

Composting Manure – What’s going on in the dark?

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Manure Management Information Sheet

Number 1

INTRODUCTION

Composting is the controlled aerobic biological decomposition of organic matter into a stable, humus-like product. Compost consists of the biomass of dead and living microorganisms, undegradable raw material, and stable by-products of decomposition. Because manure is high in digestible organic material, it can be composted to transform it into a stable, versatile soil amendment.

This document is intended to supplement the information in Conservation Practice Standard 317, “Compost Facility.”



Figure 1. Mature compost

WHY DO IT?

Benefits of composting manure and other organic wastes include:

- Dry matter reductions, generally about 50%, and up to 75% (usually a greater reduction for dairy manure than for swine)
- Volume reductions, generally about 50 to 60%, and as high as 85%
- Compost can be transported more easily, cheaply, and farther than raw manure
- Facilitates nutrient removal from the farm
- Stable product that can be land applied at farmer’s convenience

- Reduction in odors, flies, pathogens, and weed seeds
- A very flexible process that can be simple or high-tech

CRITICAL ENVIRONMENTAL CONDITIONS

Composting could be likened to livestock production... and just like all livestock, in order to thrive, the microorganisms being raised need certain environmental conditions:

- Nutrient balance
- Moisture content
- Aeration (oxygen)
- Temperature regime

Nutrient balance is determined by the ratio of carbon to nitrogen in the compost mix (C:N ratio). It is like balancing carbohydrates and protein in a diet. Bacteria, actinomycetes, and fungi require carbon and nitrogen for growth. They use roughly 30 parts of carbon to 1 part of nitrogen.

The **moisture content** of compost should ideally be 60% after the ingredients are mixed. As a rule of thumb, a mixture of organic wastes that contains 50 to 70% moisture feels damp but not soggy—like the feel of a wrung-out sponge.

Adequate **aeration** enables biological processes to thrive with optimum efficiency. Aeration affects temperature, moisture, CO₂ and O₂ content of the air in the pile, and the rate of removal of potentially toxic gasses.

The **temperature** increase during composting results from microbes breaking down organic matter.

Fresh organic matter + O₂ = humus-like substances + CO₂ + H₂O + Energy (heat) + mineral products.

Starting at ambient temperature when the pile is mixed, compost can reach 150 °F in less than two days. Heat is generated from within the compost mass. Applying external heat should not be necessary unless ambient temperatures are well below freezing or the mass of the pile is too small to maintain heat.

The bacteria, and some other microorganisms associated with composting, are generally classified into three categories according to temperatures most favorable to their metabolism and growth:

- Psychrophilic – less than 50 °F
- Mesophilic -- 50-105 °F
- Thermophilic -- 105-150 °F

Breaking down organic matter is a dynamic process accomplished by a succession of microorganisms. Each group of “bugs” reaches its peak population when conditions are optimum. As one group of microorganisms dies, another flourishes as moisture, oxygen levels and temperature rise and fall.

Composting activity rate [see Figure 2] is generally measured by the rate of carbon dioxide production. Maximum CO₂ production occurs when bacteria are most active during the thermophilic period [100-150 °F]. When the temperature exceeds 150 °F, bacteria die or retreat into spore form and the composting rate

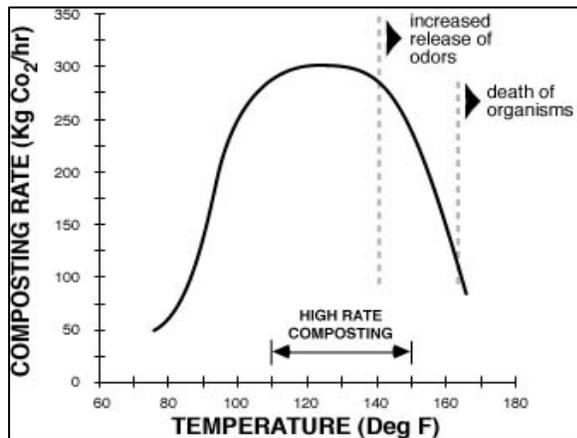


Figure 2. Carbon dioxide release vs. temperature

drops rapidly. Biological activity is negligible at temperatures higher than 160 °F, the point at which protein is cooked.

An extended period at thermophilic temperatures is necessary to kill pathogens and weed seeds.

It takes three days at 131 °F (55 °C) to kill parasites, fecal and plant pathogens. All parts

of the compost mass must be exposed to this temperature regime.

COMPOSTING STANDARDS

NRCS Conservation Practice Standard 317 defines a compost facility as “A facility to process raw manure or other raw organic by-products into biologically stable organic material.” The purpose of the practice is “To reduce the pollution potential of organic agricultural wastes to surface and ground water.”

Individual state governments may have criteria to define compost that is going to be sold, or regulatory requirements for composting operations. States may also require a composting operation to be permitted, especially if the operation processes manure from more than one farm or even several properties under one management. Large centralized operations composting the manure from many farms will need to apply for an NPDES (National Pollutant Discharge Elimination System) permit.

USDA’s National Organic Program rule defines compost as:

“The product of a managed process through which microorganisms break down plant and animal materials into more available forms suitable for application to the soil. Compost must be produced through a process that combines plant and animal materials with an initial C:N ratio of between 25:1 and 40:1. Producers using an in-vessel or static aerated pile system must maintain the composting materials at a temperature between 131°F and 170°F for 3 days. Producers using a windrow system must maintain the composting materials at a temperature between 131°F and 170°F for 15 days, during which time, the materials must be turned a minimum of five times.”

On-farm composting operations should be planned to comply with all local, state, or other regulations and standards that apply. If compost is going to be marketed, the operator needs to follow appropriate procedures to label the material properly and in accordance with any official criteria that apply.



Figure 4. Turning compost windrows. Note ponds beyond the pad for catching runoff.

COMPOSTING METHODS

WINDROWS

Aerated windrows are formed from thoroughly mixed materials, and are not turned after building. Pipes running under the windrow, on top of a porous medium, carry air into the pile.

- **Passively aerated** windrows have pipes running underneath but no blowers. Air moves into the pile through convection.
- **Actively aerated** windrows have pipes running underneath, and powered blowers to force air through the pile (either sucking or blowing). The exhaust air may be filtered through soil or a biofilter.

Non-aerated windrows are mechanically turned at intervals. The turning introduces air and improves porosity. The more frequently they are turned the more rapidly composting will progress.

Covering windrows -- Covering compost windrows with geotextiles, fleece, layers of organic material, or soil provides several benefits. In cold climates, the protection of a cover allows an operator to start a composting cycle in late summer or fall. Prolonging warm temperatures within the compost in the fall and spring can reduce maturation time. In very rainy or arid climates, the moisture regime can be improved by preventing the windrow from getting too wet or too dry. Covers can also help in high-wind locations where dust is a concern; and to some extent, covers can reduce odor emissions. Consider material cost, practicality,

and added labor when evaluating the advantages of covering.

BINS, BEDS, AND VESSELS

“**In-vessel**” composting includes any form of composting done in an enclosure. The compost might be agitated, turned, force-aerated, etc.

Bins can be constructed from wood or concrete and may or may not have forced aeration, but at minimum will have three sides and usually is roofed. A series of bins is used to turn the compost (from one bin to another) with a front-end loader. Residence time in bins is usually in months rather than weeks. Compost harvested from the last bin in line will be fully mature.

Agitated beds are formed in long parallel channels, covered by a roof, and have a turning machine that runs on tracks along the concrete



Figure 3. Swine manure and cotton gin waste composting in a continuously agitated bed. The agitator is remote controlled.

walls between channels. The beds may have forced aeration from below, on a gravel bed or concrete pad, or may be non-aerated. Suggested composting periods for commercial agitated bed systems range from two to four weeks, plus a piled curing period.

Silo or tower -- An in-vessel technique resembling a bottom-unloading silo. 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 14 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 footprint needed for composting because the materials are stacked vertically. However, the stacking also presents compaction, temperature control and air flow challenges. Because materials receive little mixing in the vessel, raw materials must be well mixed when loaded into the silo.

Rotary drum -- A horizontal rotary drum mixes and moves material through the system. The drum is mounted on large bearings and turned by a bull gear. A drum about 10 feet in diameter and 100 feet long has a daily capacity of approximately 50 tons with a residence time of three days. In a 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.

Air is supplied through the discharge end of the drum or other openings and is incorporated into the material as it tumbles. The air generally moves in the opposite direction to the material. The compost near the discharge is cooled by fresh air. Newly loaded material receives the warmest air to help encourage bacterial growth.

The drum can be single-chambered or



Figure 5. Rotary drum units

partitioned. A single-chamber drum moves all the material through continuously in the same sequence as it enters. The speed of rotation of the drum and the inclination of the axis of rotation determine the residence time. A 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.

Variations on the rotary drum -- Shipping containers, factory roll-offs, inclined drums, and other vessels are being used to adapt composting to specific needs. Enclosed composting is ideal for mortality disposal as it reduces biosecurity challenges. Exhaust air from an actively composting drum can be blown through a container of mature compost or bark chips to remove odors and trap ammonia.

In general, the shorter the active composting time, the longer the curing period, as the microbes have to be given time to finish their job.

DYNAMIC BIOLOGICAL PROCESSES

As in natural decomposition—for example, on the forest floor or in a corn field after spreading raw manure—composting organisms require adequate nutrients, oxygen, and water. We manage the process by controlling the carbon-to-nitrogen (C:N) ratio, oxygen supply, moisture content, temperature, and pH of the compost pile. All the work, however, is done by myriad unseen creatures.

LIFE IN THE PILE -- At first, the pile is quiet, as the microbial population grows. When certain bacteria reach critical mass, heat builds rapidly in the self-insulating confines of the pile. Temperature rises steadily for about three days through psychrophilic [up to 50 °F] and mesophilic [50 to 105 °F] ranges as the microbial population increases and diversifies.

As the pile heats into the thermophilic range [over 105 °F], the micro-community reaches peak growth and efficiency, eating, growing, and dividing. This intense activity sustains the prolonged heat necessary to destroy pathogens,

fly larvae, and weed seeds. Temperatures peak at 130 to 160 °F. After that, activity gradually decreases in response to depleting food and oxygen, as well as the high temperature. Microorganisms degrade material by moving simple soluble components through their body walls and by exuding extracellular enzymes to break down complex molecules before absorbing them. If the temperature becomes too high, the enzymes denature and the microorganisms begin to starve. Many form spores in order to wait out the adverse conditions.

As microbial activity decreases, more heat is lost from the pile than is generated, and it begins to cool. As the pile cools, new generations of microorganisms re-populate the pile by migrating from cooler spots or germinating from spores as conditions become suitable for survival.

Compost remains in the thermophilic range for varying timeframes, depending on availability of food, oxygen, and water. Once the temperature decreases to below 105 °F, the pile will not heat up again unless oxygen, water, or other limiting factors are replenished.

CURING is the period following active composting. It is characterized by reduced microbial activity and slow decomposition of remaining digestible material. There is no set point when compost is “finished.” Compost is deemed stable when no further decomposition is going on, the pile stays at ambient temperature even when turned, and the material in the pile is dark or black, earthy smelling, and original materials are no longer recognizable.

During curing, organic acids and decay resistant compounds continue to decompose, humic acids form, and nitrogen stabilizes as nitrates. Certain fungi that suppress plant diseases inhabit the piles. Weed seeds will rapidly re-colonize the pile during curing if it isn't covered or located away from weed sources.

Curing activities are slow and require adequate time, from one to six months. The length of the curing period varies with the type of material, the length of the active composting period, and the intended end use of the compost. The shorter the active composting phase, the more curing needed.

Immature or inadequately cured compost may retard plant growth if applied to crops or greenhouse plants, due to the C:N ratio, non-nitrate forms of nitrogen, organic acids, or other chemical constituents that come and go during the composting process.

THE MICROBES -- Microorganisms inhabiting a compost pile belong to three classes: bacteria, fungi, and actinomycetes. They may be anaerobes, aerobes, or facultative anaerobes. Various micro-communities develop in response to different levels of temperature, available food, moisture, oxygen, and pH in a compost pile. Life in the pile is dynamic and constantly changing. Compost microbes degrade a broad range of compounds from amino acids and simple sugars to complex proteins and carbohydrates.

Easily degradable material has low molecular weight and simple chemical structures. It's water soluble and can pass easily through the cell wall of the microbes, which allows it to be metabolized by a broad range of non-specialized organisms.

As the supply of easy food diminishes, microbes reach out and begin to feed on complex materials. This material has high molecular weight and polymeric (long chain) chemical structures that can't pass directly into the cells. It has to be broken down into smaller components through the action of extracellular enzymes. Some simpler organisms in the pile, (some bacteria), can't produce the enzymes and have to lie in wait for more specialized organisms, (actinomycetes and fungi), to hydrolyze the polymeric structures, so they can sneak in and absorb them.

Bacteria are small, simple organisms present in huge numbers during the early stages of composting. Bacteria are fast decomposers. They consume the most readily available nutrients, such as simple sugars, as well as digesting the products of fungal decomposition. Bacteria function optimally between pH 6 to 7.5, and a moist environment is critical. Some bacteria form spores that enable them to wait out unfavorable environmental conditions, such as high temperature or low moisture. When the environment becomes favorable again, the spores germinate and bacteria proliferate. This capacity of certain bacteria helps to continue the

composting process during the roller coaster of temperature regimes that compost endures.

Actinomycetes are technically bacteria because of their structure and size, but are similar to fungi in that they form filaments and are able to use a variety of substrates. *Streptomyces* is a well-known example. Actinomycetes are abundant in soils that are rich in organic matter and are the source of the characteristic earthy smell. They break down organic acids, sugars, starches, hemicelluloses, celluloses, proteins, polypeptides, amino acids, and even lignins. They also produce extracellular proteases (enzymes) and can dissolve other bacteria. Actinomycetes are more prevalent in the later stages of composting when most of the easily degradable compounds are gone, moisture levels drop, and pH rises.

FUNGI are larger, more complex organisms than bacteria. They form networks of individual cells in strands (filaments) that may be visible to the naked eye. Fungi tend to be present in the later stages of composting because their preferred foods include woody substances and other decay-resistant materials such as waxes, complex proteins, hemicelluloses, lignin, and pectin.

Fungi are less sensitive than bacteria to moisture and pH levels, but they are obligate aerobes, requiring oxygen to grow, and don't generally survive above 140 °F.

Macro-organisms — complex higher organisms-- begin to invade once the pile cools to suitable levels. These include protozoa, rotifers, and nematodes. They consume the bacterial and fungal biomass and aid in the degradation of lignins and pectins. Last of all come sow bugs, worms, springtails, and other visible creatures to feed on the products of decomposition and smaller inhabitants.

Vermiculture, sometimes called vermicomposting, is often lumped in with composting. Actually, vermiculture is worm farming, not composting at all, and the end product (from the end of the worm) is very different from mature compost. Worm castings are a wonderful soil amendment, especially for horticulture; however, there's no guarantee of pathogen or weed seed reduction, and the nutrients in the castings are more quickly available than in mature compost. Vermiculture

has been used commercially for disposing of horse manure, and works well with food wastes. There is no need to add worms to compost, either initially or during maturation. If they're available and want to move in you'll have them anyway.

CHEMISTRY

Important chemical transformations take place in the pile as complex compounds are broken down into simpler ones and then synthesized into new complex compounds. Before microorganisms can synthesize new cellular material, they need energy. Two energy pathways for these heterotrophic microorganisms are respiration and fermentation.

RESPIRATION can be aerobic or anaerobic.

Aerobic respiration is "better than" anaerobic respiration or fermentation for composting because it is more efficient, generates more energy, operates at higher temperatures, and does not produce the same quantity of odorous compounds. In aerobic respiration, the aerobic microorganisms use molecular oxygen, O₂, to liberate the bulk of the energy from a carbon source, producing carbon dioxide and water in the process. Aerobes can also use a greater variety of materials as a source of energy, which results in greater degradation and stabilization of the compost. The process is not as picky as anaerobic digestion.

Anaerobic respiration -- Microorganisms use electron acceptors other than oxygen, such as nitrates (NO₃), sulfates (SO₄), and carbonates (CO₃), to obtain energy for anaerobic respiration. Their use of these alternate electron acceptors leads to production of odorous or undesirable compounds, i.e. hydrogen sulfide (H₂S) and methane (CH₃). Anaerobic respiration forms organic acid precursors that tend to accumulate and are detrimental to aerobic organisms. Aerobic respiration also forms organic acid intermediates, but they are quickly consumed by subsequent reactions so they don't pose as much potential for odors as in anaerobic respiration.

FERMENTATION is the simplest means of energy generation, familiar to us as yeast reactions in making bread and beer. It does not require oxygen but is quite inefficient. Most of the carbon decomposed through fermentation is

converted to products (like alcohol), not cell material, while liberating only a small amount of energy.

CHEMICAL TRANSFORMATIONS

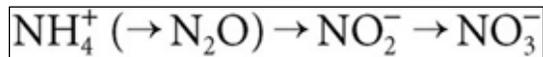
The chemistry happening in the pile relies on the balance of carbon- and nitrogen-containing materials. Biologically available **carbon** in organic matter is mineralized into carbon dioxide during composting. Loss of carbon as CO₂ is highest during the thermophilic phase. After maturing, compost will contain 30 to 50% less carbon than initially.

Nitrogen exists in both organic and inorganic forms in compost. Organic nitrogen is present in proteins, urea, nucleic acids, and microbial biomass. Microorganisms mineralize organic nitrogen to produce inorganic forms such as ammonia, nitrite, and nitrate. The inorganic forms of nitrogen are available as nutrients for plants when the compost is applied to crops.

Microbes release enzymes that break up proteins and leave complex amino compounds, carbon dioxide (CO₂), energy, and other by-products. The amino compounds can be used as cell building material, or decomposed into simpler products and 'eaten'. Amino compounds can only be used to make new cell material if enough carbon is available. Otherwise unstable nitrogen compounds accumulate as ammonia (NH₃) or ammonium (NH₄⁺) (depending on the pH and temperature of the pile).

Ammonium ions are oxidized to nitrates through **nitrification**, a two-step process. First NH₄⁺ is oxidized to form nitrites (NO₂⁻) by bacteria that use this conversion for energy. The nitrites are then rapidly converted to nitrates (NO₃⁻) by a different group of nitrifying bacteria.

Most of the nitrification happens during the curing period. Since nitrites (NO₂⁻) are toxic to plants and nitrates (NO₃⁻) are the form of



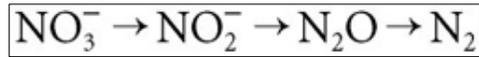
nitrogen most usable by plants, allowing time for curing facilitates the formation of nitrates in the compost. Because nitrification requires oxygen, proper aeration of the compost pile must be maintained even during curing.

Nitrogen losses -- A significant amount of nitrogen can be lost during the composting process. The amount lost varies widely and is

dependent on material, methods, and management; various studies have found anywhere from 4% to 70% N loss. Nitrogen loss is a concern because of potential contamination of ground water, odor problems, and final nitrogen content of the compost.

The potential pathways for nitrogen loss during the composting process are emissions of ammonia and nitrous oxides, leaching, and denitrification.

- Controlling factors in the release of NH₃ from compost include pH, NH₄⁺ to NH₃⁻ equilibrium, mineralization rates of organic nitrogen compounds, C:N ratio, temperature, and pile aeration.
- Ammonia emissions increase in response to warmer temperatures, a pH above 7, a low C:N ratio or adding nitrogen-rich raw material like poultry manure.
- Nitrous oxides are an interim product of the denitrification and nitrification processes. Nitrification is desirable, but denitrification is not, since nitrogen will leave the pile as either nitrous oxide or nitrogen gas.



It can be minimized by maintaining aerobic pile conditions. Nitrous oxide is a volatile, odorous compound as well as being a greenhouse gas. The N₂ is not a problem other than as a loss of nitrogen that we would prefer to keep for its nutrient value.

- Leachate can contain organically bound nitrogen, ammonium ions (NH₄⁺), and small amounts of nitrates (NO₃⁻). The greatest risk of leaching is during the first 2 weeks of the composting period or following high rainfall. Leachate should be collected and returned to the compost pile to maintain moisture.

The carbon and nitrogen that remain after composting have been transformed into highly complex molecules. This is why mature compost will release N slowly, whereas immature compost, if land applied, could lead to considerable N loss through leaching and volatilization.

Humus formation—Carbohydrates in raw compost feedstock are rapidly decomposed, leading to the synthesis of microbial biomass, and the formation of breakdown-resistant humus-like substances. The organic acids formed from the breakdown of carbohydrates

stick to metal oxides in soils, forming multi-layered clay-humic complexes that enable soil particles to cling together in aggregates, thus improving soil tilth.

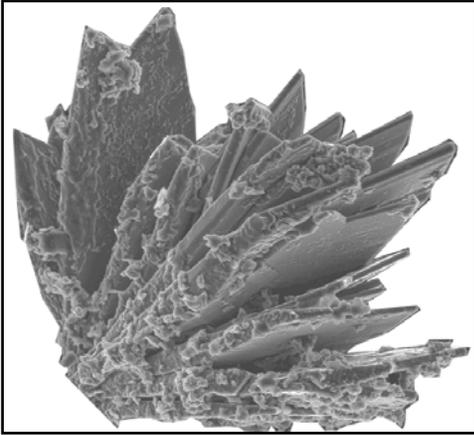


Figure 6. Clay mineral aggregate with adhering humic material. [50 microns]

Phosphorus transformations-- As composting progresses to maturity, dissolved reactive P is bound first into microbial bodies, and eventually into complex humic acids. Even some inorganic P such as that in excreted feed supplements will find its way into the microbes. The P bound in organic materials is not water-soluble until the material is broken down again in the soil environment, and will be released slowly through microbial action when the compost is land applied. NOTE: While the amount of total P in the compost pile will be the same from beginning to end (unless there are losses in runoff or leachate), the percentage will increase, because the volume of the mass has decreased. The same is true for potassium. Compost should be tested for nutrient content before land applying.

END-PRODUCTS

While the temperature profiles and maturing time of composting methods may differ, there is little chemical or biological difference in the final product. The material will have processed through the bacterial hot phase and subsequent cooler phases where actinomycetes and fungi flourish. Fully mature, or finished, compost should have the following characteristics:

- No longer heats up when turned or moistened and has the same temperature throughout the pile

- Has dark brown or black color and uniform appearance
- Has earthy smell that is not unpleasant, with no ammonia odor
- Shows no recognizable particles of the original materials

If the compost is intended for land application in an agricultural setting, the appearance, texture, and even maturity may not be that much of an issue; the fact that the material has less pathogen risk, is lighter and smaller in volume, and is more stable than raw manure may be enough to meet the customer's or operator's needs.

However, if the compost is to be sold, especially for horticultural use, the customer will look for a uniform, finely textured, mature material that will be easy to use, have no bad smells, be consistent throughout, won't heat up when moistened, and won't have any viable weed seed or dangerous plant or animal pathogens. Compost for sale may also have to meet state, local, or federal licensing and permitting requirements. Meeting these higher standards will take intense management and rigorous attention to detail, and may require more equipment and labor.

ADDITIONAL INFORMATION

NRCS Engineering Field Handbook, Chapter 2, Composting

NRAES On-Farm Composting Handbook

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

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