

# Compost Microbiology and the Soil Food Web

## Introduction

Compost is the product of an aerobic\* process during which microorganisms\* decompose organic matter into a stable amendment for improving soil quality and fertility. During composting, microorganisms use the organic matter as a food source, producing heat, carbon dioxide, water vapor, and humus\* as a result of their furious growth and activity. When applied to and mixed into the soil, humus can promote good soil structure, improve water- and nutrient-holding capacity, and help to control erosion. Humus makes up approximately 60 percent of finished compost.

A wide range of organic materials such as yard trimmings, manures, and food processing discards go into producing composts. Materials used to feed compost microorganisms are referred to as compost feedstocks.\*

Part I of this fact sheet addresses the composting process and associated microorganisms. Part II then addresses how compost contributes to the soil food web and overall plant health.

## Part I: The Composting Process and Associated Microorganisms

### *Compost Microorganisms*

**Sources.** The microorganisms needed for composting are found throughout the natural environment. They are present in compost feedstock as well as in the water, air, soil, and machinery the feedstock and compost are exposed to during processing.

These sources ensure a high diversity of microorganisms, which helps to maintain an active microbial population during the dynamic chemical and physical processes of composting, such as shifts in pH, temperature, water, organic matter, and nutrient availability. Only on rare occasions will the addition of microorganisms be warranted (see "Inoculating Compost" section).

**Microbe Types and Requirements.** The microbiological components of compost consist of bacteria and fungi. Because of their unique nature, *actinomycetes* are discussed here as a third microbiological component, though in actuality actinomycetes are a particular kind of bacteria. The majority of microorganisms responsible for the formation of compost are aerobes in that they require or work best in the presence of oxygen.

Many difficulties associated with composting may be traced to insufficient oxygen levels to support the decomposition of compost feedstock. Compost microbes also require a moist environment because they live in the water films surrounding composting organic matter particles. A 50 to 60 percent moisture content is optimal.

**Fungi.** Fungi form their individual cells into long filaments called hyphae. Fungal hyphae are larger than actinomycetes and may be more easily seen with the naked eye. They penetrate throughout the composting material, decomposing both chemically and mechanically the more recalcitrant\* organic matter fraction such as lignins and cellulose. Fungal hyphae physically stabilize the compost into small aggregates, providing the compost with improved aeration and drainage.

Fungi number between 0.01 and 1 million propagules\* per gram of soil. About 70,000 different species of fungi have been described worldwide, but an estimated 1 million additional species remain undiscovered and undescribed. Ecologically, fungi play a vital role in breakdown of dead plant materials.

**Bacteria.** The most numerous biological component of compost is the bacteria. Although they often can exceed 1 billion microorganisms per gram of soil, bacteria (with the exception of actinomycetes) do not contribute as much to the overall microbiological mass as fungi because of their relatively small size. Although bacteria (with the exception of actinomycetes) exist as individuals and do not form filaments, they also contribute to the stabilization of aggregates through the excretion of organic compounds that bind adjacent organic matter and soil particles together. Bacteria are

typically associated with the consumption of easily degraded organic matter. They are the dominant population throughout the entire composting process, whereas the actinomycetes and fungi typically proliferate in the later stages.

**Actinomycetes.** While actinomycetes are visually similar to fungi in that they have networks of individual cells that form filaments or strands, they are actually a type of bacteria. These filaments allow for a colony\* of actinomycetes to spread throughout a compost pile, where they are typically associated with the degradation of the more recalcitrant compounds.

Actinomycetes number between 0.1 and 10 million propagules per gram of soil. Their filaments contribute to the formation of the stable organic aggregates typical of finished compost.

Actinomycetes are tolerant of lower moisture conditions than other bacteria and are responsible for the release of geosmin, a chemical associated with the typically musty, earthy smell of compost.

### **Composting Process**

Composting proceeds in predictable stages. During different stages, temperatures and nutrient availabilities vary and affect the kinds and numbers of microorganisms that develop. Initially, the pile is at approximately the ambient temperature. The composting material warms through the *mesophilic*\* temperature range (50°–105°F) as the microorganisms become more active. Soon, microbial activity raises the temperature of the pile to *thermophilic*\* temperatures (106°–170°F). This is considered the most productive stage of composting.

Mesophiles and thermophiles are microbes adapted to mesophilic and thermophilic conditions, respectively. Composting proceeds at a much faster rate under thermophilic conditions. Eventually, readily available substrates within the feedstock are exhausted, temperatures gradually return to the mesophilic range, and curing begins. The following section expands on the microbiology of each stage.

**Initial Stage.** The process of transporting and manipulating the feedstock for composting exposes the organic matter to additional sources of microorganisms, all of which may contribute toward initiating the composting process. Initially, mesophiles predominate and proceed to decompose the readily degradable sugars,

proteins, starches, and fats typically found in undigested feedstocks.

The availability of easily usable organic substances enables the proliferation of the fastest-growing microorganisms, the bacteria. Mesophilic bacteria, therefore, dominate initial decomposition. These bacteria release heat from the breakdown of large amounts of easily degraded organic matter. This heat begins to raise the temperature within the pile due to the high insulating capacity of a properly sized compost pile. Within just hours the temperature of the compost pile can rise above the 106°F thermophilic threshold.

**Active Stage.** As the compost reaches higher temperatures, thermophiles begin to dominate the bacterial community. The active stage is typically the stage where most of the organic matter is converted into carbon dioxide and humus, and the microorganism population grows. The thermophilic population continues generating more heat by decomposing the remaining organic matter.

Due to limitations with isolation techniques, laboratory studies have only been able to isolate a few genera of bacteria from the thermophilic stage (*Bacillus*, *Clostridium*, and *Thermus*), but many microorganisms remain to be discovered and described. In a properly ventilated composting pile, the temperature will be maintained between approximately 131° and 155 °F. Fortunately, pathogens such as human viruses and infectious bacteria are typically unable to persist in such a hostile environment. The higher temperatures will ensure rapid organic matter processing while simultaneously providing optimal conditions for the destruction of human and plant pathogens as well as weed seeds.

Because the composting pile is cooler on its outer surface, periodic mixing of the outer layer into the pile is essential for maximum pathogen and seed kill. Mixing or turning the pile also helps to ventilate it by increasing the size and number of air pores. This is important because in an unventilated compost pile, the temperatures can exceed 160°F, effectively stopping all microbial activity. The air pores also serve as passages for oxygen to enter the pile. Microbes require oxygen to efficiently break down organic matter.

**Overheating.** If a pile does overheat, surpassing approximately 170°F, most microbes will be

destroyed and microbial activity will virtually cease. Surviving microorganisms are typically those able to survive as *spores*.<sup>\*</sup> The spores will germinate when the composting pile returns to a more favorable temperature. These spores are thick-walled structures that are formed by the microorganism under stress such as heat, cold, drought, and low nutrient conditions.

After overheating, the composting pile will cool to a mesophilic state, requiring the activity of mesophilic microorganisms to return the pile to thermophilic conditions. If the composting pile is low in readily utilizable organic substrates, the pile may not be able to support the microbial activity needed to return to thermophilic conditions. In such a case, it may be necessary to supplement the composting pile with additional feedstock to ensure maximal degradation and pathogen removal.

An overheated composting pile may return to thermophilic temperatures through the germination and activity of spore-forming microorganisms, and through the infiltration of microorganisms from the outer surface of the composting pile where the temperature was less extreme.

**Curing Stage.** A properly functioning composting pile will eventually deplete itself of a majority of the easily degradable organic substrates leaving some cellulose, but mainly lignins and humic materials. Bacteria are generally considered less adept at metabolizing these remaining compounds. Consequently, the bacterial population will decline in numbers as compared to fungi and actinomycetes. Because less heat is generated at this point, the temperature of the composting pile will slowly fall to mesophilic temperatures. With the return of mesophilic conditions, the final curing stage of composting begins.

During the curing stage, the fungi and actinomycete populations predominate, while the bacterial population may decline somewhat. Fungi and actinomycetes proliferate on the remaining less degradable organic matter such as chitin, cellulose and lignin. These compounds are more persistent because they are insoluble in water and, due to their size and chemical complexity, cannot pass into the bacterial cell. Thus, degradation of these compounds requires the use of extracellular enzymes.<sup>\*</sup>

Once the complex organic compounds are broken down into smaller and more soluble forms, they can enter the cell and become food and energy for the microorganism. Microbes able to produce extracellular enzymes suitable for breaking down recalcitrant materials will have a selective advantage at this point in the composting process.

A novel feature of many of the extracellular enzymes common in fungi is that they are capable of breaking down a wide range of compounds that would otherwise require several specific enzymes<sup>\*</sup>, a feature not commonly found in a single microorganism. Fungi, though they grow and reproduce more slowly than bacteria when food is readily available, are well suited for exploiting an environment rich in complex recalcitrant organic compounds like those found in the compost during the curing stage.

The curing process can vary in duration; a longer curing period provides more assurance that the compost is free of pathogens and phytotoxins.<sup>\*</sup> If the compost is incompletely cured (i.e., not stable), it maintains a higher microbial activity, leading to increased oxygen consumption. When unstable compost is applied in the field, it can thereby decrease the supply of oxygen available to plant roots.

In addition, immature compost can contain higher levels of soluble organic matter (i.e., organic acids), which can lead to toxicity problems for certain horticultural applications, such as seed germination. Detailed information on assessing compost stability and maturity is included in the California Integrated Waste Management Board (CIWMB) publication *Compost: Matching Performance Needs with Product Characteristics* listed at the end of this document.

As the curing stage continues, there is a gradual increase in the humus fraction. Humus is a complex class of chemicals that result from the incomplete degradation of organic matter. Humus is among the most resistant compounds to degradation in nature. It is also one of the major mechanisms for the retention of nutrients (e.g., nitrogen, phosphorus) and micronutrients (e.g., copper, zinc, iron, manganese, calcium) in the soil. Because humic compounds retain micronutrients and water so well, they are often the site for the highest biological activity, including microorgan-

isms, protozoans, invertebrates (e.g., worms, springtails) and plants.

### ***The Microbiology of Cured Compost***

**Identifying Compost Microbes.** Compost microbes are tremendously diverse and their ecologies are extremely complex. Methods used to identify individual species include analysis based upon metabolic activity and/or fatty acid content.

However, because of the great diversity, identification of individual species in cured compost is rarely done and is generally considered impractical and extraordinarily expensive. Laboratories, instead, are more likely to identify and count species by organism group, such as actinomycetes, aerobes, anaerobes, fungi, nitrogen-fixing bacteria, or pseudomonads.

Guidelines for desirable levels of each of these microbe groups are listed in the *Compost Quality Standards* document referenced at the end of this fact sheet. A commercial laboratory that specializes in compost analysis developed these levels, which are based on numerous samples and observations in various applications.

New techniques of DNA analysis are providing researchers with additional tools to identify compost and soil microbes. However, this method of identification is in its infancy and is not commonly available in commercial soil labs.

**Inoculating Compost.** Many researchers and companies suggest they can determine the “health” of a compost product and recommend inoculants to improve its quality or performance. However, there is no conclusive evidence that the addition of any specific microorganism to cured compost will improve any characteristic of compost. Native microorganisms may quickly dominate introduced microorganisms. The introduced microorganisms may provide possibly nothing more than additional nutrients to organisms already in the compost. Inoculants, if desired, can be added just prior to application of the compost.

## **Part II: Contributions of Compost to the Soil Food Web and Plant Health**

Many growers think of compost as primarily a source of nutrients to add to the soil. However, its contribution of a diverse set of microorganisms combined with its high levels of organic matter may offer even more significant benefits.

Soil consists of many organic and inorganic components that interact with each other in a dynamic, living system. From organisms as small as bacteria to larger insects such as earthworms, all of these players help cycle nutrients and contribute to the overall health of the soil food web and surrounding plant life.

A quality compost that has been prepared under aerobic conditions and adequately cured can contribute to the health of plants and the soil food web in several ways. Compost introduces a variety of microorganisms that may assist in the cycling of nutrients and in the control of pathogens. Compost also contributes organic matter to the soil that may serve as a source of food for the various microbes, among other functions.

### ***Compost Introduces Beneficial Microorganisms***

When incorporated into soil, compost introduces a wealth of beneficial microorganisms. As discussed in Part I, plant and human pathogens are destroyed during the composting process. The remaining beneficial microbes assist with a number of functions that assist in soil and plant health.

**Nutrient cycling.** To be available to plants, nitrogen must be in an inorganic form, such as nitrate ( $\text{NO}_3^-$ ) or ammonium ( $\text{NH}_4^+$ ). Plants are not capable of converting organic nitrogen to these inorganic forms. Fortunately, microorganisms commonly found in soil and compost convert organic nitrogen into inorganic nitrogen, a process called mineralization. Plants may then take up the nutrients released by these.

Soils that have been exposed to harsh agricultural pesticides, such as methyl bromide, may have reduced populations of these beneficial microorganisms. Compost may help to re-inoculate these soils with nutrient-cycling microbes. It is important to note that inadequately

cured, unstable compost may immobilize nitrogen in soil. Detailed information on assessing compost stability and maturity is included in the CIWMB publication *Compost: Matching Performance Needs with Product Characteristics* listed at the end of this document.

**Disease suppression.** Composts contain an astonishing variety of microbes, many of which may be beneficial in controlling pathogens. Beneficial microbes help to control plant pathogens through either specific or general suppression.

General suppression occurs when a beneficial microbe fills an ecological niche that would otherwise be exploited by a pathogen. For example, a beneficial organism may out-compete a pathogen for energy, nutrients, or “living space,” thereby decreasing the survival of the pathogen.

Specific suppression occurs when a beneficial organism secretes chemicals toxic to a pathogen or when it preys upon the pathogen for food. Many plant pathogens contain cellulose (the principal component of paper) or chitin (commonly found in insects, and fungi), and all contain sugar-polymers (commonly found in all life). Certain compost microorganisms, such as *Gliocladium*, *Pseudomonas*, *Trichoderma*, and *Streptomyces*, produce enzymes capable of breaking these compounds down, killing the pathogens in the process.

Exposure to heat during the thermophilic stage of composting is often responsible for killing plant and human pathogenic microorganisms. This heat also kills those beneficial microorganisms that cannot tolerate the high temperature. Thus for compost to serve as a means for minimizing plant pathogens in the field, it must be re-colonized by beneficial microorganisms.

Commercial compost producers in California do not routinely inoculate their compost. Analysis, when performed, commonly shows that this re-inoculation occurs naturally. However, some studies suggest that controlled inoculation of compost with known biocontrol agents (fungi and bacteria) is necessary for consistent levels of pathogen suppression in the field after application.

**Degradation of pollutants.** Mature compost has been shown to be an effective tool for reducing

organic pollutants in contaminated soils and water. Compost bioremediation has proven effective in degrading or altering many types of contaminants, including chlorinated and nonchlorinated hydrocarbons, solvents, pesticides, and petroleum products. The microorganisms in the compost break down the contaminants into components that pose less of an environmental hazard. The United States Environmental Protection Agency (U.S. EPA) publication *Innovative Uses of Compost: Bioremediation and Pollution Prevention* discusses bioremediation in detail. It is available on the U.S. EPA's Web site listed at the end of this document.

### **Compost Provides a Source of Organic Material**

Soil organic matter can come from a variety of sources, including crop or plant residues, cover crops, and compost. Compost consists primarily of organic matter, which serves a variety of vital functions in the soil:

- **Provides food for microorganisms.** Bacteria and fungi that release nutrients from soil use organic matter as their food or source of energy. Thus, compost provides a source of both microorganisms and their fuel. Compost also provides an excellent habitat for microorganisms.
- **Holds nutrients and water.** In addition to providing a source of nutrients, organic material can hold onto many nutrients through its cation exchange capacity.\* Because compost molecules are negatively charged, they attract and hold onto positively charged ions, such as calcium, potassium, ammonium, and magnesium.
- **Forms aggregates and increases porosity.** Organic matter increases the aggregation of soil that results in a crumb-like structure. Changes in porosity can alter water retention properties and the water infiltration rate. Consequently, consistent compost use may improve irrigation efficiency.

### **Glossary**

*Aerobic*—Requiring oxygen for metabolic processes.

*Cation exchange capacity*—The ability of negatively charged particles to hold positively charged ions (cations) through an electrical attraction.

*Colony*—A microbial population originating from the same cell.

*Extracellular enzyme*—Complex protein structures that degrade organic compounds outside the cell of the microorganism.

*Enzyme*—Commonly a protein that speeds up a chemical reaction or reactions. Lactose intolerant people lack the enzyme lactase, which is used in the chemical reaction of breaking down lactose (a sugar).

*Feedstock*—Starting materials to be composted.

*Humus*—Recalcitrant, highly stable byproducts of organic matter decomposition.

*Mesophilic*—Temperature range of 50–105°F.

*Microorganism*—Bacterium (including actinomycetes) or fungus.

*Phytotoxin*—Chemicals harmful to plant health.

*Propagule*—Any part of a microorganism that can grow and reproduce.

*Recalcitrant*—Relatively resistant to biological, chemical, and/or photodegradation.

*Spore*—A dormant and highly resilient microbial state induced by unfavorable environmental conditions.

*Thermophilic*—Temperature range over 105°F.

## Additional Resources

*Compost: Matching Performance Needs with Product Characteristics*, CIWMB Publication #443-00-005. Available from the CIWMB at (916) 341-6300 and also at [www.ciwmb.ca.gov/Publications/Organics/44300005.doc](http://www.ciwmb.ca.gov/Publications/Organics/44300005.doc).

*Composting Reduces Growers' Concerns About Pathogens*, CIWMB Publication #442-00-014. Available from the CIWMB at (916) 341-6300 and also at [www.ciwmb.ca.gov/Publications/Organics/44200014.doc](http://www.ciwmb.ca.gov/Publications/Organics/44200014.doc).

*Persistence and Activity of Pesticides in Composting*, CIWMB Publication #442-00-015. Available from the CIWMB at (916) 341-6300 and also at [www.w.ciwmb.ca.gov/Publications/Organics/44200015.doc](http://www.w.ciwmb.ca.gov/Publications/Organics/44200015.doc).

*Compost Quality Standards*, Organic Ag Advisors and BBC Laboratories, Inc. Available from the CIWMB at (916) 341-6300.

California Integrated Waste Management Board: [www.ciwmb.ca.gov/Organics/](http://www.ciwmb.ca.gov/Organics/)

Soil Quality Institute's Soil Biology Primer, [www.statlab.iastate.edu/survey/SQI/SoilBiologyPrimer/](http://www.statlab.iastate.edu/survey/SQI/SoilBiologyPrimer/)

U.S. EPA's Bioremediation Fact Sheet, [www.epa.gov/epaoswer/non-hw/compost/bioremed.pdf](http://www.epa.gov/epaoswer/non-hw/compost/bioremed.pdf)

BBC Laboratories, Inc., [www.bbclabs.com](http://www.bbclabs.com), (480) 967-5931.

Soil Foodweb, Inc., [www.soilfoodweb.com/](http://www.soilfoodweb.com/), (541) 752-5066.

**The energy challenge facing California is real.** Every Californian needs to take immediate action to reduce energy consumption. For a list of simple ways you can reduce demand and cut your energy costs, see our Web site at [www.ciwmb.ca.gov](http://www.ciwmb.ca.gov).