker	Variable	—	
Overstrom	Vibrating	Variable	—	
Note: Multiple models, sizes, and configurations of all three types of screens are available.				

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.4
Commercial screening equipment (continued)

Company and model	Type of screen	Approximate capacity (cubic yards per hour except where noted)	Approximate cost	Comments
West Salem Machinery				
24-9	Disc	Variable	—	
48-12	Disc	Variable	—	
72-12	Disc	Variable	—	
25	Oscillating (shaker)	Variable	—	
64	Oscillating (shaker)	Variable	—	
140	Oscillating (shaker)	Variable	—	

Note: Both types of screens are available in numerous models and sizes in between those listed. On disc screen models, model number indicates screen width-length in inches and feet, respectively. On oscillating (shaker) screens, model number indicates screen area in square feet

Company and model	Type of screen	Approximate capacity (cubic yards per hour except where noted)	Approximate cost	Comments
Wildcat				
6-160	Trommel	30–150	$65,000	Various options available
6-160-RHC	Trommel	30–150	$165,000	Fully automatic

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Costs are current to September, 1991. Costs and capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.5
Commercial composting systems

Rectangular Agitated Bed Systems

Compost-A-Matic System
Farmer Automatic

Compost agitated and moved forward by paddle-type agitator. Bed is 3 feet deep with 6- to 20-foot widths. Does not include a forced aeration system. Normally enclosed in simple greenhouse. Designed primarily for farm use.

IPS Composting System
International Process Systems

Automated agitator mixes and moves the compost daily. Multiple bays of 6- to 7-foot widths with 6-foot depth. Built as enclosed system with control of aeration, moisture, and odors. Designed for twenty-one-day composting time. Initially used for commercial composting of hen manure.

Paygro System
Compost Systems Company

Large-scale aerated and agitated system. Bays may be 20 feet wide, 10 feet deep, and any length. Automated, enclosed in buildings. Originally designed to compost manure from a cattle feedlot facility.

POS Composter
LH Resource Management

Flail-type agitator mixes and moves compost either manually or automatically. Agitator travels in concrete-cast channels in bed walls. Multiple beds are aerated and normally 4 feet deep and 15 feet wide. May be enclosed. Generally designed for composting time of ten days or more. Originally designed for farm use.

Royer Enclosed Dynamic Composting System
Royer Industries

Agitator mixes and moves compost daily. Multiple bays are about 9.5 feet wide and 6 feet deep. Enclosed system with automated controls for aeration, temperature, and turning. Typically designed for fifteen- to twenty-one-day composting time.

Other Agitated Systems

Buhler-Wendelin System
Buhler, Inc.

Automated in-vessel composting system with paddle wheel turner and conveyors to build, turn, and rebuild adjacent windrows or feed loadout. Aeration and moisture controls. Enclosed facilities. Bay widths up to 115 feet and any length. Designed for up to seventy days of active composting.

Dynatherm System
Compost Systems Company

Modular composting reactors fabricated from steel (44 feet long, 11 feet wide, and 9 feet high) for small applications or from concrete (120 feet long, 18 feet wide, and 10 feet high) for larger systems. Utilizes moving floor to transfer materials from feed to discharge end of reactor. Intermediate mixing provided during fourteen- to twenty-one-day composting cycle.

Fairfield Digestor
Compost Systems Company

Circular reactor with multiple vertical augers to agitate and move compost. Reactors can be 20–120 feet in diameter and 6–10 feet in depth. Normal composting time is fourteen days.

The Pierson/Naturizer Technology
Naturizer International

Horizontal digestion chambers designed to handle single day's charge of incoming material. Conveyors move materials through successive composting chambers in six days. Totally enclosed facilities. Includes controls for aeration, temperature, moisture, and odor controls.

SILODA Composting Process
OTVD Inc.

Paddle wheel turner mixes compost and screw-type conveyor transfers it into successive, adjacent bins, or beds. Enclosed facility. Normal composting time is twenty-eight days.

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all systems suppliers; only those suppliers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.5
Commercial composting systems (continued)

Rotating Drum Composting Systems

Bedminster System
Bedminster Bioconversion

Unscreened raw materials are mixed and composted for three days in Eweson rotating drum digester. Followed by screening and second stage of composting in windrows, static piles, or agitated beds. Drum is 12 feet in diameter and 180 feet long.

Dano/Reidel System
Resource Systems Corporation

Enclosed, slowly rotating drum mixes and breaks-up pre-sorted raw materials and initiates composting. Materials move through drum in four to six hours followed by screening and second stage of composting in windrows or aerated piles. Drum is 12 feet in diameter and 80 feet long.

Voest Alpine (SGP-VA) Composting System
Chambers Development Company

Paddle-wheel turner mixes and moves compost through the system. Initial mixing and composting occurs in rotating drum for about eight hours. Normal overall composting time is twenty-one days.

Silo Reactor Systems

Air Lance™ System
American BioTech

Square reactors (26 feet long, 26 feet high, and 26 feet deep) with a matrix of vertical aeration pipes—"air lances"—which extend from the top to the bottom of the reactor. Air flows crosswise between adjacent air lances. Mixed materials loaded at the top of the reactor. Compost removed at the base by an auger. Second reactor used for curing.

Taulman Composting System
The Taulman Company

Circular silo reactors. Mixed materials are loaded at top. Compost is unloaded at bottom by auger. Air flows from the reactor base to top, counter to the material movement. Two reactors are used in sequence—a primary "bioreactor" followed by a curing reactor. Total in-vessel composting time ranges from twenty-one to thirty-five days.

Commercial Systems Using Windrows and Aerated Piles

A number of commercial systems are available which rely on windrows or aerated piles along with various combinations of secondary equipment and structures. Several companies offering such systems or related services include Amerecycle, Daneco, Environmental Recovery Systems, Resource Conservation Services, and WPF Corporation.

Note: The information in this table was obtained from the manufacturers. No attempt was made to verify manufacturers' claims. This list does not include all systems suppliers; only those suppliers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned. Capacities vary considerably with materials, specific application, and optional equipment. Contact the manufacturer for the most current information; addresses of manufacturers are listed in table B.6, pages 142–145.

Table B.6
Equipment manufacturers and suppliers

A-1 Environmental
16350 Weld County Road 76
Eaton, CO 80615

Allegheny Paper Shredders Corporation
Old William Penn Highway East
Delmont, PA 15626-0080

Amadas Industries
1100 Holland Road
Suffolk, VA 23434

Amerecycle
County Road 529
Box 338
Sumterville, FL 33585

American BioTech, Inc.
2100 Corporate Square Blvd
Box 19769
Jacksonville, FL 32245

American Pulverizer Company
5540 West Park Avenue
St. Louis, MO 63110

Bandit Industries, Inc
6750 Millbrook Road
Remus, MI 49340

Bedminster Bioconversion Corporation
52 Haddonfield-Berlin Road
Suite 4000
Cherry Hill, NJ 08034

Brown Bear Corporation
Bluegrass Industrial Park
Box 29
Corning, IA 50841

Buhler, Inc.
Box 9497
Minneapolis, MN 55440

The Centaur Walker Company
5022 Christiansen
Lansing, MI 48910

Chambers Development Company
10700 Frankstown Road
Pittsburgh. PA 15235

Compost Systems Company
9403 Kenwood Road
Cincinnati, OH 45242

Daneco, Inc.
450 Park Avenue
Suite 2104
New York, NY 10022

Davis Pugmill, Inc.
Box 60
Columbia, TN 38402-0060

DK Recycling Systems, Inc.
11 North Skokie Highway
Suite 303
Lake Bluff, IL 60044

Eagle Crusher Company, Inc
4250 State Route 309
Galion, OH 44833

Eidal International, Inc.
Box 529
19960 Bluegrass Circle
West Linn, OR 97068

Environmental Recovery Systems, Inc.
1625 Broadway #2600
Denver, CO 80202

Farmer Automatic of America
Box 39
Register, GA 30452

Farmhand, Inc.
Shorewood Village Center
Box 1500
Excelsior, MN 55331

Note: The information above is provided as a service to readers and was obtained from the manufacturers. See the equipment tables (pages 115–141) for complete product information. No endorsement of these companies is intended, nor is criticism implied of similar companies which are not mentioned. Information is current to September, 1991. Contact the companies for current information on pricing and availability of products.

Table B.6
Equipment manufacturers and suppliers (continued)

Finn Corporation
9281 LeSaint Drive
Fairfield, OH 45014

Fuel Harvesters Equipment
2501 Commerce Drive
Midland, Texas 79703

Haybuster Manufacturing, Inc.
Box 1940
Jamestown, ND 58402-1940

Iggesund Recycling
Box 380
Nisswa, MN 56468

Industrial Paper Shredders, Inc.
Box 180
707 South Ellsworth Avenue
Salem, OH 44460

Innovator Manufacturing, Inc.
120 Weston Street
London, Ontario N6C 1R4
Canada

International Process Systems, Inc.
c/o Wheelabrator Technologies, Inc.
Liberty Lane
Hampton, NH 03842

Jeffery Division
Dresser Industries
Box 387
Woodruff, SC 29388

Jones Manufacturing Company
Route 1, Box 80
Beemer, NE 68716

JWC Environmental
16802 Aston Street
Suite 200
Irvine, CA 92714

Knight Industrial Division
1501 West 7th Avenue
Brodhead, WI 53520

LH Resource Management, Inc.
Walton, Ontario N0K 1Z0
Canada

Littleford Brothers, Inc.
7451 Empire Drive
Florence, KY 41042-2985

McLanahan Corporation
200 Wall Street
Box 229
Hollidaysburg, PA 16648

Multitek, Inc.
Box 170
Prentice, WI 54556

Naturizer International, Inc.
Box 755
Norman, OK 73070-0755

Norcia
RD#4, Box 451
Black Horse Lane
North Brunswick, NJ 08902

Northeast Implement
Box 402
Spencer, NY 14883

Ohio Central Steel Company
7001 Americana Parkway
Reynoldsburg, OH 43068

Olathe Manufacturing, Inc.
201 Leawood Drive
Box 4
Industrial Airport, KS 66031

OTVD
135 East 57th Street
23rd Floor
New York, NY 10022

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Table B.6
Equipment manufacturers and suppliers (continued)

PCR, Inc.
RR 1, Box 392
Coon Valley, WI 54623

Powerscreen of America
11001 Electron Drive
Louisville, KY 40299

Processall
10596 Springfield Pike
Cincinnati, OH 45215

Rader Companies, Inc.
Box 20128
Portland, OR 97220

Rapin Machinery, Inc.
200 Rapin Place
Buffalo, NY 14211

Recovery Systems Technology
18012 Bothell Everett Highway
Bothell, WA 98012

Recycling Systems, Inc.
Box 364
8507 South Winn Road
Winn, MI 48896

Resource Conservation Services
42 Main Street
Yarmouth, ME 04096

Resource Recovery Systems of Nebraska KW
Route 4, 511 Pawnee Drive
Sterling, CO 80751

Resource Systems Corporation
1312 East Burnside
Portland OR 97214

Royer Industries
Box 1232
158 Pringle Street
Kingston, PA 18704-0232

Scarab Manufacturing and Leasing
HCR 1, Box 205
Box 1047
White Deer, TX 79097

Scat Engineering
Box 265
Delhi, IA 52223

Shred-Tech Limited
Box 1508
201 Beverly Street
Cambridge, Ontario N1R 7G8
Canada

Simcorp, Inc.
Route 1, Box 202
Canyon, TX 79016

Sludge Systems, Inc.
Box 265
1125 Starr Avenue
Eau Claire, WI 54702-0265

SSI Shredding Systems
9760 SW Freeman Drive
Wilsonville, OR 97070-9286

J.C. Steele and Sons, Inc.
Box 951
Statesville, NC 28677

Sundance
Box 2437
Greeley, CO 80632

Taulman, Inc.
415 East Paces Ferry Road NE
Atlanta, GA 30305

Triple/S Dynamics, Inc.
1031 South Haskell Avenue
Dallas, TX 75223

Note: The information above is provided as a service to readers and was obtained from the manufacturers. See the equipment tables (pages 115–141) for complete product information. No endorsement of these companies is intended, nor is criticism implied of similar companies which are not mentioned. Information is current to September, 1991. Contact the companies for current information on pricing and availability of products.

Table B.6
Equipment manufacturers and suppliers (continued)

Universal Engineering
Division of Pettibone Corporation
800 First Avenue NW
Cedar Rapids, IA 52405-3999

Waste-Tech Equipment
892-898 Troy-Schenectady Road
Latham, NY 12110

Wildcat Manufacturing Company
Box 523, Highway 81
Freeman, SD 57029

Valoraction, Inc.
C.P. 892
Sherbrooke, PQ J1H 5L1
Quebec, Canada

West Salem Machinery Company
665 Murlark Avenue, NW
Box 5288
Salem, OR 97302

WPF Corporation
Box 381
Bellevue OH 44811

Note: The information above is provided as a service to readers and was obtained from the manufacturers. See the equipment tables (pages 115–141) for complete product information. No endorsement of these companies is intended, nor is criticism implied of similar companies which are not mentioned. Information is current to September, 1991. Contact the companies for current information on pricing and availability of products.

Table B.7
Temperature probe distributors

Arthur Technology
Tech-Line Instrument
574 Prairie Road
Box 1236
Fond du Lac, WI 54936-1236
(414) 922-6970
1-800-328-7518
FAX (414) 922-1085

Atkins
3401 Southwest Fortiers Drive
Gainesville, FL 32608
(904) 378-5555

Camx Scientific
Box 747
Rochester, NY 14603-0747
(716) 482-1300

Meriden Cooper Corporation
112 Golden Street Park
Box 692
Meriden, CT 06450-0692
(203) 237-8448
1-800-466-8448
FAX (203) 238-1314

Omega Engineering, Inc.
One Omega Drive
Box 4047
Stamford, CT 06907-0047
(203) 359-1660
1-800-826-6342
FAX (203) 359-7807

Reotemp Instrument Corporation
11568 Sorrento Valley Road #10
San Diego, CA 92121
(619) 481-7737
1-800-648-7737
FAX (619) 481-7150

Walden Instrument Supply Company
910 Main Street
Wakefield, MA 01880
(617) 245-2944

Note: The information above is provided as a service to readers and was obtained from the manufacturers. No endorsement of these companies or products is intended, nor is criticism implied of similar companies or products which are not mentioned. Information is current to April, 1992. Contact the companies for current information on pricing and availability of products.

C Troubleshooting & Management Guide

Table C.1
Troubleshooting and management guide

Condition or situation	Possible source or reason	Other clues	Remedy
Pile fails to heat	Materials too dry	Cannot squeeze water from material	Add water or wet ingredients
	Materials too wet	Materials look or feel soggy; pile slumps; moisture content greater than 60%	Add dry amendments and remix
	Not enough nitrogen, or slowly degrading or stable materials	C:N ratio greater than 50:1; large amount of woody materials	Add high-nitrogen ingredients; change composting recipe
	Poor structure	Pile settles quickly; few large particles; not excessively wet	Add bulking agent
	Cold weather and small pile size	Pile height less than 3.5 feet	Enlarge or combine piles; add highly degradable ingredients
	pH excessively low	pH measures less than 5.5; garbage-like odor	Add lime or wood ash and remix

Table C.1
Troubleshooting and management guide (continued)

Condition or situation	Possible source or reason	Other clues	Remedy
Temperatures falls consistently over several days	Low oxygen; need for aeration	Temperature declines gradually rather than sharply	Turn or aerate pile
	Low moisture	Cannot squeeze water from material	Add watei
Uneven temperatures or varying odors in pile	Poorly mixed materials	Visible differences in the pile moisture and materials	Turn or remix pile
	Uneven airflow or air short circuiting	Visible differences in the pile moisture and materials	Shorten aeration pipe; remix pile
	Materials at different stages of maturity	Temperature varies along the pile length	None required
Gradually falling temperatures; pile does not reheat after turning or aeration	Composting nearing completion	Approaching expected composting time period; adequate moisture available; C:N ratio less than 20:1	None required
	Low moisture	Cannot squeeze water from materials	Add water and remix
Pile overheating (temperature greater than 150°F)	Insufficient aeration for heat removal	Pile is moist	Turn pile or increase the airflow rate
	Moderate to low moisture; limited evaporative cooling	Pile feels damp but not excessively wet or dry	Add water; continue turning and aeration to control temperature
	Pile is too large	Height greater than 8 feet	Decrease the pile size
Extremely high temperatures (greater than 170°F) in pile: composting or curing/ storage	Pyrolysis or spontaneous combustion	Low moisture content; pile interior looks or smells charred	Decrease pile size; maintain proper moisture content; add water to charred or smoldering sections; break down pile, combine with other piles

Table C.1
Troubleshooting and management guide (continued)

Condition or situation	Possible source or reason	Other clues	Remedy
High temperatures or odors in curing or storage pile	Compost is not stable	Short active composting period; temperature and odor change after mixing	Manage pile for temperature and odor control, turn piles as necessary; limit pile size
	Piles are too large	Height greater than 8 feet; width greater than 20 feet	Decrease pile size
Ammonia odor coming from composting piles	High nitrogen level	C:N ratio less than 20:1	Add high-carbon amendments
	High pH	pH greater than 8.0	Lower pH with acidic ingredients and/or avoid alkaline ingredients
	Slowly available carbon source	Large woody particles; C:N ratio less than 30:1	Use another carbon amendment or increase the carbon proportion
Rotten-egg or putrid odors coming from composting piles continually	Anaerobic conditions	Low temperatures	
	Materials too wet		Add dry amendment
	Poor structure		Add bulking agent
	Pile compacted		Remix pile and add bulking agent if necessary
	Insufficient aeration		Turn pile or increase the airflow rate
	Anaerobic conditions	High temperatures	
	Pile too large		Decrease the pile size
	Airflow uneven or short circuiting		Remix pile; change recipe
Odors generated only after turning	Odorous raw materials	High temperatures	Frequent turnings; increase porosity; add odor-absorbing amendment
	Insufficient aeration; anaerobic interior	Falling temperatures	Shorten time interval between turnings; increase porosity

Table C.1
Troubleshooting and management guide (continued)

Condition or situation	Possible source or reason	Other clues	Remedy
Site-related odors (piles not odorous)	Raw materials	Odor is characteristic of the raw material	Handle raw materials promptly with minimal storage
	Nutrient-rich puddles because of poor drainage	Standing puddles of water; ruts in pad	Divert runoff away; maintain pad surface
	Holding pond or lagoon overloaded with nutrients or sediment	Heavy algae and weed growth; gas bubbles on pond surface	Install sediment trap; enlarge pond surface area; use runoff and pond water on cropland
Fly or mosquito problems	Flies breeding in compost piles	Fresh manure or food material at pile surface; flies hover around piles	Turn piles every four to seven days; cover static piles with a 6-inch layer of compost
	Flies breeding in raw materials	Wet raw materials stored on site more than four days	Handle raw materials promptly
	Mosquitoes breeding in stagnant water	Standing puddles of water; nutrient-rich pond or lagoon	Grade site properly; maintain pad surface; maintain holding pond or lagoon in aerobic condition
Compost contains clumps of materials and large particles; texture is not uniform	Poor mixing of materials or insufficient turning	Original raw materials discernible in compost	Screen compost; improve initial mixing
	Airflow uneven or short-circuiting	Wet clumps of compost	Screen or shred compost; improve air distribution
	Raw materials contain large particles and non-degradable or slowly degradable materials	Large, often woody, particles in compost	Screen compost; grind and/or sort raw materials
	Active composting not complete	Curing piles heat or develop odors	Lengthen composting time or improve composting conditions

D Work Sheets and Forms

Sample temperature monitoring forms

Compost pad area calculation

Site temperature monitoring record

Date ______________________ Time of day ______________________

Data collected by ______________________

Weather (sunny, raining, and so on) ______________________

Ambient (air) temperature __________ °F Wind direction ______________________

General site observations and comments ______________________

____

____

____

Pile number	Moisture rating	Odor rating	Temperature (°F)			
			Distance from end of pile			
			feet	feet	feet	feet

Recorded by date

Windrow/pile temperature monitoring record

Windrow, pile, or cell number ______________________________
Date constructed ______________________________
Ingredients and comments ______________________________
____
____
____

Date	Time	*Moisture* rating	*Odor* rating	Temperature (°F)			
				Distance from end of pile			
				feet	feet	feet	feet

Recorded by windrow, pile, or cell

Compost pad area calculation

1. Raw materials and daily volumes

Material	Daily volume	
____________________	__________	cubic feet per day
____________________	__________	cubic feet per day
____________________	__________	cubic feet per day
____________________	__________	cubic feet per day
____________________	__________	cubic feet per day
Total daily volume =	__________	cubic feet per day

1A. Adjust for volume reduction because of combining raw materials (optional)

Reduced volume = daily volume (from step 1) x 0.80
= __________ cubic feet per day x 0.80
= __________ cubic feet per day

2. Calculate pad volume. Pad volume is the total volume of material on the pad at one time.

Pad volume = composting period x daily volume (from step 1 or 1A)
= __________ days x __________ cubic feet per day
= __________ cubic feet

2A. Adjust volume for shrinkage (optional)

Adjusted volume = shrinkage factor x volume
= __________ x __________ cubic feet
= __________ cubic feet

3. Windrow/pile dimensions

Length = __________ feet (determined by site limitations)

Height = __________ feet

Width = __________ feet

(determined by equipment available for forming and turning windrows)

4. Windrow/pile volume

A = __________ (formula from table 7.2, page 70)

= __________

= __________ square feet

or A = __________ square feet (from table 7.3, page 72)

Volume = A x length

= __________ square feet x __________ feet

= __________ cubic feet

5. Number of windrows/piles = pad volume (step 2 or 2A) ÷ windrow/pile volume (step 4)

= __________ cubic feet ÷ __________ cubic feet

= __________ or __________ windrows/piles

6. Windrows/piles layout and spacing (required space between windrows is estimated in figure 7.9, page 71). Sketch below.

7. Pad width, length, and area

Width of windrows/piles = number of windrows/piles x width of each
= _________ x _________ feet
= _________ feet

Aisle space = _________ feet + _________ feet (see figure 7.9, page 71)
= _________ feet

Perimeter space = _________ feet + _________ feet
= _________ feet

Total pad width = width of windrows/piles + aisle space + perimeter space
= _________ feet + _________ feet + _________ feet
= _________ feet

Pad length = windrow/pile length + perimeter space
= _________ feet + _________ feet
= _________ feet

Pad area = pad width x length
= _________ feet x _________ feet
= _________ square feet

Check to see if the pad dimensions are consistent with required setbacks.

Compost pad area calculation
(example completed with data from chapter 7)

1. Raw materials and daily volumes

Material	Daily volume	
Hen manure	210	cubic feet per day
Sawdust	630	cubic feet per day
		cubic feet per day
		cubic feet per day
		cubic feet per day
Total daily volume =	840	cubic feet per day

1A. Adjust for volume reduction because of combining raw materials (optional)

Reduced volume = daily volume (from step 1) x 0.80
= 840 cubic feet per day x 0.80
= 672 cubic feet per day or approximately 700

2. Calculate pad volume. Pad volume is the total volume of material on the pad at one time.

Pad volume = composting period x daily volume (from step 1 or 1A)
= 60 days x 700 cubic feet per day
= 42,000 cubic feet

2A. Adjust volume for shrinkage (optional)

Adjusted volume = shrinkage factor x volume
= .75 x 42,000 cubic feet
= 31,500 cubic feet

3. Windrow/pile dimensions

Length = 150 feet (determined by site limitations)

Height = 8 feet (determined by equipment available

Width = 14 feet for forming and turning windrows)

4. Windrow/pile volume

A = $\frac{2}{3} \times b \times h$ (formula from table 7.2, page 70)

= $\frac{2}{3} \times 14 \times 8$

= 75 square feet

or A = 75 square feet (from table 7.3, page 72)

Volume = A x length

= 75 square feet x 150 feet

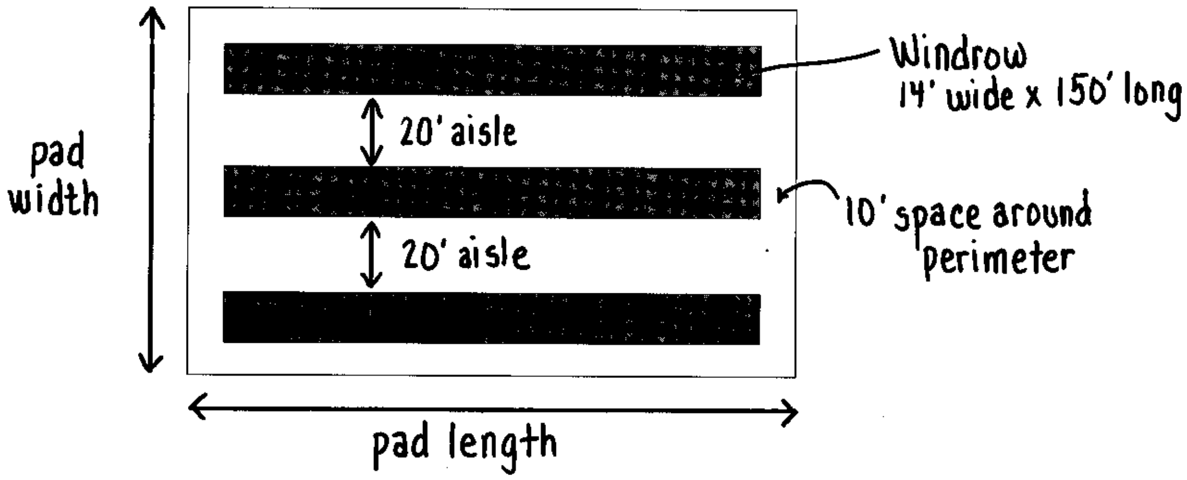
= 11,250 cubic feet

5. Number of windrows/piles = pad volume (step 2 or 2A) ÷ windrow/pile volume (step 4)

= 31,500 cubic feet ÷ 11,250 cubic feet

= 2.8 or 3 windrows/piles

6. Windrows/piles layout and spacing (required space between windrows is estimated in figure 7.9, page 71). Sketch below.



7. Pad width, length, and area

Width of windrows/piles = number of windrows/piles x width of each

= 3 x 14 feet

= 42 feet

Aisle space = 20 feet + 20 feet (see figure 7.9, page 71)

= 40 feet

Perimeter space = 10 feet + 10 feet

= 20 feet

Total pad width = width of windrows/piles + aisle space + perimeter space

= 42 feet + 40 feet + 20 feet

= 102 feet

Pad length = windrow/pile length + perimeter space

= 150 feet + 20 feet

= 170 feet

Pad area = pad width x length

= 102 feet x 170 feet

= 17,340 square feet

Check to see if the pad dimensions are consistent with required setbacks.

E Environmental Agencies

State environmental agencies

Alabama

Department of Environmental Management
Solid Waste Division
1751 Congressman William Dickinson Drive
Montgomery, AL 36109
(205) 271-7726

Alaska

Department of Environmental Conservation
Division of Environmental Quality
Solid Waste Program
410 Willoughby Avenue, Suite 105
Juneau, AK 99801-1795
(907) 465-5150

Arizona

Energy Office
3800 North Central #1200
Phoenix, AZ 85012
(602) 280-1402

Arkansas

Department of Pollution Control and Ecology
Solid Waste Division
8001 National Drive
Box 8913
Little Rock, AR 72219-8913
(501) 562-6533

California

Department of Conservation
Division of Recycling
801 "K" Street
Sacramento, CA 95814-3500
(800) 642-5669

Colorado

Department of Health
4210 East 11th Avenue
Denver, CO 80220-3783
(303) 320-8333

Note: Every attempt was made to verify the addresses of these state environmental agencies; however, absolute accuracy cannot be guaranteed. Information is current to April, 1992. Readers should contact the specific offices listed above only if they have questions about state composting guidelines and related matters. Other questions may have to be directed to different state offices.

State environmental agencies (continued)

Connecticut

Recycling Program
Department of Environmental Protection
165 Capitol Avenue
Hartford, CT 06106
(203) 566-5847

Delaware

Department of Natural Resources and
Environmental Control
89 Kings Highway
Box 1401
Dover, DE 19901
(302) 739-3820

District of Columbia

Department of Public Works
Water and Sewer Utility Administration
5000 Overlook Avenue SW
Washington, DC 20032
(202) 767-7651

Florida

Library
Department of Environmental Regulation
2600 Blair Stone Road, Room 441
Tallahassee, FL 32301
(904) 488-0890

Georgia

Department of Natural Resources
205 Butler Street, SE
1170 East Tower
Atlanta, GA 30334
(404) 656-2833

Hawaii

Office of Solid Waste
Department of Health
Box 3378
Honolulu, HI 96801
(808) 586-4227

Idaho

Division of Environmental Quality
Idaho Department of Health and Welfare
1410 North Hilton Street
Boise, ID 83720-9000
(208) 334-0502

Illinois

Department of Energy and Natural Resources
325 West Adams Street, Room 300
Springfield, IL 62704-1892
(217) 524-5454

Indiana

Indiana Department of Environmental
Management
105 South Meridian Street
Indianapolis, IN 46225
(317) 232-3210

Iowa

Iowa Department of Natural Resources
Waste Management Division
900 East Grand Avenue
Des Moines, IA 50319
(515) 281-8941
FAX (515) 281-8895

Kansas

Solid Waste Section
Department of Health and Environment
Forbes Field
Topeka, KS 66620
(913) 296-1590

Kentucky

Department for Environmental Protection
Divisions of Waste, Water, and Air Quality
14 Reilly Road
Frankfort, KY 40601
(502) 564-2150

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State environmental agencies (continued)

Louisiana

Solid Waste Division
Department of Environmental Quality
Box 82178
Baton Rouge, LA 70884
(504) 765-0249

Maine

Department of Environmental Protection
Station #17
Augusta, ME 04333
(207) 582-8740

Maryland

Department of the Environment
201 West Preston Street
Room 212
Baltimore, MD 21201
(301) 225-5647

Massachusetts

Recycling Program Coordinator
Department of Environmental Protection
Division of Solid Waste Management
1 Winter Street, 4th Floor
Boston, MA 02108
(617) 292-5589

Michigan

Resource Recovery Section
Department of Natural Resources
Box 30241
Lansing, MI 48909
(517) 373-4741

Minnesota

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, MN 55155
(612) 296-6300

Mississippi

Department of Environmental Quality
Box 20305
Jackson, MS 39289-1305
(601) 961-5000

Missouri

Department of Natural Resources
Solid Waste Management Program
Box 176
Jefferson City, MO 65102
(314) 751-3176

Montana

Solid and Hazardous Waste Bureau
Department of Health and Environmental Sciences
836 Front Street
Helena, MT 59620
(406) 444-1430

Nebraska

Department of Environmental Control
Box 98922
Lincoln, NE 68509-8922
(402) 471-2186

Nevada

Department of Conservation and Natural Resources
123 West Nye Lane
Room 214
Carson City, NV 89710
(702) 885-4360

New Hampshire

Department of Environmental Services
6 Hazen Drive
Concord, NH 03301
(603) 271-3503

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State environmental agencies (continued)

New Jersey

Department of Environmental Protection and Energy
Division of Solid Waste Management
Bureau of Resource Recovery
CN 414
Trenton, NJ 08625-0414
(609) 530-8885

New Mexico

New Mexico Environment Department
Box 26110
Santa Fe, NM 87502-6110
(505) 827-2850

New York

Bureau of Waste Reduction and Recycling
Department of Environmental Conservation
50 Wolf Road, Room 200
Albany, NY 12233-4015
(518) 457-7337

North Carolina

North Carolina Department of Environment, Health, and Natural Resources
Division of Solid Waste Management
Solid Waste Section
Box 27687
Raleigh, NC 27611-7687
(919) 733-0692

North Dakota

Division of Waste Management
Solid Waste Program
North Dakota Department of Health
1200 Missouri Avenue, Room 302
Box 5520
Bismarck, ND 58502-5520
(701) 221-5166

Ohio

Division of Solid and Infectious Waste Management
Ohio Environmental Protection Agency
1800 Watermark Drive
Columbus, OH 43266-0149
(614) 644-2917

Oklahoma

Oklahoma State Department of Health
Solid Waste Management 0206
1000 NE 10th Street
Oklahoma City, OK 73117-1299
(405) 271-7159

Oregon

Department of Environmental Quality
811 SW 6th Avenue
Portland, OR 97204-1319
(503) 229-5913
FAX (503) 229-6124
TDD (503) 229-6993

Pennsylvania

Bureau of Waste Management
200 North 3rd Street
Box 2063
Harrisburg, PA 17105-2065
(717) 787-9870

Rhode Island

Department of Environmental Management
Office of Environmental Coordination
83 Park Street
Providence, RI 02908
(401) 277-3434

South Carolina

Bureau of Solid and Hazardous Waste Management
Department of Health and Environmental Control
2600 Bull Street
Columbia, SC 29201
(803) 734-5200

South Dakota

Department of Environment and Natural Resources
Foss Building, Room 416
Pierre, SD 57501
(605) 773-3153

Note: Every attempt was made to verify the addresses of these state environmental agencies; however, absolute accuracy cannot be guaranteed. Information is current to April, 1992. Readers should contact the specific offices listed above only if they have questions about state composting guidelines and related matters. Other questions may have to be directed to different state offices.

State environmental agencies (continued)

Tennessee

Department of Environment and Conservation
Division of Solid Waste Management
Customs House, 4th Floor
701 Broadway
Nashville, TN 37243-1535
(615) 327-3540

Texas

Municipal Solid Waste Division
Texas Water Commission
Box 13087, Capitol Station
Austin, TX 78711
(512) 834-6625

Utah

Division of Solid and Hazardous Waste
Department of Environmental Quality
288 North 1460 West Street
Box 144880
Salt Lake City, UT 84114-4880
(801) 538-6170

Vermont

Solid Waste Management Division
Department of Environmental Conservation
103 South Main Street
Waterbury, VT 05671-0407
(802) 244-7831

Virginia

Department of Waste Management
Monroe Building, 11th Floor
101 North 14th Street
Richmond, VA 23219
(804) 225-2667

Washington

Department of Ecology
Waste Reduction, Recycling, and Litter Control Program
Box 47600, Mail Stop 7600
Olympia, WA 98504-7600
(206) 438-7482
FAX (206) 438-7789

West Virginia

Division of Natural Resources
Waste Management Section
1356 Hansford Street
Charleston, WV 25301
(304) 348-5929
FAX (304) 348-0256

Wisconsin

Bureau of Solid Waste Management
Department of Natural Resources
101 South Webster Street
Madison, WI 53707
(608) 266-1327

Wyoming

Solid Waste Management Program
Department of Environmental Quality
Herschler Building
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7752

Note: Every attempt was made to verify the addresses of these state environmental agencies; however, absolute accuracy cannot be guaranteed. Information is current to April, 1992. Readers should contact the specific offices listed above only if they have questions about state composting guidelines and related matters. Other questions may have to be directed to different state offices.

Environmental Protection Agency (EPA) regional offices

Region 1

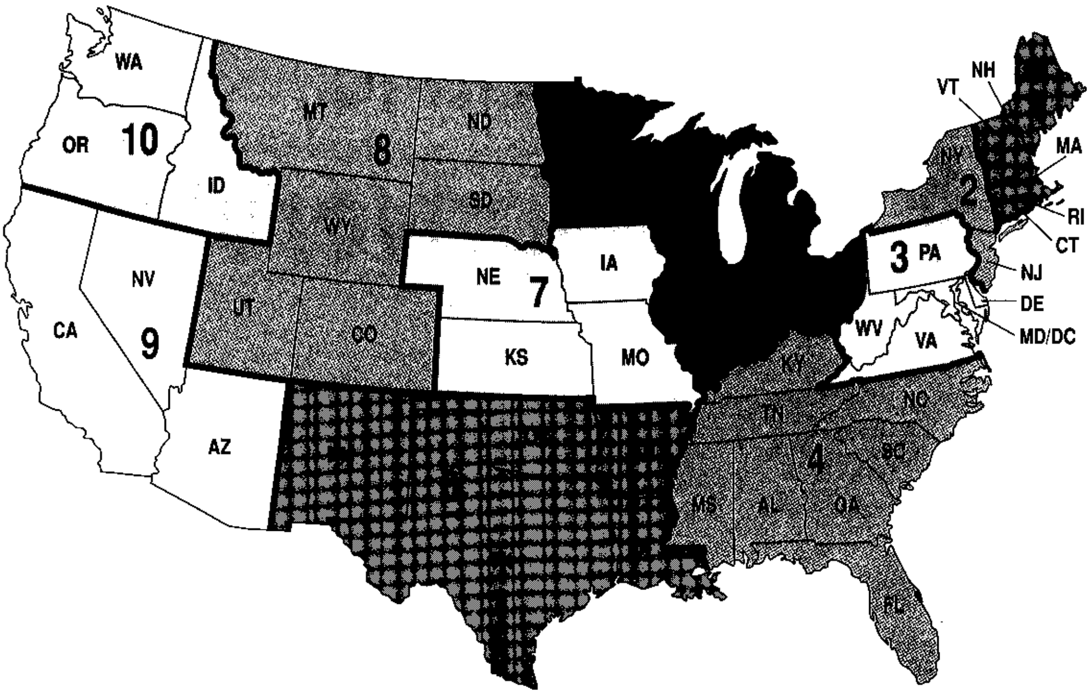
U.S. EPA Region 1
JFK Federal Building
Boston, MA 02203
(617) 565-3420

Region 2 [a]

U.S. EPA Region 2
26 Federal Plaza
Room 906
New York, NY 10278
(212) 264-2525

Region 3

U.S. EPA Region 3
841 Chestnut Street
Philadelphia, PA 19107-4431
(215) 597-9800



Region 4

U.S. EPA Region 4
345 Courtland Street, NE
Atlanta, GA 30365
(404) 347-4727

Region 5

U.S. EPA Region 5
77 West Jackson Blvd
12th Floor
Chicago, IL 60604
(312) 353-2000

Region 6

U.S. EPA Region 6
1445 Ross Avenue
Suite 1200
Dallas, TX 75270
(214) 655-6444

Region 7

U.S. EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7000

Region 8

U.S. EPA Region 8
999 18th Street
Suite 500
Denver, CO 80202-2405
(303) 293-1603

Region 9 [b]

U.S. EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-1510

Region 10 [c]

U.S. EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
(206) 553-4973 or
1-800-424-4EPA

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[a] Region 2 includes Puerto Rico.
[b] Region 9 includes Hawaii.
[c] Region 10 includes Alaska.

Note: Every attempt was made to verify the addresses of these regional EPA offices; however, absolute accuracy cannot be guaranteed. Information is current to April, 1992. Readers should contact the specific offices listed above only if they have questions about composting guidelines and related matters. Other questions may have to be directed to different offices.

F

Metric Conversions

Table F.1
Metric conversions

From U.S. Customary System units		To SI (metric) units		Multiply by
Unit	Abbreviation	Unit	Abbreviation	U.S. to SI conversion factor
Area				
acre	acre	hectare	ha	0.4047
square foot	ft^2	square meter	m^2	0.0929
square inch	in^2	square centimeter	cm^2	6.4516
square mile	mile^2	square kilometer	km^2	2.5900
Conductance, electric				
mho	mho	siemens	S	1
Density (mass)				
pounds per cubic foot	lb/ft^3	kilograms per cubic meter	kg/m^3	16.0185
pounds per cubic inch	lb/in^3	kilograms per cubic meter	kg/m^3	27,679.90
pounds per cubic yard	lb/yd^3	kilograms per cubic meter	kg/m^3	0.5933

Table F.1
Metric conversions (continued)

From U.S. Customary System units		To SI (metric) units		Multiply by
Unit	Abbreviation	Unit	Abbreviation	U.S. to SI conversion factor
Energy				
British thermal unit	Btu	kilojoule	kJ	1.0551
foot-pound	ft-lbf	joule	J	1.3558
kilocalorie	kcal	kilojoule	kJ	4.1868
Flow volume				
cubic feet per second	ft^3/s	cubic meters per minute	m^3/min	1.6990
cubic feet per second	ft^3/s	cubic meters per second	m^3/s	0.0283
gallons per hour	gal/h or gph	liters per hour	L/h	3.7854
gallons per minute	gal/min or gpm	liters per minute	L/min	3.7854
gallons per second	*gal/s or gps*	*cubic meters per second*	m^3/s	0.0037854
gallons per second	gal/s or gps	liters per second	L/s	3.7854
Length				
foot	ft	meter	m	0.3048
inch	in	centimeter	cm	2.54
micron	micron	micrometer	µm	1
mile	mile	kilometer	km	1.6093
yard	yd	meter	m	0.9144
Mass				
ounce	oz	gram	g	28.3495
pound	lb	kilogram	kg	0.4536
ton (long)	ton	ton, Megagram	t, Mg	1.016
ton (short)	ton	ton, Megagram	t, Mg	0.9072

Note: The symbol t is used to designate metric ton. The unit metric ton (exactly 1 Mg, or 1 million grams) is in wide use, but its applications are limited.

Mass per time				
ton (short) per hour	ton/h	t or Megagram per hour	t/h, Mg/h	0.9072

Table F.1
Metric conversions (continued)

From U.S. Customary System units		To SI (metric) units		Multiply by
Unit	Abbreviation	Unit	Abbreviation	U.S. to SI conversion factor
Power				
horsepower	hp	kilowatt	kW	0.7457
Pressure				
inches of water	in H_2O	kilopascals	kPa	0.2488
Temperature				
degrees Fahrenheit	°F	degrees Celsius (Centigrade)	°C	$t_{°C} = (t_{°F} - 32) \div 1.8$
Velocity				
feet per minute	ft/min or fpm	meters per minute	m/min	0.3048
feet per second	ft/s	meters per second	m/s	0.3048
inches per second	in/s	millimeters per second	mm/s	25.4
miles per hour	mile/hour	kilometers per hour	km/h	1.6093
Volume				
bushel	bushel	liter	L	35.2391
cubic foot	ft^3	cubic meter	m^3	0.0283
cubic yard	yd^3	cubic meter	m^3	0.7646
gallon	gal	liter	L	3.7854
ounce	oz	milliliter	mL	29.5735
pint	pt	liter	L	0.4732
quart	qt	liter	L	0.9464

Conversion factors reprinted with permission from the American Society of Agricultural Engineers. Source: ASAE Engineering Practice EP285.7, Use of SI (Metric) Units, revised editorially and reconfirmed December, 1990. Published in *ASAE Standards*, ©American Society of Agricultural Engineers.

Glossary

A

Actinomycete. A group of microorganisms, intermediate between bacteria and true fungi, that usually produce a characteristic branched mycelium. These organisms are responsible for the earthy smell of compost.

Aerated static pile. Forced aeration method of composting in which a freestanding composting pile is aerated by a blower moving air through perforated pipes located beneath the pile.

Aeration. The process by which the oxygen-deficient air in compost is replaced by air from the atmosphere. Aeration can be enhanced by turning.

Aerobic. An adjective describing an organism or process that requires oxygen (for example, an aerobic organism).

Agitated-bed. An in-vessel composting method in which the materials are contained in a bin or reactor and are periodically agitated by a turning machine or by augers. Usually some means or forced aeration is also provided.

Agricultural wastes. Wastes normally associated with the production and processing of food and fiber on farms, feedlots, ranches, ranges, and forests. May include animal manure, crop residues, and dead animals. Also agricultural chemicals, fertilizers, and pesticides that may find their way into surface and subsurface water.

Air pressure loss (also called static pressure or resistance). The pressure or energy lost as air moves through a system such as the compost pile, pipe, blower, and filter pile of an aerated static pile. The air pressure loss indicates the amount of energy required to move air through the system at the desired flow rate. The pressure loss must be estimated in order to select an appropriate fan or blower.

Ambient air temperature. The temperature of the air in the vicinity of the compost pile.

Amendment. See **composting amendment** and **soil amendment.**

Ammonia (NH_3). A gaseous compound comprised of nitrogen and hydrogen. Ammonia, which has a pungent odor, is commonly formed from organic nitrogen compounds during composting.

Ammonium (NH_4^+). An ion comprised of nitrogen and hydrogen. Ammonium is readily converted to and from ammonia depending on conditions in the compost pile.

Anaerobic. An adjective describing an organism or process that does not require air or free oxygen.

Anion. An atom or molecule with a negative charge (for example, nitrate, NO_3^-).

Aspergillus fumigatus. Species of fungus with spores that cause allergic reactions in some individuals. It can also cause complications for people with certain existing health problems.

Availability, nutrient. See **nutrient availability.**

B

Bacteria. A group of microorganisms having single-celled or noncellular bodies. Bacteria usually appear as spheroid, rodlike, or curved entities but occasionally appear as sheets, chains, or branched filaments.

Batch mixer. A type of mixer which blends materials together in distinct loads or batches. The materials are loaded, mixed, and then unloaded in sequence rather than moved through in a continuous flow. Batch mixers for composting are often modified livestock feed mixers using paddles or augers as the mixing mechanisms.

Bedded manure pack. A mixture of bedding and manure that accumulate over time in a livestock barn. A bedded pack forms when bedding materials are regularly added to the manure that is deposited by livestock in the barn. The manure-bedding mixture is not frequently removed but gradually builds up and becomes the surface on which the livestock stand and lie. To provide a firm surface, a large amount of bedding is required. Therefore, bedded pack manure usually is dry.

Bedding. Dry absorbent materials used to provide a dry lying surface for livestock. Bedding materials such as sawdust and straw absorb moisture from livestock wastes, the soil, and the environment.

Bin composting. A composting technique in which mixtures of materials are composted in simple structures (bins) rather than freestanding piles. Bins are considered a form of in-vessel composting, but they are usually not totally enclosed. Many composting bins include a means of forced aeration.

Biochemical oxygen demand (BOD). The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. Normally five days at 20°C unless otherwise stated. A standard test used in assessing the biodegradable organic matter in municipal wastewater. See also **chemical oxygen demand.**

Biogas. A mixture of gases, including methane and carbon dioxide, which is generated by the anaerobic biological decomposition of organic materials (for example, manure). Biogas can be burned as a fuel.

BOD. See **biochemical oxygen demand.**

Buck wall. A relatively short strong wall, often made of concrete or treated wood. It is used primarily as a support to push against when scooping and lifting loose or flowing materials (for example, manure).

Bucket loader. A vehicle which employs a hydraulically operated bucket to lift materials. Includes farm tractors with bucket attachments, skid loaders, and large front-end loaders.

Bulk density. Weight or mass per unit of volume of a material comprised of many individual particles. For example, the weight of a pile of wood chips divided by the volume of the pile is the bulk density. This is different from the particle density (which, in this case, equals the weight of a single wood chip divided by its volume). See also **density.**

Bulking agent. An ingredient in a mixture of composting raw materials included to improve the structure and porosity of the mix. Bulking agents are usually rigid and dry and often have large particles (for example, straw). The terms "bulking agent" and "amendment" are commonly used interchangeably. See also **composting amendment.**

C

C. Chemical symbol for carbon.

Carbon dioxide (CO_2). An inorganic gaseous compound comprised of carbon and oxygen. Carbon dioxide is produced by the oxidation of organic carbon compounds during composting.

Carbon-to-nitrogen ratio (C:N ratio). The ratio of the weight of organic carbon (C) to that of total nitrogen (N) in an organic material.

Cation. A atom or molecule which has a positive charge (for example, ammonium, NH_4^+).

Cellulose. A long chain of tightly bound sugar molecules that constitutes the chief part of the cell walls of plants.

Chemical oxygen demand (COD). A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specified test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. See also **biochemical oxygen demand.**

CO_2. Chemical symbol for carbon dioxide.

COD. See **chemical oxygen demand.**

Compost. A group of organic residues or a mixture of organic residues and soil that have been piled, moistened, and allowed to undergo aerobic biological decomposition.

Composting. Biological degradation of organic matter under aerobic conditions to a relatively stable humus-like material called compost.

Composting amendment. An ingredient in a mixture of composting raw materials included to improve the overall characteristics of the mix. Amendments often add carbon, dryness, or porosity to the mix.

Compost stability. See **stability, of compost.**

Contamination. Any introduction into the environment (water, air, or soil) of microorganisms, chemicals, wastes, or wastewater in a concentration that makes the environment unfit for its intended use.

Cubic yard. A unit of measure equivalent to 27 cubic feet or 22 bushels. A box that is

1 yard wide, 1 yard long, and 1 yard high has a volume of 1 cubic yard. A cubic yard is often loosely referred to as a "yard" (for example, a one-yard bucket).

Curing. Final stage of composting in which stabilization of the compost continues but the rate of decomposition has slowed to a point where turning or forced aeration is no longer necessary. Curing generally occurs at lower, mesophilic temperatures.

D

Damping off disease. The wilting and early death of young seedlings caused by a variety of pathogens.

Decomposers. The microorganisms and invertebrates that cause the normal degradation of natural organic materials.

Degradability. Term describing the ease and extent that a substance is decomposed by the composting process. Materials which break down quickly and/or completely during the time frame of composting are highly degradable. Materials which resist biological decomposition are poorly or even non-degradable.

Denitrification. An anaerobic biological process which converts nitrogen compounds to nitrogen gas or nitrous oxide.

Density. The weight or mass of a substance per unit of volume. See also **bulk density.**

Detention basin. See **holding pond.**

Dry matter. The portion of a substance that is *not* comprised of water. The dry matter content (%) is equal to 100% minus the moisture content (%).

E

Electrical conductivity. A measure of a solution's ability to carry an electrical current; varies both with the number and type of ions contained in the solution.

Enzymes. Any of numerous complex proteins produced by living cells to catalyze specific biochemical reactions.

Ericaceous. Belonging to the plant family *Ericaceae,* the heath family of plants. Characterized by evergreen or deciduous shrubs, trees, and woody plants growing in acid soil and having simple leaves, often showy flowers either solitary or in clusters, and fruit in the form of a berry or capsule.

Evaporative cooling. The cooling that occurs when heat from the air or compost pile material is used to evaporate water.

Exchange capacity. A measure of the nutrient holding power of a soil or soil amendment, such as compost. Indicates a soil's ability to attract and retain plant nutrients which exist as charged molecules or ions. Cation exchange capacity concerns positively charged ions. Anion exchange capacity refers to negatively charged ions. Cation exchange is usually stressed because most soils have a negative charge and, therefore, attract the positively charged cations typically supplied by fertilizers.

Extended pile. A pile form used in the aerated static pile composting technique in which a large pile is constructed of individual cells, each with an aeration system. Cells are added daily and stacked against the previous cell, giving the overall pile a nearly rectangular cross section.

F

Fertilizer value. An estimate of the value of commercial fertilizer elements (N, P, K) that can be replaced by manure or organic waste material. Usually expressed as dollars per ton of manure or quantity of nutrients per ton of manure.

Filter press cakes. Residues from filter press operations after filter presses remove liquids.

Forced aeration. Means of supplying air to a composting pile or vessel which relies on blowers to move air through the composting materials.

Fungus. Plural **fungi.** A group of simple plants that lack a photosynthetic pigment. The individual cells have a nucleus surrounded by a membrane, and they may be linked together in long filaments called hyphae. The individual hyphae can grow together to form a visible body.

G

Green manure. Plant material incorporated into the soil, while green, to improve the soil.

Grinding. Operation which reduces the particle size of materials. Grinding implies that particles are broken apart largely by smashing and crushing rather than tearing or slicing. See also **shredding.**

H

Heavy metals. A group of metallic elements that include lead, cadmium, zinc, copper, mercury, and nickel. Can be found in considerable concentrations in sewage sludge and several other waste materials. High concentrations in the soil can lead to toxic effects in plants and animals ingesting the plants and soil particles. Federal and many state regulations restrict the land application of materials which contain high concentrations of heavy metals.

Herbicides. Agents used to inhibit plant growth or kill specific plant types.

Holding pond (also called retention basin or detention basin). An earthen basin to temporarily store precipitation runoff and other water for later use or disposal. Holding ponds can be excavated or formed above grade by constructing earthen embankments.

Humic acids. The chemical or biological compounds composed of dark organic substances that are precipitated upon acidification of a basic extract from soil.

Humus. The dark or black carbon-rich relatively stable residue resulting from the decomposition of organic matter.

Hydrogen sulfide (H_2S). A gas with the characteristic odor of rotten eggs, produced by anaerobic decomposition.

Hyphae. See **fungus.**

I

Immobilization, nitrogen. Conversion of nutrient compounds from an inorganic form, available to plants, into the organic tissue of microorganisms (or other plants). The nutrients are unavailable until the microorganisms die and the microbial tissues containing the nutrients decompose. Nitrogen immobilization occurs when materials with a high C:N ratio are land applied. The microorganisms that use the carbon also assimilate the available nitrogen, rendering it unavailable to plants.

Infiltration area. An area or strip of land that is vegetated (usually with grass) where water enters the soil in a controlled manner. Infiltration areas can be relatively flat to gently sloping parcels of land or long, narrow, low-sloping channels. Pasture or hay crop land can serve as an infiltration area. Infiltration areas can be used to treat dilute waste water and nutrient-laden runoff.

Inoculum. Plural **inocula.** Living organisms or material containing living organisms (such as bacteria or other microorganisms) which are added to initiate or accelerate a biological process (for example, biological seeding).

In-vessel composting. A diverse group of composting methods in which composting materials are contained in a building, reactor, or vessel.

K

K. Chemical symbol for potassium.

L

Land application. Application of manure, sewage sludge, municipal wastewater, and industrial wastes to land either for ultimate disposal or for reuse of the nutrients and organic matter for their fertilizer value.

Leachate. The liquid that results when water comes in contact with a solid and extracts material, either dissolved or suspended, from the solid.

Lignin. A substance that, together with cellulose, forms the woody cell walls of plants and the cementing material between them. Lignin is resistant to decomposition.

Liquid manure (thin slurry). Manure which has had sufficient water added so that it can be pumped easily. Normally fibrous material such as chopped straw or waste hay is not present. See also **manure.**

Litter, poultry. Dry absorbent bedding material such as straw, sawdust, and wood shavings that is spread on the floor of poultry barns to absorb and condition manure. Sometimes the manure-litter combination from the barn is also referred to as litter.

M

Manure. The fecal and urinary excretion of livestock and poultry. Sometimes referred to as livestock waste. This material may also contain bedding, spilled feed, water or soil. It may also include wastes not associated with livestock excreta, such as milking center wastewater, contaminated milk, hair, feathers, or other debris. See also **liquid manure, semi-solid manure, slurry manure,** and **solid manure.**

Manure storage. A storage unit to keep manure contained for some period of time prior to its ultimate utilization or disposal. Manure storages are usually classified by type and form of manure stored and/or construction of the storage; for example, above- or below-ground liquid manure tank, earthen storage basin, solid manure storage. See also **manure.**

Mesophilic. Operationally, the temperature range most conducive to the maintenance of optimum digestion by mesophilic bacteria, generally accepted as between 50 and 105°F (10 and 40°C).

mho. See **mmho.**

Microbe. See **microorganism.**

Microfauna. Populations of microscopic animals including protozoa and nematodes.

Microflora. Populations of microscopic plants including bacteria, actinomycetes, fungi, and algae.

Microorganism. An organism requiring magnification for observation.

mmho. Plural **mmhos.** A millimho. One-thousandth of a mho (pronounced mo with a long O). A mho is a unit of measurement for electrical conductivity which is the basis for measuring soluble salt concentration. (mho is the backward spelling of ohm, the unit of measurement for electrical resistance.)

Moisture content. The fraction or percentage of a substance comprised of water. Moisture content equals the weight of the water portion divided by the total weight (water plus dry matter portion). Moisture content is sometimes reported on a dry basis. Dry-basis moisture content equals the weight of the water divided by the weight of the dry matter.

Mulch. A material spread over the soil surface to conserve moisture and porosity in the soil underneath and to suppress weed growth. Grass clippings, compost, wood chips, barks, sawdust, and straw are common mulch materials.

Mycelium. The collective term for fungus filaments or hyphae.

N

N. Chemical symbol for nitrogen.

Nitrate-nitrogen. A negatively charged ion comprised of nitrogen and oxygen (NO_3^-). Nitrate is a water soluble and mobile form of nitrogen. Because of its negative charge, it is not strongly held by soil particles (also negative) and can be leached away.

Nitrification. The biochemical oxidation of ammonia nitrogen to nitrate.

Nutrient availability. The relative proportion of a nutrient in the soil that can be absorbed and assimilated by growing plants.

Nutrient-holding capacity. The ability to absorb and retain nutrients so they will be available to the roots of plants. See also **exchange capacity.**

O

Organic matter. Chemical substances of animal or vegetable origin, consisting of hydrocarbons and their derivatives.

P

P. Chemical symbol for phosphorus.

Pad, composting. The surface or area occupied by actively composting windrows and piles.

Passive aeration. Air movement through composting windrows and piles which occurs by natural forces including convection, diffusion, wind, and the tendency of warm air to rise (thermal buoyancy).

Passive composting. Method of composting in which there is little management and manipulation of the materials after they are mixed and piled. Turning occurs infrequently (for example, monthly). Forced aeration is not provided.

Passively aerated windrow composting. A composting method in which windrows are constructed over a series of perforated plastic pipes, which serve as air ducts for passive aeration. Windrows are not turned.

Pathogen. Any organism capable of producing disease or infection. Often found in waste material, most pathogens are killed by the high temperatures of the composting process.

PCBs. Polychlorinated biphenyls. Persistent, immobile contaminants found in industrial waste and sewage sludge. Federal and many state regulations restrict the land application of materials which contain high concentrations of PCBs.

Peat. Unconsolidated soil material consisting largely of organic matter accumulated under conditions of excessive moisture. The organic matter is not decomposed or is only slightly decomposed.

Perlite. Volcanic mineral used as an amendment in potting soil.

pH. A measure of the concentration of hydrogen ions in a solution. pH is expressed as a negative exponent. Thus, something that has a pH of 8 has ten times fewer hydrogen ions than something with a pH of 7. The lower the pH, the more hydrogen ions present, and the more acidic the material is. The higher the pH, the fewer hydrogen ions present, and the more basic it is. A pH of 7 is considered neutral.

Phytophthora. A group of fungal plant pathogens which cause a serious root, crown, and sometimes foliar (leaf) disease on a large number of plants. These fungi are most active under conditions of high soil moisture.

Phytophthora root rot. See **phytophthora** and **root rot.**

Phytotoxic. An adjective describing a substance that has a toxic effect on plants. Immature or anaerobic compost may contain acids or alcohols that can harm seedlings or sensitive plants.

Pollution. The presence in a body of water (or soil or air) of a substance (pollutant) in such quantities that it impairs the body's usefulness or renders it offensive to the senses of sight, taste, or smell. In general, a public-health hazard may be created, but in some instances only economic or aesthetics is involved, as when foul odors pollute the air.

Polychlorinated biphenyls. See **PCBs.**

Porosity. A measure of the pore space of a material or pile of materials. Porosity is equal to the volume of the pores divided by the total volume. In composting, the term porosity is sometimes used loosely, referring to the volume of the pores occupied by air only (without including the pore space occupied by water).

Poultry litter. See **litter, poultry.**

PTO. Power take off. Drive shaft and coupling on a tractor which transmits power from the tractor engine to implements and secondary equipment (for example, pumps, grinders, and windrow turners).

Pullet. A young hen, less than one year old.

Pythium. A fungal plant pathogen which causes seed, seedling, and root rots on a large number of plants. These fungi are most active under conditions of high moisture.

Pythium root rot. See **pythium** and **root rot.**

R

Recipe. The ingredients and proportions used in blending together several raw materials for composting.

Retention basin. See **holding pond.**

Root rot. A disease of plants characterized by discoloration and decay of the roots.

S

Saturated Paste. A laboratory technique in which solid particles are rendered into a paste in order to measure characteristics such as pH and soluble salt concentration.

Semi-solid manure. Manure which has had some bedding added or has received sufficient air drying to raise the solids content such that it will stack but has a lower profile than solid manure and seepage may collect around the outside. It may be pumped with positive displacement jumps or handled with a front-end loader. See also **manure.**

Septage. Waste pumped from septic tanks. Contains human wastes.

Setback. A prescribed distance separating the area of a particular activity and a neighboring boundary (for example, the distance between the composting pad and the property line).

Sewage sludge. Solid portion of waste from sewage treatment plants. Contains human wastes.

Shredding. An operation which reduces the particle size of materials. Shredding implies that the particles are broken apart by tearing and slicing. See also **grinding.**

Slurry manure. Slurry manure has a near liquid consistency. It can be handled with conventional, centrifugal manure pumps and equipment, but the solids content may be too high for irrigation equipment. See also **manure.**

Soil amendment. Any substance (such as lime, sulfur, gypsum, or sawdust) used to alter the properties of a soil (generally, to make it more productive). Fertilizers are one type of soil amendment. However, many soil amendments (such as soil conditioners) do not have significant fertilizer value. See also **soil conditioner.**

Soil conditioner. A soil additive that stabilizes the soil, improves its resistance to erosion, increases its permeability to air and water, improves its texture and the resistance of its surface to crusting, makes it easier to cultivate, or otherwise improves its quality.

Soil structure. The combination or arrangement of primary soil particles into secondary particles, units, or peds. Compost helps bind primary soil particles to improve the structure of soil.

Soil texture. A characterization of soil type, based on the relative proportions of sand, silt, and clay in a particular soil.

Solid manure. Manure which has had sufficient bedding or soil added or has received sufficient air drying to raise the solids content to where it will stack with little or no seepage. It is best handled with a front-end loader. See also **manure.**

Sour compost. Compost which has been produced or stored under anaerobic conditions. It is generally acidic and may contain phytotoxic compounds.

Specific conductance. See **electrical conductivity.**

Spontaneous combustion. Self heating and ignition of a combustible substance because of chemical reactions that occur within the substance. Can occur at moisture contents between 25 and 45%.

Stability, of compost. The rate of change or decomposition of compost. Usually stability refers to the lack of change or resistance to change. A stable compost continues to decompose at a very slow rate and has a low oxygen demand.

Structure, of composting mix or raw material. The ability to resist settling and compaction. Structure is improved by large rigid particles.

T

Texture, of composting mix or raw material. Characteristic which describes the available surface area of particles. A fine texture implies many small particles with a large combined surface area. A course texture implies large particles with less overall surface area.

Thermophilic. Heat-loving microorganisms that thrive in and generate temperatures above 105°F (40°C).

Thin slurry. See **liquid manure.**

Tipping fees. Fees charged for treating, handling, and/or disposing of waste materials.

Top-dressing. Applying a layer of compost, or other material, to the surface of soil.

Turning. A composting operation which mixes and agitates material in a windrow pile or vessel. Its main aeration effect is to increase the porosity of the windrow to enhance passive aeration. It can be accomplished with bucket loaders or specially designed turning machines.

V

Vermicomposting. The process by which worms convert organic waste into worm castings—the dark, fertile, granular excrement of a worm. Castings are rich in plant nutrients.

Vermiculite. A natural mineral used as an amendment in potting soil.

Vermin. Noxious or objectionable animals, insects, or other pests, especially those of a small size. For example, rats, mice, and flies.

Volatile compound. A compound or substance which vaporizes ("evaporates") at relatively low temperatures or is readily converted into a gaseous by-product. Examples include alcohols and ammonia. Volatile compounds are easily lost from the environment of a composting pile.

W

Windrow. A long, relatively narrow, and low pile. Windrows have a large exposed surface area which encourages passive aeration and drying.

Y

Yard. See **cubic yard.**

Yard waste. Leaves, grass clippings, yard trimmings, and other organic garden debris.

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Appendix A

Table A.1. Characteristics of Selected Raw Materials

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222 Main Street
Emmaus, PA 18098
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Note: Suggested readings are listed by chapter beginning on page 175.

Acknowledgments

continued from inside front cover

Equipment tables are provided in appendix B as further information to readers. The information in these tables was obtained from the manufacturers; no attempt was made to verify the manufacturers' claims. These lists do not include all equipment manufactured; only those manufacturers that responded to a survey are included. Mention of company names does not imply an endorsement of the product, nor is criticism implied of similar products which are not mentioned.

The authors have listed specific journals, books, and articles in this handbook. These publications will be useful to readers who want to maintain an awareness of new developments in composting technology. No endorsement of named publications is intended, nor is criticism implied of similar publications which are not mentioned.

Address lists are provided in appendix E for state environmental agencies and regional offices of the Environmental Protection Agency (EPA). Every attempt was made to verify the addresses of these agencies; however, absolute accuracy cannot be guaranteed. In addition, no guarantee is made that these agencies will be able to provide answers to specific questions that readers may have.

Address lists are provided in appendix B for temperature probe distributors and equipment manufacturers. This information is provided as a service to readers and was obtained from the manufacturers. No endorsement of these companies or their products is intended, nor is criticism implied of similar companies or products which are not mentioned.

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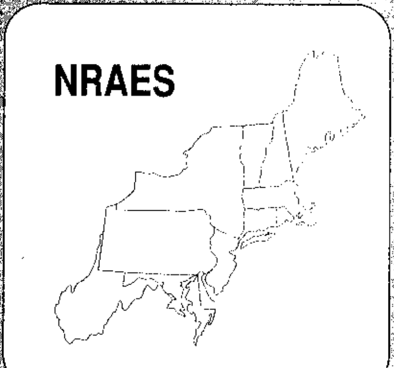

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