Manure Management Technology
Development Team
East National Technology Support Center

Managing for Better Compost

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INTRODUCTION

Making consistently good compost from manure takes skill and attention to detail. Experience will show you what works; understanding the environmental factors that control the composting process will help you interpret what you see.

Keep in mind the definition of composting:

"The controlled aerobic biological decomposition of organic matter into a stable, humus-like product."

Note: Composting mortality is a viable and safe way to dispose of deadstock and slaughter waste, but is beyond the scope of this document. Refer to NRCS and university websites for more information on large and small carcass composting.

This document discusses the factors that most influence the success of a composting operation: C:N ratio, aeration, moisture, particle characteristics, and temperature, along with some information on environmental concerns connected to composting. It is intended to supplement the information in Conservation Practice Standard 317, "Compost Facility."

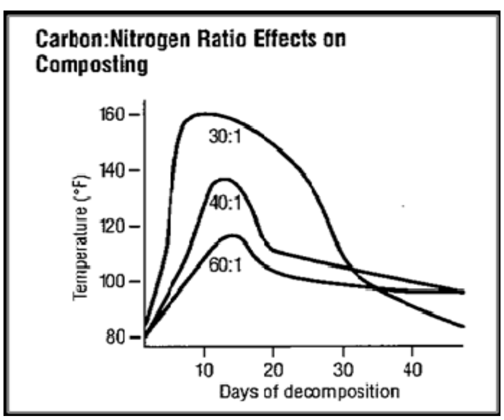

Figure 1. From 'Compost Fundamentals', Washington State University

C:N RATIO

Microorganisms require certain nutrients in large amounts, including carbon (C), nitrogen (N), phosphorus (P), and potassium (K). The relative amounts of available carbon and nitrogen greatly effect the composting process, so the carbon/nitrogen ratio [written as C:N] is used as a primary indicator of nutrient content.

Carbon is a source of energy for microbe growth. In aerobic decomposition, part of the carbon is released as CO_2 while the rest is combined with nitrogen in the bodies of microorganisms. As a result, the carbon content of a compost pile is continuously decreasing.

Nitrogen is used for the synthesis of cellular material, amino acids, and proteins and is continuously recycled through the microbe's bodies. Any nitrogen that is incorporated into the cells becomes available again when the microorganism dies.

An initial C:N ratio of 20:1 to 40:1 is recommended for rapid composting. (See Figure 1.) However, C:N ratios as low as 14:1 have worked for composting animal mortalities. If carbon is present in excessive amounts relative to nitrogen so that the C:N ratio is above the optimal range, the composting process slows. In this case, nitrogen availability is the limiting factor. With only limited nitrogen resources to use, microorganisms take longer to use the excess carbon. Several life cycles of organisms are required to reduce the C:N ratio to a more suitable level.

If the C:N ratio is too low because the raw material is rich in nitrogen, the limiting nutrient will instead be carbon. If enough carbon is not available to provide energy for the microbes to incorporate nitrogen compounds into their cells, unstable ammonia will form.

The calculated C:N ratio of a compost mix does not always accurately reflect the amount of nutrients available to the microorganisms.

Microbial systems, especially bacteria, respond primarily to readily available nutrients. The mix of raw materials not only needs the proper C:N ratio, but the nutrients need to be in forms that can be consumed. Material containing simple sugars, such as fruit waste, decomposes rapidly while woody material bound by decay-resistant lignins is more difficult. Most nitrogen sources decay easily except for keratin (horns, hair, wool, and feathers).

Maximize the availability of the carbon and nitrogen in your compost feedstock by mixing thoroughly and grinding material into smaller pieces if necessary.

OXYGEN AND CARBON DIOXIDE: Oxygen is obviously necessary to the survival of aerobic organisms. If there is not enough oxygen to sustain aerobes, anaerobes will dominate the pile, slowing the composting process and producing unpleasant odors. A minimum oxygen concentration of 5% is required to maintain aerobic conditions.

Oxygen (O_2) can be supplied to the pile using either forced or passive aeration. Regardless of the method, the amount of air being supplied does not necessarily reflect the amount of O_2 actually reaching microorganisms. Bacteria live within a thin liquid film on the surface of compost particles. [See Figure 2] Since the diffusion of O_2 through water is significantly slower than through air, the pile must be porous enough, and particle sizes small enough, to allow air to reach all the wetted surfaces.

Oxygen levels can be used as an indicator of active composting. As aerobic activity increases, O_2 levels should drop. Measuring O_2 levels is not quite as accurate as measuring temperature, but adds useful information. It is a good way to show that stability has been reached. As the pile reaches maturity and microbial activity slows, O_2 levels rise.

Because carbon dioxide (CO_2) is a product of aerobic respiration, it can also be used as an indicator of microbial activity. CO_2 levels should increase as microbial activity develops and decrease as the composting process approaches maturity.

Oxygen transport -- Oxygen moves from the open air into a pile by convection and diffusion. Convection can be "forced" (driven by mechanical means) or "natural" (caused by the buoyancy of hot air). In a passive system, heat can often be seen rising out of the pile, while natural convection pulls cool oxygen rich air in to replace it.

Waterlogged pores block uniform convective air movement. One of the reasons to mix and turn compost is to redistribute moisture and maintain porosity.

Diffusion through smaller pores and into the aqueous film surrounding compost particles is essential to maintaining aerobic conditions for active microbes. Water saturation dramatically reduces oxygen diffusion, which is 6000 to 10,000 times greater in air than in water.

WATER is essential for the survival of compost microbes. They require an aqueous environment in which to move, reproduce, and transport nutrients, and water is the medium for most chemical reactions. Aqueous does NOT mean saturated. The ideal moisture content for composting is a compromise between achieving adequate moisture for the microbes and adequate oxygen flow. Forty to 65% moisture is recommended, making the compost the consistency of a wrung-out sponge (the “squeeze test”).

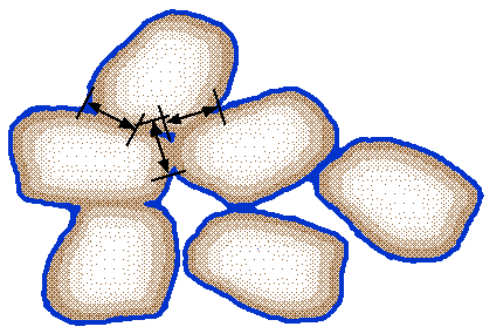

Figure 2. Properly wetted compost. [Cornell Waste Management Institute]

Another function of moisture is evaporative cooling. If the pile becomes too dry during the thermophilic stage, it may overheat and even burn because of insufficient evaporative cooling.

In hot, arid climates, moisture is especially difficult to maintain because of excessive evaporation losses. If the pile gets too dry, composting can be halted prematurely. In wet or humid climates, piles may require additional turning, adding more dry amendments, or roofing to prevent them from getting too wet.

The simplest way to correct a low moisture problem is to turn the pile right after rainfall, or to spray water on it during turning. Runoff and leachate from the composting area, collected in a pond or sump, should be returned to the compost.

Figure 3. Adding water while turning [Midwest Biosystems Inc.]

The inherent **pH LEVELS** of raw material do not necessarily influence the composting process because different microorganisms thrive at different pH levels. The first several days of active composting may show a drop in pH to as low as 4.0, due to formation of organic acids. The ideal range for microbial activity is between 6.5 and 8.0.

Composting continues at extremes, but the process slows. Acidic conditions are detrimental to aerobic microorganisms, particularly bacteria, and slow the composting process. It will not stop; a population of fungi eventually develops that can use the acidic compounds. As they are consumed, the pH goes up. By the end of the composting process, pH generally stabilizes between 7.5 and 8.0, regardless of the beginning pH.

In most cases, pH does not need to be adjusted, because of the natural buffering capacity of organic matter. However, if the mix is too high in nitrogen, a basic pH (> 8.5) promotes conversion of excess nitrogenous compounds to ammonia. Ammonia formation further increases alkalinity and not only slows the rate of composting, but also promotes loss of nitrogen through ammonia volatilization.

A slightly basic pH helps to control odors by preventing the formation of organic acid intermediates. Lime can be used, cautiously, to push pH upward.

PARTICLE CHARACTERISTICS -- The physical characteristics of compost ingredients (porosity, texture, and structure) affect aeration, rate of decomposition, and the ability of a pile to maintain aerobic conditions.

Porosity is a measure of air space and indicates the capacity for airflow. If pores are filled with water because of high moisture content, then resistance to airflow increases. Improve porosity by uniformly mixing materials, maintaining proper moisture, and including some larger particles or a bulking agent to increase pore size.

Texture is the relative proportion of various particle sizes of a material and dictates the amount of surface area available to the microorganisms. The finer the texture, within reasonable limits (see porosity), the greater the surface area exposed to microbial activity.

Structure refers to the ability of a particle to resist compaction and settling. It is a key factor in establishing and maintaining porosity during the composting process. A mix that has all of the necessary components, but poor structure, may not be able to sustain rapid composting. If the pile settles and air spaces close up as the material decomposes, composting slows down.

TEMPERATURE -- Temperature is a critical indicator of microbial activity. Daily temperature records will help detect deviation from normal patterns. Temperature should rise steadily as the microbial population develops. If it does not begin to rise within the first several days, adjustments must be made in the compost mix.

Temperature is the one factor that most operators will measure while composting, even if they pay little attention to anything else.

- Lack of heat indicates that aerobic decomposition is not happening. Check for lack of aeration, inadequate carbon or nitrogen content, low moisture, or low pH. It may be necessary to add a bulking agent to improve porosity, or dry amendments with good absorbency (for example, sawdust) to decrease moisture content.
- The pile may fail to heat because it's too small or over-exposed to cold weather and therefore losing heat too rapidly. A compost pile out in the open should usually be twice as wide as it is high, with no dimension smaller than four feet, in order to be able to maintain heat. Bins and containers would rarely be designed with the smallest dimension less than four feet.

- Uneven temperatures within a pile indicate a non-uniform mix of material. Cold spots in the mix may be pockets of anaerobic activity. This is generally a problem only with static piles.
- Exceedingly high pile temperatures (>170 ºF) are not so much an indicator of vigorous microbial activity as a sign that the pile is unable to control its temperature. A pile begins to overheat if it traps too much of the heat being produced. Generally, the pile is too deep or too dry to allow for enough cooling through evaporation. Rebuild the pile with a smaller cross-section, add water, or both.
- Note: if a pile has gotten very hot, adding water without aerating may make matters worse, since it just jacks up the microbial activity and adds even more heat. In high-nitrogen manures like poultry litter, this can lead to combustion.
- A pile that begins to cool after achieving thermophilic temperatures for several days is nearing the end of the composting process or has become unable to maintain the bacterial population. The pile may have run out of air, water, or readily accessible food. Active conditions can be reestablished by turning and mixing the pile and adding water as needed, up to the time that the pile has matured and won't heat up anymore.

MONITORING -- The type of monitoring equipment used depends on how closely the operator wants to manage the compost. Every operation needs at least a thermometer to establish normal temperature profiles, indicate when it's time to turn the pile, or check for microbial activity. Sophistication of the equipment varies. The simplest and cheapest is a dial thermometer with a 3-foot-long pointed probe. It saves time, though, to purchase a fast-response digital thermometer.

The price of pH meters depends on accuracy, temperature compensation, automatic calibration, and range. CO_2 and O_2 testers are available with sensors, an aspirator, and a sniffer probe. Samples should be taken from the part of the pile where microbial activity is expected to be the most vigorous and O_2 levels expected to be the lowest (inner core of the pile). Carbon dioxide levels should trend in the opposite direction to oxygen levels because carbon dioxide is a product of aerobic respiration.

ODORS -- Odor generation is an issue for any composting facility. On the positive side, odor is a simple indicator of whether pile conditions are aerobic or nitrogen losses are occurring through ammonia volatilization. Odor management is important if the operation is in close proximity to neighbors.

Odors produced at the beginning of the composting period are generally caused by the raw material. Fresh manure or fish processing wastes just have strong odors, but they will diminish as composting proceeds. Adding a bulking agent, sufficient carbon sources, and enough oxygen will help mitigate these odors.

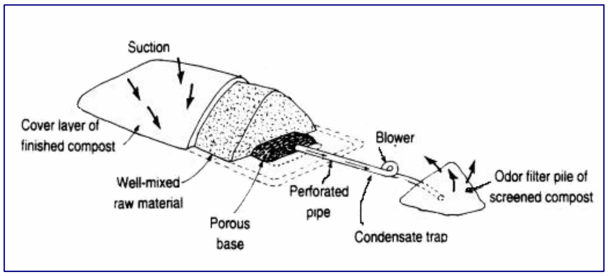

Figure 4. Simple example of a biofilter for forced air windrows. [Washington State Univ.]

Odors generated during the composting cycle result from microbial respiration or chemical reactions. The main compounds responsible for odor involve sulfur, nitrogen, and volatile fatty acids. Although strong odors are generally associated with anaerobic conditions, aerobic decomposition also generates them, particularly through the volatilization of ammonia.

Odorous compounds produced within a compost pile aren't necessarily released. These compounds can move by diffusion to other parts of the composting pile where they are decomposed to non-odorous compounds. For example, hydrogen sulfide that is produced through anaerobic decomposition can be converted to sulfur rather quickly in aerobic zones. If this doesn't happen, then the compounds are released into the atmosphere and odor results.

Peat, moderately fine textured soils, matured compost, and some other materials can effectively adsorb odors and ammonia and reduce ammonia losses. They work best when used either to cover the static pile or to filter the exhaust air coming out of a mechanically aerated pile, rather than mixing them directly into the compost.

ADDITIVES, INOCULUM, AND STARTERS Starters, also referred to as inocula, consist of microbes and enzymes. They are added to the initial compost material and generally make up about 10% of the mix. Additives are substances added to the initial mix to adjust the C:N ratio or pH or to control odors.

Adding an inoculant to compost is intended to eliminate the need for a native microbial population to grow and develop. Vigorous microbial activity and decomposition could begin almost immediately. However, this won't work unless the inoculant contains a microbial population specifically suited to the feedstock. Inocula are also useful only if they supply microorganisms more effective than those already present in the waste. Given the dynamic, variable environment in a compost pile, the inoculum may be less effective than the indigenous microbial populations.

The enzymes in starters are intended to start breaking down organic matter to speed decomposition. While this would make some sense if composting materials that don't contain easily digested compounds, manure is already primed with organic acids, proteins, and other readily available food for bacteria. The correct enzymes are also difficult to pinpoint because of their specificity and their sensitivity to environmental conditions, including temperature fluctuations.

Fertilizers added to the compost mix to adjust the C:N ratio (urea or other concentrated sources of nitrogen) lower the ratio without altering the moisture content of the mix and often provide the required amount of nitrogen (in a low nitrogen mix) at low cost. The drawback is that chemical nitrogen is available at a faster rate than organic carbon. This can result in ammonia production.

If you want to try any of these products, test them in field conditions by inoculating one pile and using another pile as a control. Compare the composition of each pile after composting to see if the starter performed as claimed.

The simplest inoculant may be your own finished compost, already containing the microbes needed to work in your situation.

If a little initial boost is needed and fresh chicken litter is available, try using "hot litter" as a starter or inoculant. A convenient way to keep fresh litter "hot" is to maintain a supply that is kept moist and turned daily. As part of the hot litter is removed to enrich new compost piles, an equal volume of raw litter is mixed into the hot pile. This maintains a microorganism-rich litter supply to use as a starter.

PATHOGENS -- Inadequately heated compost can be a source of pathogens to the environment and a health threat to humans and animals. Pathogenic microorganisms in compost may include bacteria, viruses, fungi, and parasites. Conditions unfavorable to pathogen growth include a lack of consumable organic matter and a pile with moisture content of less than 30%. Because such conditions are difficult to achieve in mature compost, pathogen destruction happens primarily during the thermophilic phase.

Pathogens can be destroyed by heat, competition, destruction of nutrients, antibiosis, and time. Most pathogens can be killed by exposure to high temperature. The few exceptions to this are some fungal diseases of plants, which can withstand temperatures over 180 ^{o}F. Most pathogens originating from animals cannot survive prolonged heat above 130 ^{o}F.

The two essential elements in achieving good pathogen destruction are:

- All of the material must be exposed to lethal conditions.
- The exposure must last for a sufficient amount of time to maximize its effectiveness.

All composting methods have the potential to leave some material in the pile un-heated or not heated for a long enough time. Extending the number of turnings and the length of heated time can maximize pathogen destruction.

COMPOST QUALITY is determined by its physical, chemical, and biological characteristics. An assessment of quality depends on the desired use of the compost.

Stable, mature compost has completed active composting and cured sufficiently so that organic acids and lignins have decomposed, some humic compounds are present, and nitrogen is in organic or nitrate-nitrogen form.

Physical characteristics used to gauge compost quality, particularly for sale, include:

- Particle size—relatively uniform small particles; crumbles easily in the hand; no big hard chunks
- Texture—crumbly, potting-soil-type feel
- Appearance—dark brown or black, no visible signs of the original raw materials
- Absence of non-compostable debris—customers do not want to find glass, plastic, metal, or medication containers in their compost
- Moisture content—30 to 50%. If wetter, it will be clumpy and if drier, too dusty

If compost is applied to cropland, the appearance and texture are obviously less important, as long as the material can be spread evenly.

Figure 5. Screening compost for sale [Jetcompost screeners]

Desirable **chemical characteristics:**

- pH is within a range of 6 to 8. A pH of 5.5 to 6.5 is recommended for potting soil, and a pH of 5.5 to 7.8 for soil amendments, top dress, and mulch.
- Laboratory analysis is required to determine crop nutrient content; nutrients in compost, including phosphorus, potassium, and magnesium, should be included in the farm's nutrient management plan.
- The Kjeldahl nitrogen [TKN] test determines the amount of organic nitrogen in the compost. Together with nitrate nitrogen, this gives total nitrogen [TN]. NO_3-N will be immediately available. In large amounts, ammonium nitrogen can be detrimental to some horticultural plants. As the compost is allowed to mature, NH_4-N is gradually converted into NO_3-N.
- If the C:N ratio is too high when land applied, micro-organisms compete with crop plants to consume the available soil nitrogen in order to degrade the carbon in the compost. The resulting nitrogen immobilization may negatively affect the growth of the plants.
- The heavy metal content of the compost is important particularly when the compost is used on crops for human consumption. This is a greater risk for composts incorporating sewage sludge, municipal waste, or brown paper and cardboard.
- Soluble salts can be harmful to plants especially in potting soil or germination mixes. Potting soils generally require soluble salts content below 2 to 4 mmhos/cm. On cropland, salt buildup should be monitored wherever manure or manure compost are applied continuously.

Biological characteristics:

If compost is still microbially active, it may inhibit plant growth because the microbes compete with growing plants for nutrients.

When compost will be used for greenhouse production, laboratory tests for acceptable characteristics may include heat production, CO2 production, oxygen consumption, and nitrogen release.

Seed germination tests screen for phytotoxicity from heavy metals, toxic compounds, salts, organic acids and excess oxygen or nitrogen demand. In a standard seed-sprouting test, one seed (commonly cress, wheat, or lettuce) is planted in each of 100 pots or plugs and observed for the normal number of days to germination. The percent germination is compared to a control in which 100 seeds are sprouted on moistened paper towels. A further test of compost suitability as a growth medium is to grow radish and green bean seedlings. Radishes are very sensitive to phytotoxins while green beans are more tolerant.

PLANNING COMPOSTING PROJECTS

For the most part, composting is a "green" process, contributing to long-term environmental sustainability. However, it does involve capital costs, labor, and maintenance. Composting is a commitment. It takes the same kind of energy and time to produce quality compost that it does to grow a quality pig or produce good eggs. Water management, manure handling, bedding, housing, even feed management may need modifications.

When adding composting to a farm operation, in addition to the required design considerations, address the following:

- Traffic patterns. Minimize material movement and machinery where feasible.
- Space. Include room for equipment movement, leachate capture, piles of maturing compost, and storage for raw materials, especially bulking agents like woodchips or sawdust. If compost will be marketed, add product handling and storage space and a way for the customers to get to the product.
- Labor. Compost has to be managed, and it does take time. In addition to building piles and turning, there's taking temperatures, checking and adding moisture, sampling for nutrient testing, and pre-market handling.
- Drainage. The pile, bin, or container needs to be in a dry, relatively level area with good drainage, provision for capturing leachate and runoff, and a water source.
- Maintenance. Bins, equipment, pads, and other components have to be maintained, and the area around the composting facility kept free of weeds, disease vectors, and pests.

Every bell and whistle you add to a composting system increases the facility cost, and may increase labor and operating costs. Adding greater complexity or higher technology than the operation really needs is counterproductive.

I'VE GOT COMPOST – NOW WHAT?

Before diving into composting, the planner and the operator have to think through the final destination for the product.

Land Application -- Before turning to marketing, exhaust on-farm uses for your compost. It's a wonderful soil amendment for building tilth. However, since the manure solids that are composted usually contain most of the manure stream's phosphorus, farms that already have excess soil test P values may have a tough time using up all the compost made unless it's transported to distant fields or supplied to neighbors in need of the P.

Application rates for compost used on the farm must be based on phosphorus and nitrogen content as part of a nutrient management plan. Physically, it is recommended that application rates not exceed 50 dry tons per acre per year, which is roughly an inch thick. (This would probably far exceed the nutrient needs of the crop.)

Compost probably serves its most important function as a soil conditioner, adding humus and organic matter. This increases water and nutrient holding capacity of the soil, decreases soil bulk density, and improves soil aeration and pore structure.

Compost has other benefits, including increasing the soil cation exchange capacity and adding buffering capacity. It works to suppress plant diseases by fostering microbial population and diversity in the soil, giving beneficial organisms a competitive edge over pathogens.

The advantage of using compost to replace an equivalent amount of chemical fertilizer is that it releases nutrients slowly, generally under the same warm, moist soil conditions required for plant growth, so nutrient release matches plant uptake. The amount of nitrogen available during the first growing season ranges anywhere from 8 to 35% of the total, depending on raw materials and composting methods. It is generally assumed that 10 to 25% of other nutrients are available during the first season.

Marketing -- There's a big difference between just adding composting as a step in the manure treatment process, and composting with the intention of marketing. Everybody thinks they can sell compost. In reality, once you get past the neighbors-with-pickup-trucks market, it's not easy. Remember, the customer dictates what they want and the farmer has to try to produce it; there have to be enough customers to use what's produced; the compost has to get to the customer; and the supply flow is often different from the demand flow. Compost marketed based on its fertilizer content requires licensing by most State Departments of Agriculture. More commonly, compost is sold as a soil amendment, with no particular claims about nutrient content.

Approaches to try:

- Find a commercial composter in the area and see if they will take the farm product to add to their raw material stream.
- Have an outside entity (non-profit, gardening supply shop, or farmer's market) take the product and sell it.
- Join with other farmers to produce enough compost to make marketing commercially profitable.

- Find a large single customer, such as a turf farm, to take all the compost.

ENVIRONMENTAL CONCERNS

Composting is not free of environmental concerns. Both air and water resources can be unfavorably affected if composting isn't managed properly.

Several gases are emitted during composting (ammonia, methane, nitrous oxide, hydrogen sulfide, volatile organic compounds, and carbon dioxide.) Ammonia and methane are two that can be addressed through management.

Ammonia –- Composting normally involves some loss of nitrogen. Ammonia forms as part of nitrogen transformations. Ammonia volatilization is associated with high temperature, low moisture content and alkaline pH. If the C:N ratio is too low (not enough carbon), the microbes don't have enough available energy to incorporate all the nitrogen into their cells. In that case, the microbes will "eat" all the carbon that's there, but the excess nitrogen will be eliminated as ammonia.

Ammonia losses can be minimized by:

- Thoroughly mixing feedstock with proper proportions of carbon and nitrogen
- Meeting the need for oxygen, water, and other essentials
- Covering static piles with peat moss or finished compost, to absorb ammonia as it volatilizes
- Manures high in nitrogen (e.g. poultry litter) sometimes can't be economically amended with enough carbon to avoid ammonia losses. If this is a serious air pollution concern for an operation, the exhaust air from forced-air or in-vessel composting can be scrubbed or filtered to remove the ammonia.

Methane – Methane (CH_4) is produced under anaerobic conditions by methanogenic bacteria, and if any portion of a compost mass is allowed to "go anaerobic" because of too much water, too little porosity, or compaction, methane will be produced. As a greenhouse gas, methane is more than 20 times as effective (or detrimental) as carbon dioxide. Because the interior of large particles in even the best compost piles is essentially a low-oxygen environment, even good composting will yield some methane. It can also be produced during the rapid thermophilic phase when O_2 is being consumed so fast that areas within the pile become anoxic. The amount of methane emitted can be minimized by aerating, reducing the presence of clumps, avoiding compaction, and not letting the pile get too wet.

Leachate and runoff from the composting facility can carry NO_3, soluble P, organic matter, and pathogens. All leachate and runoff should be captured and preferably returned to the pile to make up moisture needs.

Dust from exposed compost windrows can carry odors, nutrients, air pollutants, and pathogens. Locating the pile where airflow will not carry dust to residential areas, covering the pile, maintaining adequate moisture, and avoiding windy days for turning can all help to reduce aerial distribution of pollutants.

The main factors controlling air and water pollution from composting are the choice of raw material (influences gas emissions), and the choice of composting location (affects leaching and runoff).

ADDITIONAL INFORMATION

NRCS Engineering Field Handbook, Chapter 2, Composting

The Art & Science of Composting, University of Wisconsin-Madison, Center for Integrated Agricultural Systems, March 29, 2002

Cornell Waste Management Institute
http://cwmi.css.cornell.edu/Composting.html

Ohio State University http://www.oardc.ohio-state.edu/ocamm/