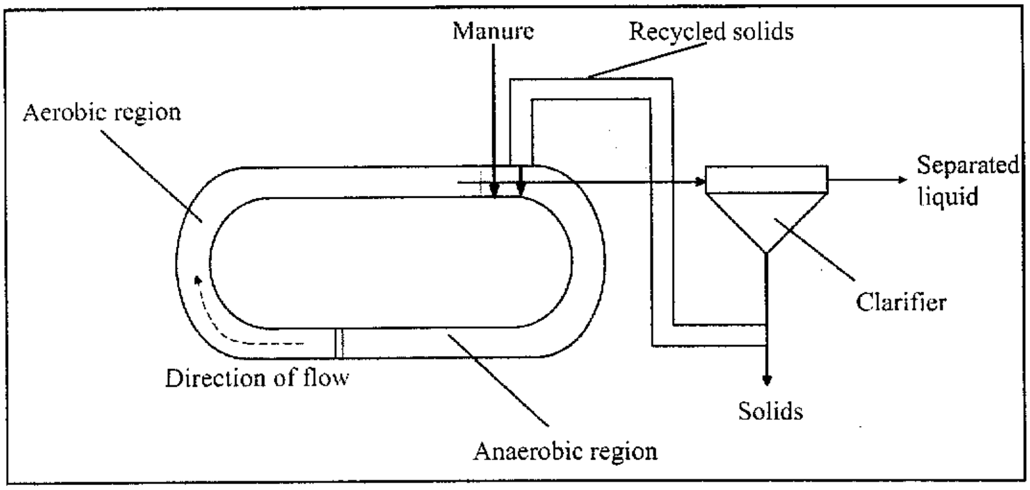

Figure 6.5: Diagram of oxidation ditch (adapted from Crites and Tchobanoglous, 1998).

nitrification-denitrification process. An oxidation ditch is a system where nitrification and denitrification occurs in the same vessel. An oxidation ditch is typically a racetrack-shaped basin with both an aerobic and an anoxic zone. **Figure 6.5** is a diagram of an oxidation ditch. The aerobic zone provides the appropriate environment for nitrification to occur, and the anoxic zone is where denitrification occurs. While the ditches are relatively shallow, they require a greater area than tank reactors.

Oxidation ditches are suited for smaller farm operations because they offer the same biological treatment with less operational and maintenance costs than reactor-style nitrification-denitrification. Oxidation ditches may be located directly below housing units with slatted flooring if proper ventilation is provided for the animals. **Figure 6.6** is a photograph of an oxidation ditch.

Oxidation ditches may have relatively long HRTs compared to separate nitrification-denitrification systems. The longer HRT helps buffer the system from sudden surges of high-strength manure. The long retention time also produces less sludge, since the hungry microorganisms have more time to consume and digest the solids.

6.6 Summary

Nitrification-denitrification is the two-stage biological process for nitrogen removal. Nitrogen removal is especially important for farms lacking sufficient land for manure application and nitrogen assimilation and utilization by growing crops. *Nitrosomonas* and *Nitrobacter*, autotrophic aerobic bacteria, convert the ammonia to nitrate during nitrification. Denitrification occurs when heterotrophic anoxic bacteria transform the nitrate to dinitrogen gas, which can be harmlessly released to the atmosphere. Nitrification-denitrification can occur in separate reactors or be combined into a single reactor, and systems may be either suspended growth or attached growth processes.

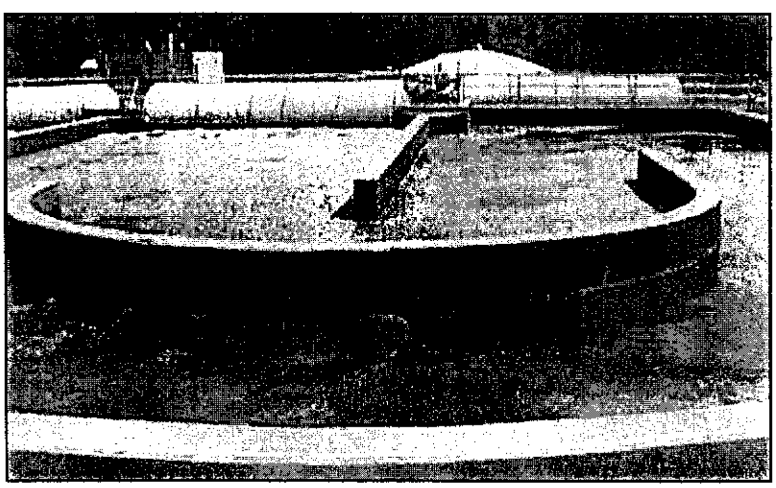

Figure 6.6: Photograph of oxidation ditch (K. Redmond, 2004).

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Chapter 7
Composting

7.1 Introduction

Composting is a simple process. It is the natural decomposition process of organic matter under **aerobic** conditions. Aerobic bacteria and other microorganisms devour organic waste, assimilating the organic matter into their own bodies and converting the manure into nutrient-rich compost or **humus** as depicted in **table 7.1.** Composting occurs naturally when an adequate supply of water, oxygen, and **biodegradable** organic matter coexist, and the pile of organic matter is warm enough for microorganisms to live.

Table 7.1: Potential composting benefits.

Chapter Number	Chapter Name	Treatment Process	Reduce Nitrogen	Reduce Phosphorus	Reduce Biochemical Oxygen Demand	Stabilize Manure	Reduce Manure Volume	Reduce Pathogens	Reduce Manure Gases	Reduce Odor	Reduce Ammonia Volatilization	Operate at Low Temperatures	Minimal Footprint	Low Energy Requirement	Create Biogas	Create Value-Added Products
7	Composting	Unaerated static pile				√	√	√	√	√	√	√		√		√
		Aerated static pile				√	√	√	√	√	√	√				√
		Windrow				√	√	√	√	√	√	√		√		√
		In-vessel				√	√	√	√	√	√	√	√			√
		Pit				√	√	√	√	√	√	√		√		√
		In-barn				√	√	√	√			√	√	√		√

Aerobic: An oxygenated environment or requiring an oxygenated environment to survive.

Humus: Decomposed organic matter.

Biodegradable: A material that can be broken down by biological processes.

Anaerobic: An oxygen-free environment or requiring an oxygen-free environment to survive.

Pathogen: A disease-causing organism.

Soil amendment: Compounds used to build and maintain the physical properties of soil.

Natural decomposition can be harnessed as part of a manure management plan. Animal manure, carcasses, municipal waste, food processing waste, food scraps, and yard waste are all biodegradable organic matter and can be composted when the right conditions exist. **Figure 7.1** is a photograph of compost.

Figure 7.1: Compost (Cayuga Nature Center, 2001).

While composting is a biochemical process that occurs without human interaction, this chapter focuses on the aspects of composting that can be optimized by humans to effectively harness the process for manure treatment. The steps in the process, design considerations, and different types of composting systems are discussed in detail. Compost as a value-added product is also addressed.

Composting is suitable for treating manure with a low moisture content or separated solids as well as anaerobically digested solids. Farms with existing solids separators, available space for composting, and markets to sell the compost for landscaping and agricultural uses may best benefit from this treatment technology.

7.2 Advantages and Disadvantages of Composting

As with any manure management strategy or treatment technology, composting alone is not a magic bullet for solving manure management problems. A treatment system is more robust than a single treatment unit process. Several variables influence the appropriateness of composting for a given farm, including climate, cost, operations and management considerations, compatibility with current manure handling systems, and treatment goals. **Table 7.2** summarizes some of the advantages and disadvantages of composting animal manure.

7.2.1 Advantages

Composting reduces bulk, pathogens, and odors and yields a useful **soil amendment.** When animal manure is effectively composted, the easily degradable organic material is decomposed, and pathogens in the manure are destroyed by the high temperatures achieved during composting. The resulting compost is a stable material that is not susceptible to further rapid decomposition or anaerobic digestion, which can release offensive odors. Well-composted animal manure has a benign earthy smell. In addition to resolving odor and pathogen problems, composting converts manure nutrients, particularly phosphorus and potassium, into forms readily available for plant uptake. The resulting compost is a value-added soil

Table 7.2: Advantages and disadvantages in composting systems (Bonhotal, 2001).

Advantages	Disadvantages
Stabilizes manure	Management intensive
Reduces odor	Additional land required
Reduces or eliminates **pathogens**	Climate sensitive
Value-added product	

amendment that, if marketed, can be a supplemental source of income. Any compost that is moved offsite removes surplus nutrients from the farm's nutrient cycle.

7.2.2 Disadvantages

Composting large quantities of manure can be complex because of the simultaneous need to regulate temperatures, aeration, and moisture to achieve optimal performance and prevent potential pollution problems, such as ammonia emissions. Monitoring and balancing these variables can make composting management intensive.

While composting transforms the nutrients found in manure, it does not remove nitrogen and phosphorus, potential water pollutants, from the manure. The nutrient value of compost is what makes it a readily marketable product but it can still pose a water quality hazard if not properly stored and utilized.

Also, not all types of composting systems are suitable for all climates; excessive precipitation and temperature extremes may not support particular composting styles. Another drawback to composting is its additional land requirement.

Types of composting systems may be described in terms of the intensity level—the amount of time, maintenance, power, and labor required for each type of system. **Table 7.3** summarizes the compost type by intensity level. The different compost systems are discussed in Section 7.5.

7.3 Composting Process

Composting is a five step process:

1. A long pile, or windrow, of compost is created by mixing dewatered manure solids with **amendments** and **bulking agents** to change the moisture, **porosity**, and carbon-to-nitrogen ratio.

2. Aerobic microorganisms break down the organic matter into a nutrient rich compost or humus. These microorganisms fall into three major categories—bacteria, fungi, and **actinomycetes**. Bacteria typically flourish during the first stages of decomposition as they dine on the easily degradable organic matter. During this feeding frenzy, the bacteria give off heat, raising the temperature of the compost to the point where pathogens are killed. The bacteria responsible for composting are naturally found in manure and the environment, so inoculation with commercially available additives or municipal waste sludge do not create a benefit (Miner et al., 2000).

3. The mixture is aerated or turned periodically to provide oxygen for the microorganisms, and to control moisture and temperature.

4. Bulking agents, if used, are screened out of the compost for reuse.

Table 7.3: Composting systems by intensity level (Bonhotal, 2001).

Low Intensity Systems	Medium Intensity Systems	High Intensity Systems
Unaerated static piles	Aerated static piles	In-vessel systems
Passively aerated windrows	Turned windrows	Vermicomposting*
In-barn composting†	Pit composting†	

* See Chapter 9, Miscellaneous Treatment Technologies. † Miner et al., 2000.

Amendments: Organic material added to the manure to change bulk weight, moisture content, carbon content, and porosity. Examples of amendments are sawdust, straw, recycled compost, rice hulls, cured compost, and peanut hulls. Amendments are chosen based on cost, availability, and degradable carbon content; they become part of the finished product.

Bulking agent: Organic or inorganic material used to provide structural support and to increase the porosity of the mixture for effective aeration. Wood chips are one of the most common bulking agents, although recoverable agents such as shredded tires are also gaining in popularity. Bulking agents are usually screened from the finished compost and can be reused.

Porosity: The degree to which a material is permeated with pores or cavities through which fluids and gases, including air, can move. Porosity is measured by the ratio of the volume of air spaces to the total volume of the material.

Actinomycetes: Specialized bacteria with branching cell chains called filaments that have a superficial resemblance to fungi and a hunger for tough, raw tissues in manure.

Curing stage: The final stage in composting where the microbial population shifts from bacteria to fungi and actinomycetes, which can break down the less degradable organic matter like chitin, cellulose, and lignin.

Stabilization: A microbial process that results in material that cannot be easily decomposed.

Bulk density: Weight per unit volume.

Ammonia volatilization: A process in which gaseous nitrogen-ammonia is released to the atmosphere.

5. The compost undergoes the **curing stage** for an additional 30 to 60 days to complete the **stabilization** process (Crites and Tchobanoglous, 1998). At this stage, the easily degradable matter has been consumed and the bacteria die off—they eat themselves out of a job. The compost pile cools down and actinomycetes and fungi take over. These microorganisms will decompose the harder to degrade organic matter in a process that does not release significant heat. At the end of curing, the compost may be screened again and ground for sale.

7.4 Composting Design Considerations

Although composting is a naturally occurring process, employing nature's work to treat manure requires special design considerations. Like humans and other animals, composting organisms have environmental requirements to survive—a steady supply of water and nutrients, comfortable temperatures, and plenty of oxygen. The carbon-to-nitrogen ratio, moisture content, **bulk density,** and temperature of the compost materials are the most important design considerations for a successful composting system.

7.4.1 Carbon-to-Nitrogen Ratio

The aerobic bacteria need carbon as an energy source. Bacteria also use carbon and nitrogen to build new cells. Optimal composting conditions require about a 30:1 carbon-to-nitrogen ratio (Bonhotal, 2001) but can range from 20:1 to 40:1 (Haith, 1999). When the ratio is 30:1, **ammonia volatilization** transfers a small amount of nitrogen to the atmosphere. Ammonia-nitrogen that is volatized is an air pollutant. If a treatment goal is to create a nutrient-rich fertilizer, it is important to retain nitrogen, an essential plant nutrient, in the compost. When the ratio falls below 20:1, usually a rare occurrence, ammonia volatilization to the atmosphere can be as high as 40 percent (Miner et al., 2000).

The carbon-to-nitrogen content of manure is typically 19:1, but will vary with the kind of animal and their diet (Bonhotal, 2001). The ratio will also fluctuate if bedding or waste feed is mixed with the manure. Amendments may be added to adjust the total carbon-to-nitrogen ratio for the composting mixture. **Table 7.4** lists some compostable materials and their carbon-to-nitrogen ratios. The total carbon-to-nitrogen ratio of the compost is the proportional sum of the carbon-to-nitrogen ratios of the individual materials—the manure, amendments, waste feed, and bedding that may be present.

Table 7.4: Typical properties of compostable materials (Haith, 1999).

Material	Carbon-to-Nitrogen Ratio	Moisture Content (percent)	Bulk Density (kg/m^3)
Food wastes	15	70	290
Vegetable waste	20	85	540
Fruit waste	40	80	670
Mixed paper	155	20	285
Newspaper	370	10	130
Cardboard	565	10	150
Yard waste*	40	45	190
Grass clippings	15	80	205
Leaves	55	40	120
Cow manure	20	80	865
Horse manure	30	70	820
Poultry manure	5	70	880
Biosolids	10	80	840
Wood chips	600	30	315
Straw	80	10	135
Corn stalks	65	10	20

* Equal mix of shrub trimmings, grass, and leaves.

Table 7.5: Characteristics of compost amendments and bulking agents used in composting (Metcalf and Eddy, 2003).

Amendment or Bulking Agent	Comments
Wood chips	May have to be purchased; high recovery rate by screening; provides supplemental carbon source
Chipped brush	Possibly available as a waste material; low recovery rate by screening; provides supplemental carbon source; longer curing time of compost
Leaves and yard waste	Must be shredded; wide range of moisture content; readily available source of carbon; relative low porosity; nonrecoverable
Shredded tires	Often mixed with other bulking agents; supplemental carbon is not available; nearly 100 percent recoverable; may contain metals
Ground waste lumber	Possibly available as waste material; poor source of carbon

7.4.2 Bulk Density

The bulk density of the compost should be less than 600 kg/m^3 (37.5 lb/ft^3) (Haith, 1999). **Table 7.4** lists the bulk density for several different materials. Bulking agents can be used to reduce the bulk density and to increase porosity. **Table 7.5** describes several common materials used as bulking agents or amendments.

7.4.3 Moisture Content

The microorganisms responsible for composting need water to survive. The moisture content should be in the range of 40 to 65 percent (Haith, 1999). The target moisture content will depend on the characteristics of the manure and other waste materials. For example, a compost pile with a lot of straw, a common bedding material, will function better at a high moisture content while a pile with a lot of shredded newspaper, another common bedding material, will function best at a lower moisture content. This is because straw will maintain its strength and shape in high moisture conditions, increasing the bulk density and porosity to allow air to circulate through the pile while paper will become soggy in high moisture conditions and pack so densely that airflow is restricted. The total moisture content is the sum of the moisture contents of the constituent materials. **Table 7.4** lists some other compostable materials and their moisture contents.

Composting is usually done in long piles called windrows. It is important that the tops of the windrows are rounded to prevent rain from accumulating on or in the compost, which can saturate the compost material. Saturated compost is more susceptible to anaerobic conditions because the excess water displaces oxygen in the pile. When anaerobic conditions prevail composting stops and foul odors are released. However, rounded tops create runoff that needs to be treated in the same manner as any other manure-laden runoff. Additionally, the turning of compost should be avoided during periods of heavy rain to prevent the interior of the compost pile from becoming waterlogged.

Tipping fees: The fees earned for the collection of unwanted materials.

Facultative: An environment that contains both oxygenated and oxygen-free regions or microorganisms that can live in both oxygenated and oxygen-free environments. When oxygen is not available, these organisms can switch from respiration to fermentation.

Obligate: Microorganisms that can only exist in oxygen-free environments.

Exothermic: A process that gives off heat.

7.4.4 Tipping Fees

One person's waste may be another's resource. It is often possible to earn extra money and reduce the cost of purchasing amendments and bulking agents by collecting other wastes, such as municipal solid waste, restaurant food waste, grass clippings, or animal carcasses for composting. Such waste may be a critical requirement for achieving the appropriate carbon-to-nitrogen ratio, moisture content, or bulk density. The fees earned for the collection of the waste are called **tipping fees.**

7.4.5 Aeration

Composting is an aerobic process. Oxygen can be provided by either turning or mixing the compost or by forcing air through the compost from the bottom. If the compost doesn't have enough oxygen the aerobic bacteria will die and be replaced by **facultative** anaerobes and **obligate** anaerobes. Such conditions lead to odor problems. Excessive moisture can also decrease oxygen levels, creating conditions that are favorable for anaerobic bacteria to proliferate. Anaerobic states are characterized by a temperature drop during the first seven to ten days of composting or by a strong foul odor (Miner et al., 2000). Aerobic conditions can be reinstated by turning the compost daily.

7.4.6 Temperature

Temperature is an extremely important design factor in the composting process. The compost must be warm enough for the aerobic bacteria to thrive, but not so hot that they are killed. Aerobic decomposition, the main process responsible for composting, is an **exothermic** process, which releases a large amount of heat. Compost is good insulation, and the internal temperatures of the compost pile will rise during the decomposition process. In a well-designed pile, the internal temperature will reach 45 to 50° C (113 to 122° F) within 24 hours and will achieve the optimum temperature for efficient decomposition and pathogen kill, 60° C (140° F), within three to five days (Miner et al., 2000). The aerobic bacteria will die if temperatures exceed 70° C (158° F) (Miner et al., 2000). Aeration can control the temperature; compost reaching temperatures higher than 70° C (158° F) can be turned or agitated frequently to release heat (Miner et al., 2000).

Internal temperatures will vary with the size of the compost pile, ambient temperature, moisture content, degree of agitation and aeration, and the nature of the initial materials. If the pile fails to reach the optimal temperature within three to six days, or becomes too hot, then each of these factors must be assessed to solve the problem. The pile size can be adjusted during various seasons to control temperature. In cold weather, deeper piles will increase insulation and keep temperatures high. In warmer weather, shallower piles will allow for convective cooling. If the pile becomes too wet, then anaerobic decomposition may take over—a process that does not generate high temperatures. If the pile becomes too dry, then the microorganisms will begin to die and heat generation will stop. Like humans and other animals, bacteria need essential nutrients to survive—limiting those nutrients will result in a drop in microbial action. Temperature is an important design criteria if pathogen destruction is a primary treatment goal. **Table 7.6** summarizes several common pathogens found in waste and the required kill temperature and time.

Table 7.6: Temperature and time of exposure required for destruction of common pathogens and parasites (adapted from Tchobanoglous et al., 1993).

Pathogen or Parasite	Kill Time and Temperatures
Salmonella typhosa	No growth beyond 46° C; death within 30 minutes at 55-60° C; destroyed in short time under compost conditions
Salmonella sp.	Death within one hour at 55° C and within 15-20 minutes at 60° C
Shigella sp.	Death within one hour at 55° C
Escherichia coli	Most die within one hour at 55° C and within 15-20 minutes at 60° C
Entamoeba histolyica cysts	Death within a few minutes at 45° C and within a few seconds at 55° C
Taenia saginata	Death within a few minutes at 55° C
Trichinella spiralis **larvae**	Quickly killed at 55° C, instantly killed at 60° C
Brucella abortus or Br. Suis	Death within three minutes at 62-63° C and within one hour at 55° C
Micrococcus pyogenes var. aureus	Death within ten minutes at 50° C
Streptococcus pyogenes	Death within ten minutes at 54° C
Mycobacterium tuberculosis var. *hominis*	Death within 15-20 minutes at 66° C or after momentary heating at 67° C
Corynebacterium diphtheria	Death within 45 minutes at 55° C
Necator americanus	Death within 50 minutes at 45° C
Ascaris lumbricoides eggs	Death in less than one hour at temperatures exceeding 50° C

Salmonella: A bacteria found in the digestive tracts of animals that can cause food poisoning in humans.

Larvae: (pl. of larva) Insects that are in the immature, worm-like stage after hatching from the egg.

Vector: An agent that transfers a disease or pathogen from one organism to another.

Compost temperature can be measured with a long thermometer or estimated by inserting a metal rod at least two feet long into the pile for ten to 15 minutes (Miner et al., 2000). **Figure 7.2** is a photograph of a compost thermometer. Under ideal composting conditions the rod should be too hot to hold comfortably for an extended period after extraction.

7.4.7 Fly and Pest Control

Insect eggs may be present in manure, and adult flies and other **vectors** may be attracted to manure or compost. A number of options exist to prevent pest problems. Initial treatments such as anaerobic digestion, aerobic digestion, or grinding may kill the majority of fly larvae. The heat released in the center of the compost pile or windrow is high enough to kill the eggs and larvae, but some larvae will crawl to the outside of the pile to escape the heat and emerge as adults. Frequent turning or mixing will limit the survival of larvae and flies. Situating the compost on a concrete pad or other impervious non-soil pad will also reduce fly problems. The impervious surface acts as a barrier to ground-dwelling insects that may crawl into the compost from below.

Preventive measures, including good housekeeping, will keep flies, weed seeds, and other pests from entering composting facilities. The facilities should be kept clean and free of manure and feed spills. Areas surrounding outdoor curing locations should be kept free of weeds to prevent seeds from blowing onto the compost.

Figure 7.2: Compost thermometer (S. Ausmus, 2003).

7.4.8 Design Summary

When designing a composting system to manage animal waste it is important to keep the treatment goals, site constraints, and future farm plans in mind. **Table 7.7** summarizes the design considerations for creating a successful composting manure management system.

Table 7.7: Design considerations for sludge composting processes (Metcalf and Eddy, 2003).

Consideration	Comment
Type of manure	Both untreated and digested manure may be composted successfully; untreated manure has greater potential for odors, particularly in windrow systems; untreated manure has more energy available, will degrade more readily, has higher oxygen demand
Amendments	Moisture content, particle size, available carbon, and other amendment and bulking agent characteristics affect the process and quality of product; bulking agents should be readily available
Carbon-to-nitrogen ratio	Should be in range of 20:1 to 40:1 by weight; at lower ratios ammonia is volatized; carbon should be checked to ensure it is readily biodegradable
Volatile solids	Should be greater than 30 percent of the total solids content; dewatered sludge will usually require an amendment or bulking agent to adjust the solids content
Air requirements	Air with at least 50 percent oxygen should reach all parts of the compost pile, especially in mechanical systems
Moisture content	Should not be greater than 60 percent for static pile and windrow systems and not greater than 65 percent for in-vessel systems
pH control	Should generally be in the range of 6.0 to 9.0; to achieve optimum decomposition the pH should remain in the 7.0 to 7.5 range.
Temperature	Should be maintained between 50 and 55° C for the first few days and between 55 and 60° C for the remainders of the active composting period; if the temperature exceeds 66° C for a significant amount of time biological activity will be reduced
Pathogen control	It is possible to kill all pathogens, weeds, and seeds during composting; temperature must be maintained between 60 and 70° C for 24 hours
Mixing and turning	To prevent drying, caking, and air channeling, composting material should be mixed or turned on a regular schedule or as required, frequency of mixing or turning depends on type of composting system
Heavy metals and trace organics	Should be monitored in finished compost to ensure that the concentrations do not exceed applicable regulations for end use of product
Site constraints	Consider available area, access, proximity to treatment plant, other land uses, climatic conditions, buffer zone, and system for collecting leachate and runoff

7.5 Types of Composting Designs

There are three main types of composting systems: static pile composting, windrow composting, and in-vessel composting. Three additional, less common approaches are also described.

7.5.1 Static Pile

Static systems require the least amount of labor. There are two kinds of static pile composting systems—unaerated static piles and aerated static piles.

a. Unaerated Static Pile

Unaerated static pile composting is also known as passive composting. In this approach, the manure is mixed with the amendments and bulking agents, and formed into piles. Since the piles are not aerated or turned, the pile must be porous enough to allow air movement to prevent anaerobic conditions from forming. Each pile should be no taller than two meters (6.6 feet) or wider than four meters (13 feet), but may be any length (Bonhotal, 2001). **Figure 7.3** is a diagram of an unaerated static pile composting process.

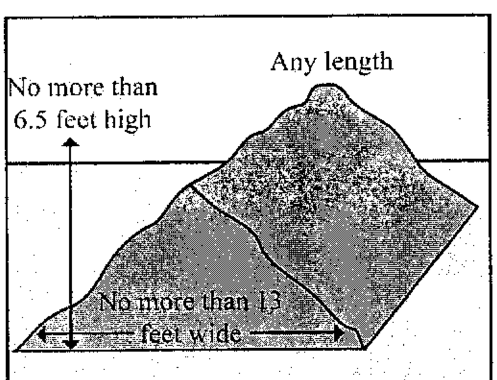

Figure 7.3: Unaerated static pile compost (C. White, 2004).

This composting method requires the least amount of maintenance and capital of all the composting systems, but takes the longest amount of time for the composting process to complete. Since the compost is not physically aerated there is a higher risk of odor associated with anaerobic conditions. Odor control can be achieved by covering the static pile with a thick layer of bulking agent.

b. Aerated Static Pile

In aerated static pile composting, manure is mixed with the amendments and bulking agents and formed into piles. The piles are aerated to improve oxygenation. There are two common methods of aeration—either the compost pile is formed over a concrete floor with built-in vents to force air through the compost or the pile is formed around pipes attached to a blower that forces air through the pile. Aerated static pile compost systems may be 1.5 to 2.5 meters high (4.9 to 8.2 feet) and three to five meters wide (9.8 to 16.4 feet) (Bonhotal, 2001). If using a piped system, the width ultimately depends on the layout of the pipes. The piles can be any length. **Figure 7.4** is a diagram of an aerated static pile process.

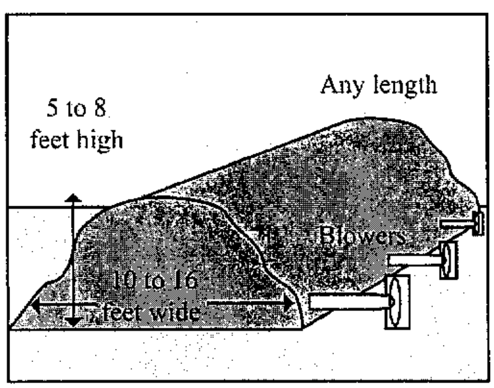

Figure 7.4: Diagram of aerated static pile compost (United States Department of Agriculture, 1992).