Special Compost Issue

COMMON SENSE PEST CONTROL QUARTERLY

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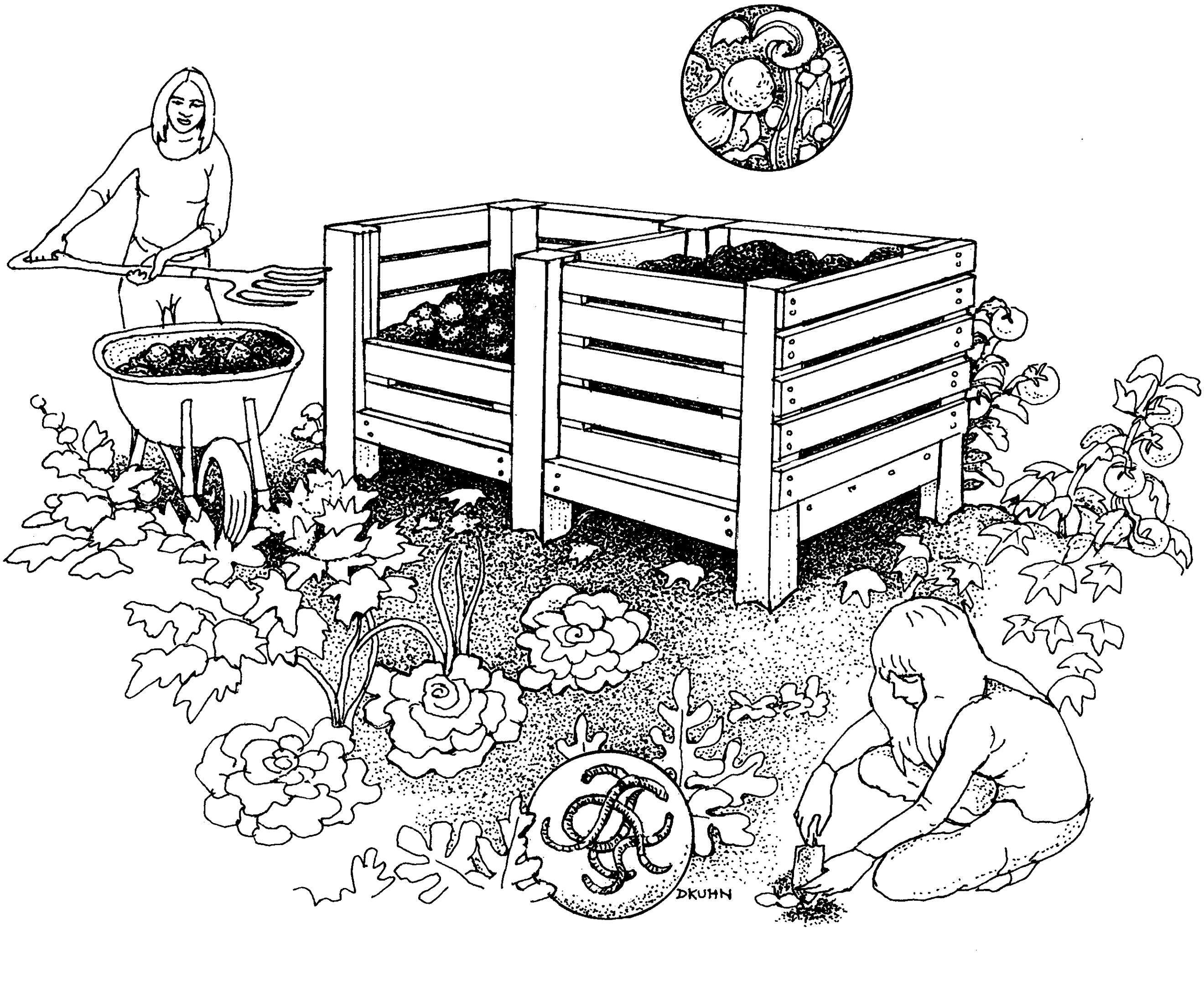
Composts for a Healthy Organic Garden



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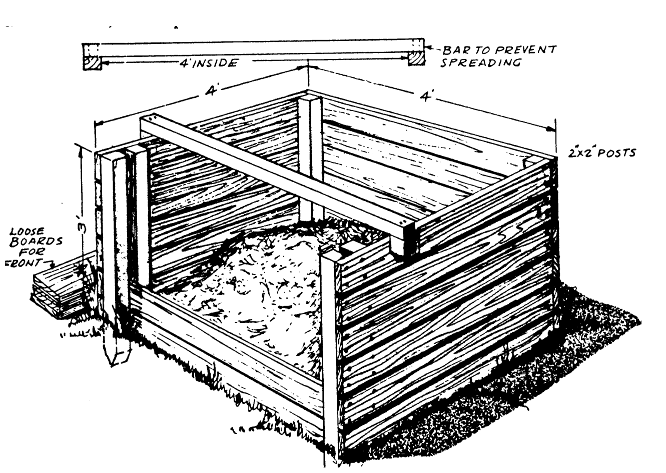
Making a Hot Compost Pile

By William Quarles

If an organic mulch is spread over the top of a garden bed, it slowly decomposes. Since one gram of garden soil contains about 8,000,000 bacteria, 800,000 actinomycetes, 30,000 fungi, 16,000 algae, and 10,000 protozoa, the decomposition process is inevitable (Waksman 1932). In a process called sheet composting, microorganisms will also slowly decompose manure, plant debris and other organic wastes that are incorporated into the top layer of soil. The endpoint of the decomposition is the formation of humus, an organic material that resists further breakdown (Waksman 1938).

These natural processes can be accelerated and controlled if the organic waste is gathered together in the familiar hot compost pile. Hungry microbes swiftly metabolize the organic matter, liberating heat and carbon dioxide. This article reviews the aerobic or thermal composting process, and gives tips on how to produce healthy compost for your garden. Another form of composting, called vermicomposting, where organic matter is digested by worms in bins, will not be discussed here (Appelhof 1997).



This is a compost bin designed by organic farming pioneer Sir Albert Howard. Removable boards in front make it easy to turn compost.

From: Campbell 1975

Making a Compost Bin

Although hot compost can be produced just by piling organic material on the ground, it is better to contain the material in bins to protect it from animals, from rain, and from complaints of neighbors. Many cities in California and elsewhere will supply plastic compost bins to encourage the composting of green waste. You can obtain one by contacting your local recycling center. You can also construct a simple rectangular bin made out of wooden boards. Pioneers of the organic gardening movement Sir Albert Howard and J.I. Rodale have each produced designs for compost bins, and a simple one made of notched boards was recently described in *Fine Gardening* (Reich 2001; Rodale 1955; Campbell 1975).

You must make your compost bin large enough that you are able to turn the compost to provide proper aeration. The ideal compost pile should be at least 3 ft (0.9 m) high when it is assembled, because smaller piles have difficulty retaining heat necessary to kill pathogens and weed seeds. If it is any taller than 6 ft (1.8 m), the pile is harder to turn and may scatter in the wind. As the material composts, expect a 20-60% reduction in the original volume depending on the degree of shredding in the raw material.

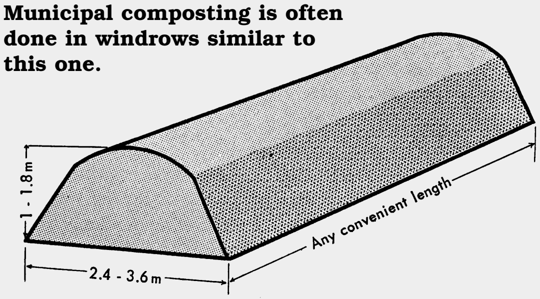
It is important that the bottom of the pile can drain properly and has access to oxygen. Wooden forklift pallets are readily available, and these can be used for the bottom of a compost bin. The pallets have spaces between the boards that allow drainage and access of oxygen. Without aeration from the bottom, the pile will have to be turned more often to prevent anaerobic decomposition (Gotaas 1956).

Alternatively, the compost pile can be built on loosely stacked wooden branches. As the pile heats up, air will be sucked into the pile from the bottom, providing aeration. Some gardeners suggest having two or more bins. The second bin can be used to collect material for composting or to make it easier to turn the material for aeration (Hanson 1997). Commercial tumblers or roller bins are also available that minimize the work needed to turn and aerate the compost (see Resources).

Box A. Municipal Composting

Hot composting probably started with piles of manure. Homer in the Odyssey describes stockpiling of manure for use in agriculture, and the Romans heated vegetable beds with hot compost in the winter (Hanson 1997). George Washington and Thomas Jefferson experimented with compost production, but much of what has led to modern day composting started with Sir Albert Howard in the 1920s. While in India, he developed what is now known as the Indore or Bangalore process. Garbage, manure, plant waste, and other materials were composted in stacks 5 feet (1.5 m) high, or composted in pits about 3 feet (0.9 m) deep. The original method involved turning the piles only twice during a 6-month period. Compost piles of this nature were initially aerobic, but probably decomposed for long periods under anaerobic conditions (Howard 1940; Howard 1947; Gotaas 1956).

Municipal composting is often done in windrows similar to this one.



Many cities in the U.S. and Europe have tried to adapt composting principles to processing of muncipal waste. The Beccari process was patented in 1920. Compost materials are added to an enclosed cell for anaerobic fermentation, then the material is ventilated for a final aerobic stage to remove odors. Compost has been made in silos, and in long rotating cylinders known as biostablizers (Gotaas 1956).

If land is available, composting in windrows is preferred by many ongoing muncipal operations. Compost is stacked in rows about 2.5-3.5 meters (9 ft) wide and about 1-1.8 meters (3-6 ft) high. The tops of the rows are rounded so that water will run off more easily. New compost material is conveniently added at the end of each row. Machines are available that can run alongside the windrow, turning the piles for aeration (Gotaas 1956).

Tree bark is often composted in windrows. For example, piles of bark 2.5 to 3 m (9 ft) high and 4 to 5 m wide (13-16 ft) are left to decompose outside in rows of variable length sheltered by roofs from rain. Temperatures of 40-50°C (104-122°F), moisture contents of 50 to 65% and pHs of 6.5 to 8.5 are maintained. The compost is turned 3 to 5 times over a 4 to 8 month period to make sure the center of the pile is aerated. Pine bark with low cellulose content can be composted within 4 months, hardwood bark can take a year. Ammonia or chicken manure is added as a nitrogen source in aerated windrows. Bark is also sometimes composted in aerated tanks (Hoitink 1980).

Municipal sludge is composted in large tanks at 40-60°C (104°F-140°F) (4x7x150 meters) using wood chips as bulking agents. The sludge must be composted at temperatures of 55°C (131°F)or greater for 3 days to destroy all fecal pathogens. To help maintain high temperatures, perforated floors in the compost tanks are aerated by fans. After batch composting, the sludge is cured in windrows (Hoitink et al. 1984; Kuter et al. 1985).

Muncipal green waste is usually composted in windrows. Grass clippings are usually the nitrogen source. The pH is about 7.7 and initial moisture should be about 60%. Compost temperatures are maintained at 55-65°C (131-149°F) for about 3 months. The compost dries to a final moisture of about 30% (Grebus et al. 1994;1993).

Though compost bins are the best way to produce backyard compost, municipal composting operations use static piles, combinations of anaerobic and aerobic processes, and windrows (see Box A).

Starting Materials

Organic materials such as leaves, grass, manure, kitchen scraps in a compost pile provide rich nutrients for the growth of microbes. Microbes oxidize sugars, cellulose, protein and other sources of available carbon, then use the energy obtained to convert nitrogen in the compost into the structural proteins and enzymes needed for their growth. A quiet pile of compost is really a seething, boiling mass of microbial growth.

To make sure that a hot microbial reaction occurs and that no nitrogen is lost to the atmosphere in the form of ammonia, the starting materials in the compost bin should have the proper ratios of carbon and nitrogen. Experiments conducted early in the 20th century showed that most microbes need much more carbon than nitrogen to sustain their lifestyles. About 2/3 of the carbon is burned to supply energy, and 1/3 is used to build amino acids, proteins and other structural materials such as polysaccharides. For every 30 grams of usable carbon fed the microbes, about 10 grams will become part of their bodies (Gotaas 1956).

The structural carbon to nitrogen (C:N) ratio in the average bacterium is between 4:1 and 6:1; in fungi the ratio is between 5:1 and 15:1; and the ratio for the average soil microorganism is between 5:1 and 8:1 (Waksman 1932; Paul and Clark 1989). Since a lot of carbon is burned for energy and some of it is metabolized very slowly, the ideal ratio of carbon to nitrogen is about 30:1 at the start of composting (Gotaas 1956).

Green and Brown

Barnyard materials and animal manures are high in nitrogen, and much of the compostable materials picked up for disposal in cities are relatively low in nitrogen. If you live in a rural area, you may find that composting manure with straw or crop residues will make a properly balanced compost pile (Gotaas 1956).

To compost in a small backyard garden, proper balance can be reached by combining equal proportions of green waste, which is richer in nitrogen, with brown waste that has less nitrogen. This method works if you include in "greens" fresh leaves or plants, weeds, grass clippings, seaweed, kitchen scraps, pruned vegetation, flowers, coffee grounds, and if possible manure.

"Browns" include dried leaves and plants, straw or hay, pine needles, twigs, newspaper, eggshells, woodchips, fireplace ashes, or sawdust. Make sure that large chunky materials are first chopped into smaller pieces (Hanson 1997). To get compostable sizes from woody prunings, electric and gasoline powered shredders can be purchased (see Resources). You might be able to share the cost of one of these with your neighbors, and shredders can also be rented. Although wooden branches are resistant, a rotary lawnmower can be used to shred weeds, cornstalks, dried up garden plants, and other such items. A list of materials and their C:N ratios are given in Table 1. More complete lists can be found in Campbell (1975), Rodale (1955), and Gotaas (1956).

Unbalanced Piles

What happens if too much carbon is in the compost pile relative to nitrogen? If the nitrogen deficit is really large, the compost pile might not heat up at all. In this case, addition of a rich source of nitrogen such as soybean meal, alfalfa meal, or animal manure might be needed. These items can be purchased at gardening supply stores.

If the pile heats up, but the initial carbon to nitrogen ratio is greater than 30 to 1, the microbes will incorporate all the nitrogen in their bodies before all the available carbohydrate is utilized. Microbe populations will be limited by the scarcity of nitrogen, and the time needed for finished compost will be extended. Many generations of microbes will have to live and die until all the available carbon has been utilized and is stabilized (Gotaas 1956). Unbalanced compost of this sort can have negative effects on plant growth if added to soil before it stabilizes (see Compost-Soil Interactions).

What happens if there is too much nitrogen? Microbes preferentially use carbohydrates as a fuel source. When carbohydrates are not readily available, nitrogen-rich proteins are attacked, and the microbes start turning amino nitrogen into gaseous ammonia, which is lost to the atmosphere. Loss of nitrogen can be avoided by adding more carbon to the pile or by adding more water to hold the ammonia gas as ammonium hydroxide. When a nitrogen-rich compost of this sort is added to soil, there is an immediate fertilizer effect because soluble nitrogen is readily available (see Compost-Soil Interactions) (Waksman 1932; Gotaas 1956).

In properly composted material, carbon is burned by microbes for energy until the C:N ratio is down to about 15. At this point, most of the nitrogen and much of the carbon is contained in the bodies of microbes. Carbon that remains is in a form that cannot be easily metabolized. As the microbes die, the nitrogen in their bodies becomes a slow-release fertilizer when compost is added to the soil. Over time, slow microbial metabolism of carbon compounds drives the C:N ratio downward, until it reaches 10:1, which is the average ratio found in humus (Waksman 1932; Waksman 1938).

Table 1. Carbon-Nitrogen Ratios of Dry Material

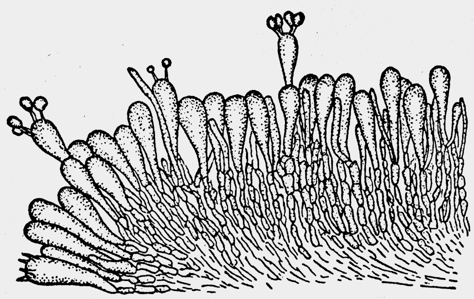
Material	C:N Ratio	% Nitrogen
Bacteria	4-6 (5)	8-13 (10)
Fungi	5-15 (10)	2-7 (5)
Algae	———	7
Insects	———	11-12
Humus	8-12	——-
Finished Compost	15	——-
Compost Start	30	——-
——————	——————	——————
Urine	0.8	15-18
Night Soil	6-10	5.5-6.5
Fish Scrap	——-	6.5-10
Poultry Manure	——-	6.3
Purslane	8	4.5
Young Grass Clippings	12	4.0
Vegetables	11-13	2-4
Grass Clippings	19	2.4
Horse Manure	——-	2.3
Buttercup	23	2.2
Garbage	25	2.1
Seaweed	19	1.9
Cow Manure	——-	1.7
Oat Straw	48	1.1
Paper Pulp	90	——-
Wheat Straw	128	0.3
Rotted Sawdust	208	0.25
Raw Sawdust	511	0.11

Data from Gotaas 1956; Waksman 1932; Baars 2001

Box B. Inactivation of Pathogens and Pesticides

Most pathogens can be killed by the hot composting process. For instance, cucumber green mottle mosaic tobamovirus was inactivated by thermal composting of infected cucumber residues. The virus was below detection levels after 3 days of composting (Avgelis et al. 1992). Small scale aerobic composting will destroy oak root fungus, *Armillaria mellea*, and the wilts caused by *Rhizoctonia solani*, *Verticillium dahliae* and *Sclerotium rolfsii* (Yuen and Raabe 1984).

The most difficult pathogenic fungus to destroy by composting may be *Fusarium oxysporum*, as it is heat resistant. Viruses with high inactivation temperatures, such as tobacco rattle virus are also resistant to heat (Bollen 1985). *Plasmodiophora brassicae* that causes brassica clubroot, and tobacco necrotic virus require 3-4 days at about 55°C (131°F) (Lopez and Foster 1985). *Phytophthora* and *Pythium* can be destroyed by composting (Hoitink et al. 1975).



Pathogens such as the oak root fungus, *A. mellea*, are destroyed by hot composting.

A muncipal green waste operation in Australia was monitored over a 2-year period for the possibility of spreading weeds and pathogens. About 26% of the incoming green waste was composed of weeds. In the first year, 49 of the most serious weed species appeared in the green waste sample. Although conditions in the compost were variable, temperatures of 55°C (131°F) for 3 days eliminated viable weed seeds and a number of pathogens including tobacco mosaic virus, *Plasmodiophora brassicae*, *Sclerotium rolfsii*, *Armillaria* sp., and *Sclerotinia sclerotiorum* (Tee et al. 1999). Moist compost is important, as it is easier to kill moist seeds with heat. Though some seeds, such as black nightshade, *Solanum nigrum*, are more resistant than others, all should be killed by 3 days at 55°C (131°F) (Grundy et al. 1998).

Although most pathogens are destroyed by the composting process, pesticides are not completely removed. Organochlorines are especially resistant, and chlordane has shown up in some municipal composts from contaminated soil of termite treatments. Grass clippings are the source of most pesticide contamination in muncipal composts. However, most of the time composting will reduce concentrations, and composts may even be helpful in reclaiming contaminated soil (Büyüksönmez et al. 1999;2000).

Municipal composts often have pesticide residue levels lower than that seen on food (Büyüksönmez et al. 2000). However, herbicides can be a problem. Recently, commercial compost produced in Pullman, WA and in Austin, TX was contaminated with picloram, a highly persistent herbicide. Gardeners who used this compost were amazed when their plants were injured. Another problem herbicide is clopyralid (Long 2001; Bezdicek 2001).

Composting No-Nos

Do not add meat to an urban compost pile. It will draw pests and possibly release odors. Plastics will be unaffected and should not be added. Colored paper may contain toxic inks. Kitty litter, dog droppings and human waste should not be used because pathogens might not be destroyed if the compost pile does not reach the proper temperatures. Pesticide treated materials should be avoided, especially if you are trying to raise an organic garden. If proper temperatures are reached, diseased plants can be composted. However, some pathogens are easier to destroy with heat than others (Sullivan 2001). (See Box B for heat inactivation of pathogens and pesticides.)

Moisture

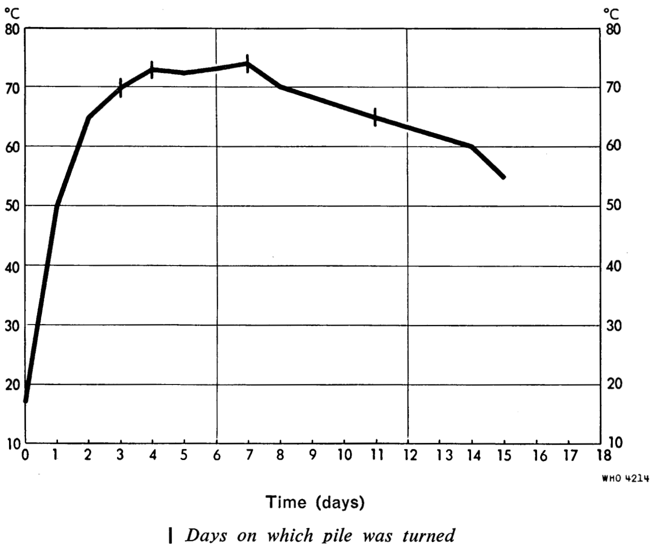
Water should be added as you make your compost pile, to make sure everything is moist. The moisture content for aerobic composting should vary between 40-60%. If the moisture content is too high, water will displace oxygen in the spaces between particles, risking anaerobic conditions. You can do a simple moisture test by grasping a handful of compost and squeezing. If water is easily squeezed out, it is too moist. If it feels moist and stays clumped together, it is about right. If it is dusty and does not hold together after compression, it is too dry. An iron rod or a coat hanger when thrust into the pile should be wet when removed. If the compost contains large amounts of straw, larger percentages of water can be tolerated (Gotaas 1956).

Moisture in the pile is related to the distribution of heat. When moisture content of the pile is high, heat is conducted out nearer to the surface, and the high temperature zone will be closer to the outside of the pile.

Thermal Compost Process

Hot composting is the biological decomposition of organic waste under controlled conditions. The complex molecules in the waste are broken down into simple molecules that can be utilized for plant growth. The microbially controlled process must be aerobic to produce useful compost, and thus oxygen should be readily available throughout the decomposition. There are five phases:

Stages of the hot compost process can be followed by temperature. A quick rise in temperature is followed by a period of sustained high temperature. This is followed by a cooling phase.



From: Gotaas 1956

- Mesophilic induction, where microbials that function well near room temperature (mesophilic) grow quickly, producing heat. Temperatures climb to 45-50°C (115-125°F) within 24 hours.
- Explosive thermophilic growth, where heat-loving organisms produce so much heat that most mesophilic organisms are killed. Temperature rises to 60-70°C (140-160°F) over a period of 1-3 days.
- Thermophilic steady state, where temperatures remain high until most of the cellulose is degraded. During this time, pathogens, weed seeds and nematodes are killed. This period can last a few days or a few weeks according to the amount of material being composted.
- A cooling phase, where temperatures slowly decline, decomposition rates decrease, and mesophilic organisms start to recolonize.
- Finally, there is a compost maturity or curing phase where metabolism slows, and recolonization is nearly complete. This is a continuation of the cooling phase.

The composting process is most readily controlled by regulating heat loss through adjustment of pile composition and size. Products produced are ammonia, carbon dioxide, water and heat (Gotaas 1956; Waksman 1932; Waksman 1938; Waksman 1952; Paul and Clark 1989; Hoitink and Fahy 1986; Hoitink et al. 1991).

The various phases of the composting process can be followed by measuring temperature in the center of the pile as a function of time (see Figure). High temperatures will develop in an aerobic pile, especially if the material is well shredded and moisture content is on the low side. Optimum temperatures for destruction of weed seeds, pathogens and nematodes are 60-70°C (140-160°F). Decomposition rates are higher at higher temperatures and the pile will move more quickly toward stabilization. If temperatures run higher than 180°F (82°C), nutrients will be lost. Watering the pile or turning the pile to cool it will not be effective. An overheated compost pile can be cooled by removing material. After the pile has cooled, material can be added to bring operating temperatures into the correct range (Gotaas 1956).

Monitoring the Compost

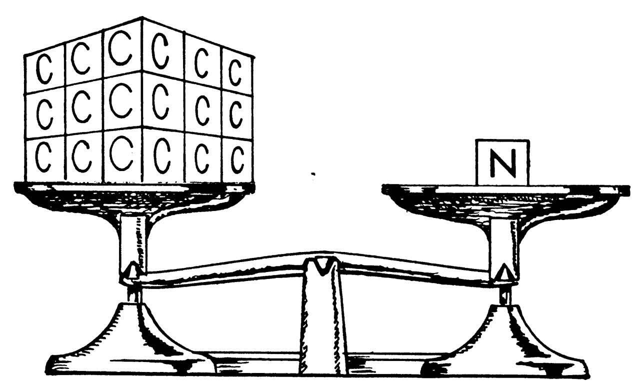
Once the pile is assembled and proper moisture has been added, composting progress and problems should be with monitored with a thermometer and with your nose. A compost thermometer (see Resources) is the best way to follow your compost through the various metabolic stages. If the center of the pile does not reach temperatures of 60-70°C (140-160°F) in 3 days, your pile is too small, there is too much or too little moisture, an inadequate C:N ratio, insufficient nutrients, insufficient oxygen, or a toxin such as a pesticide is present (Gotaas 1956).

If the problem is improper aeration, you might detect foul odors. Also, when you look at the center of the pile the material will have a "pale green color, faintly luminous, that shows little change from day to day," whereas a properly aerobic compost is characterized by a progressively darkening color (Gotaas 1956). Improper aeration is remedied by turning the compost (see below).

If a strong odor of ammonia can be detected, there is too much nitrogen in the pile. It will still make a satisfactory finished compost, but the some of the nitrogen in the pile is being lost. The remedy for this is to add sawdust or other "brown" compost stock or to increase moisture, which will prevent volatilization of the ammonia being produced.

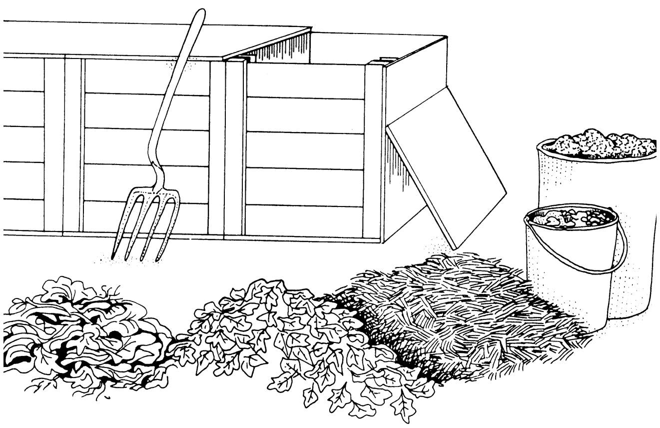
Turning the Pile

Microbes may grow with or without oxygen. In an aerobic environment, where oxygen is present, glucose



From: Campbell 1975

A properly constructed compost pile contains much more carbon than nitrogen. If the pile does not heat, add more nitrogen.



From: Olkowski et al. 1975

Equal amounts of "greens" and "browns" will give a workable compost pile. Use more green if you are making compost for a vegetable garden.

and other energy-rich carbohydrates are oxidized completely. Electron flow from the carbohydrates to oxygen is harnessed to make high energy phosphate (ATP) which drives structural assembly and metabolism of the microbes. Most of the energy produced by animals comes from this kind of chemical reaction. The chemical waste products of composting in an aerobic environment are mainly carbon dioxide and water.

When oxygen is not present or is limited, anaerobic organisms metabolize carbohydrates to lactic, butryic and other organic acids. Other waste products such as methane and hydrogen sulfide are produced (Waksman 1932). These anaerobic products can be toxic to plants, and give the compost an acidic pH. The amount of energy produced is low, and anaerobic piles are slower, cooler, smellier, and can harbor pathogens. For backyard composting, material should be turned often enough to allow oxygen access to the interior of the pile (Gotaas 1956; Waksman 1952).

Proper aeration in a small compost pile can be maintained by turning the compost to expose it to air. A manure fork is an excellent tool for compost turning, although aeration tools are commercially available (see Resources). The compost is turned so that material on the outside ends up toward the center. The pile cools during turning, but then quickly reheats. Piles with more moisture have to be turned more often because water interferes with oxygen diffusion. Turning frequently during the first 15 days leads to the same degree of stabilization as the same number of turns over a longer period of time. Greater aeration initially will lead to quicker stabilization of the compost.

The composting method described in this article is sometimes called the University of California method (Rodale 1960). If piles are properly balanced, materials are shredded and moistened, and piles are turned often for aeration, a finished compost can be made in 14 days. The first turn should be after the 3rd day. For moist piles (60-70%) turn every 2 days thereafter until the compost stabilizes. About 4-5 turns will be needed. With 40-60% moisture, turning every 3rd day up to 3 or 4 turns should be enough. If there is more than 70% moisture, you must turn it every day.

If you are composting by another method, compost piles may need less turning but completion time is longer. If foul odors are emitted when it is disturbed, it is time to aerate. If temperatures drop, and the pile has not stabilized, aeration is probably needed (Gotaas 1956).

Climate

In very cold climates, the size of the pile must be increased to maintain proper composting temperatures. In colder climates, piles have to be turned less often, because it takes longer for microbial heating to restore the proper temperatures. Well shredded material is more resistant to cooling by wind. Large piles with rounded tops are less affected by rain. However, the composting area must have proper drainage to keep water from accumulating around the pile. To keep from losing soluble nitrogen, the compost might have to be sheltered from rain. This is easy to do by just covering the top of the pile with a plastic sheet (Gotaas 1956).

Organic Compost

Although your backyard compost is certainly organic, it is worth mentioning that there are now specific requirements for the production of organic compost. According to the Final Rule of the National Organic Program (NOP 2000), organic compost is "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 (55°C) and 170°F (77°C) for 3 days. Producers using a windrow system must maintain the composting materials between 131°F (55°C) and 170°F (77°C) for 15 days, during which time the materials must be turned a minimum of five times."

Microbe Populations

A compost pile can be a laboratory for the study of soil microbiology. According to Gotaas (1956), "aerobic composting is a dynamic process in which the work is done by the combined activities of a wide succession of mixed bacterial, actinomycetic, fungal, and other biological populations, each suited to a particular environment of relatively limited duration and each being most active in the decomposition of some particular type of organic matter, the activities of one group complementing those of another."

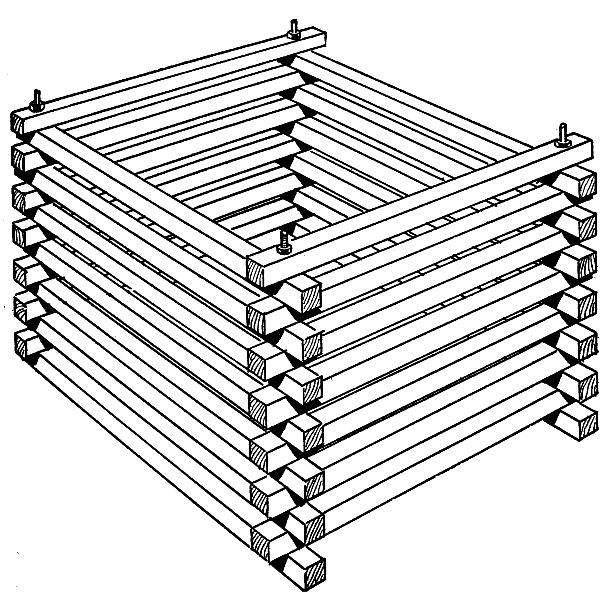
As mentioned earlier, pile oxidation starts with mesophilic bacteria, but these are replaced by thermophilic bacteria as the temperature increases.

Thermophilic fungi show up after about 5 days, and actinomycetes are found during the final stages (Waksman et al. 1939 abc). [Actinomycetes are bacteria that grow in colonies that mimic the growth pattern of fungi.] Fungi and actinomycetes grow at the outer 2-6 inch (5-15 cm) layer of the pile, where it is cooler. Frequent turning of the pile inhibits growth of these fungi. Fungi and actinomycetes are very important in utilizing paper, straw, lignins and other resistant material (Gotaas 1956; Waksman 1932).

Compost will ultimately be used to condition soil, provide slow release fertilizer and provide a rich source of microbials for plant growth. Since trees have slightly different microbial needs than vegetables, composts can be prepared to favor the growth of one kind of crop versus another. Trees and woody ornamentals respond best to fungi in the compost. Fungi are encouraged by straw, bark, leaves and other such "brown" material. Vegetable crops respond better to composts rich in bacteria. Bacteria are encouraged by more "green" material and about 25% of a high nitrogen material such as manure (Ingham 2001; Ingham 2000).

Inoculation

Microbial inoculants should not be needed to start the composting process, since the rotting pile is already teeming with microbes. As the heat sterilized pile begins to cool, however, there is a slow colonization by airborne microbes. At this point in time, inoculation of the compost with *Bacillus subtilis*, *Trichoderma* sp., *Streptomyces* sp. or some other commercially available biocontrol agent might be useful. VAM fungi could also be added at this point (see Quarles 1993; Quarles 1999ab; Quarles 2000) (see Resources).



From: Rodale 1955

This is a compost bin designed by organic gardening pioneer J.I. Rodale. This bin is easy to take apart, and provides good aeration.

Inoculation could make the compost more effective for disease prevention. Suppression of some pathogens such as *Rhizoctonia* spp. requires specific microbial antagonists (see the next article in this issue). Whether or not the right antagonist finds its way into the compost depends partly on where the compost is cured. For instance, Kuter et al. (1983) found that muncipal sludge compost that was cured near a forest area was suppressive to *Rhizoctonia*, but that which was cured away from this source of microbial diversity was conducive. To insure effective colonization by biocontrol agents or to provide a compost with more predictable disease suppressive properties, microbial inoculation might be justified (Grebus et al. 1993; see Quarles and Grossman 1995).

Compost Quality and Maturity

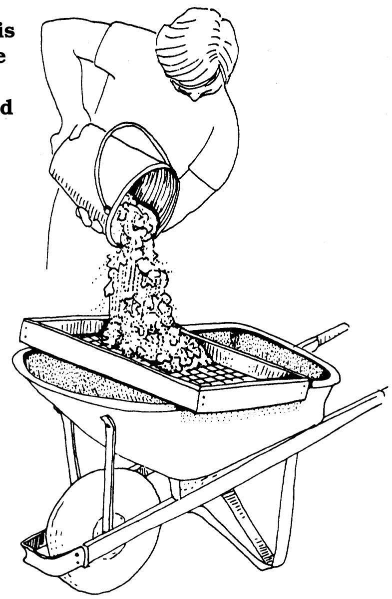
According to composition, amounts, and composting method, the time needed to produce stable compost can range from 3 days to 6 months. Typical for initial C:N ratios of 30 to 1 and backyard composting is about two weeks. The time needed may not be that important as long as all the pathogens are destroyed. The temperature of the compost pile after turning is one sign that the composting process is complete. If the pile does not reheat after turning, all readily available nutrients have been used, and the composting process is nearly complete. However, before it is used for plant growth, it should be be cured for a while by letting it sit in the open air. Finished compost should be grayish black or brownish black with an earthy smell (Gotaas 1956).

Although temperature is a useful guide, there are commercial tests for compost maturity. One test is the Solvita test (see Resources). This test measures amounts of carbon dioxide and ammonia being produced. Low carbon dioxide and low ammonia production correlates with low microbial activity and is one sign of a mature compost.

There are also simple tests for compost maturity. One test is to add wetted compost to a plastic bag, seal it and keep it for a week at room temperature. Bad odors mean the compost has not stabilized. To test for phytotoxicity, you can try to germinate a fast developing seed such as radish in a sample of the compost.

If you are thinking about making compost tea, a mature aerobic compost should be used. If a compost is to be used for disease suppression (see the next article in this issue), it should be newly made but cured by aging in the open air. To help maintain uniform characteristics, it could be inoculated in the cooling phase.

If you want to buy compost, most municipal composting operations will provide quality assurance assays. Look for a pH near neutral, a high cation exchange capacity (CEC), and a compost balanced in amounts of nitrogen, phosphorous and potassium. If you want to have your homemade compost analyzed, BBC Labs or Soil Foodweb (see Resources) will provide these param-



Before compost is used it should be screened to remove rocks and large sticks. Screened compost is a good growth medium for containers.

From Campbell 1975

eters along with the numbers of aerobic or anaerobic bacteria, fungi, actinomycetes, and pseudomonads present. Compost high in pseudomonads tends to be more effective for prevention of plant disease. Composts high in actinomycetes and fungi may be best for thatch control (Dinelli 2000).

Compost and Soil Interactions

If the initial organic material was properly shredded and clean of rocks and big chunks, the finished compost will be mostly a pile of microbes, some active, some dormant, along with carbon sources such as lignins, fulvic and humic acids and other organic materials that microbes have difficulty metabolising (Waksman 1938).

Compost when added to soil slowly becomes humus. Humus typically has a C:N ratio of about 10:1. So a good compost pile starts with a 30:1 C:N ratio, which becomes about 15:1 in finished compost. Carbon is then slowly burned by the remaining microbials in the mature compost until humus is produced (Waksman 1952).

As mentioned earlier, the starting ratio of carbon to nitrogen is critical. If the C:N ratio is too high, all the available nitrogen will be incorporated into the bodies of microbes before the carbon food supply is utilized. If a compost of this sort is applied to soil, the microbes use the excess carbon as energy to draw all available nitrogen out of the soil, and they incorporate this nitrogen into their bodies. This nitrogen is not immediately available to plants, as it has been immobilized in the bodies of the microbes. Plants might even show signs of nitrogen deficiency (Gotaas 1956).

When a properly prepared compost is added to soil, the microbial count is much larger than the soil can sustain. Plants will select the microbials they want by feeding them through their roots with the products of their photosynthesis. The compost then acts as a slow release fertilizer. As some of the starving microbes die, the nitrogen in their amino acids is released as ammonia. The ammonia is either incorporated immediately by plants or is further oxidized to nitrate by soil bacteria (Waksman 1932; Ingham 2000; Ingham 2001).

Conclusion

Composting is a good solution to disposal of table scraps, tree leaves, grass clippings, and garden waste. Composts produced in your backyard can be added to the soil in your organic garden to produce healthier plants. Compost can also be used as part of a container mix for your back porch and backyard flower pots. Proper balance of starting materials, and attention to moisture and aeration are all you will need. The microorganisms will do all the work.

References

Appelhof, M. 1997. *Worms Eat My Garbage*, 2nd ed. Flower Press, Kalamazoo, MI. 162 pp.

Avgelis, A.D. and V.I. Manios. 1992. Elimination of cucumber green mottle mosaic tobamovirus by composting infected cucumber residues. *Acta Hort.* 302:311-314.

Baars, B. 2001. Compost for health. *Organic Farming* 70:30-31.

Bezdicek, D., M. Fauci, D. Caldwell, R. Finch and J. Lang. 2001. Persistent herbicides in

Resources

Bins, Thermometers, Aerators

Aerators—Beckner, 15 Portola Avenue, San Rafael, CA 94903; 415/472-4203; Fax 415/491-0353; Harmony, 3244 Gravenstein Hwy, No. B., Sebastopol, CA 95472; 707/823-9125; Fax 707/823-1734. Peaceful Valley Farm Supply, PO Box 2209, Grass Valley, CA 95945; 530/272-4769; Fax 530/272-4794.

Bins—Peaceful Valley Farm Supply, Harmony see above

Thermometers—Harmony see above, Peaceful Valley Farm Supply see above. BioQuip Products, 17803 LaSalle Ave., Gardena, CA 90248; 310/324-0620, Fax 310/324-7931.

Shredders—Troy Bilt, 102nd St. and 9th Ave., Troy, NY 12180; 800/833-6990; MacKissic, Dept. F101, PO Box 111, Parker Ford, PA 19457; 800/348-1117; Fax 610/495-5951; Gardener's Supply (electric shredder)—128 Intervale Road, Burlington, VT 05401; 800/955-3370.

Tumblers—Harmony Farm Supply, Peaceful Valley see above

Test Kits and Labs

Compost Assays—Soil Foodweb, 980 NW Circle Blvd., Corvallis, OR 97330; 541/752-5066; Fax 541/752-5142; www.soilfoodweb.com. BBC Laboratories, 1217 North Stadem Drive, Tempe, AZ 85281; 480/967-5931, Fax 480/967-5036; www.bbclabs.com. Soil Test Lab, West Experiment Station, North Pleasant St., Univ. of Massachussetts, Amherst, MA 01003.

Maturity Test Kit (Solvita)—Woods End, PO Box 297, Mt. Vernon, ME 04352; 207/293-2457; Fax 207/293-2488; www.woodsend.org

Biocontrol Inoculants

Trichoderma sp.—Bioworks (Rootshield)—122 N. Genesee St., Geneva, NY 14456; 800/877-9443; 315/781-1703; Fax 315/781-1793. Ag Tech Corporation (Plant Helper), 4720 W. Jennifer Ave., Suite 105, Fresno, CA 93710; 559/271-2458, 559/271-2417.

Bacillus subtilis (Serenade)—AgraQuest, 1530 Drew Avenue, Davis, CA 95616; 530/750-0150.

Streptomyces grieseoviridis (Mycostop)—AgBio Development, 9915 Raleigh St. Westminister, CO 80030; 303/469-9221; Fax 303/469-9598.

VAM Fungi—BioOrganics, 53606 Bridge Drive, La Pine, OR 97739; 888/332-7676; Fax 541/536-1583; Plant Health Care, 440 William Pitt Way, Pittsburgh, PA 15238; 800/421-9051.

compost. *BioCycle* July:25

Büyüksönmez, F., R. Rynk, R.F. Hess and E. Bechinski. 1999. Occurrence, degradation, and fate of pesticides during composting. Part I. Composting, pesticides and pesticide degradation. *Compost Sci. and Util.* 7(4):66-82.

Büyüksönmez, F., R. Rynk, R.F. Hess and E. Bechinski. 2000. Occurrence, degradation, and fate of pesticides during composting.Part II. Occurrence and fate of pesticides in compost and composting systems. *Compost Sci. and Util.* 8(1):61-81.

Bollen, G.J. 1985. The fate of plant pathogens during composting of crop residues. In: J.K.R. Gasser, *Composting of Agricultural and other Wastes*, Elsevier, Barking, UK, pp. 282-290.

Campbell, S. 1975. *Let it Rot! The Gardener's Guide to Composting.* Garden Way Publishing, Storey Communications, Pownal, VT. 152 pp.

Dinelli, D. 2000. Composts to improve turf ecology. *IPM Practitioner* 22(10):1-6.

Gotaas, H.B. 1956. *Composting: Sanitary Disposal and Reclamation of Organic Wastes.* World Health Organization, Geneva. 205 pp.

Grebus, M.E., K.A. Feldman, C.A. Musselman and H.A.J. Hoitink. 1993. Production of biocontrol agent-fortified compost-amended potting mixes for predictable disease suppression. *Phytopathol.* 83:1406 (Abstract).

Grebus, M.E., M.E. Watson and H.A.J. Hoitink. 1994. Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and disease suppression. *Compost Sci. and Util.* 2(1):57-71.

Grundy, A.C., J.M. Green and M. Lennartsson. 1998. The effect of temperature on the viability of weed seeds in compost. *Compost Sci. and Util.* 6(3):26-33.

Hanson, B. 1997. *Easy Compost: The Secret to Great Soil and Spectacular Plants.* Brooklyn Botanic Garden, Brooklyn, NY. 111 pp.

Hoitink, H.A.J., A.F. Schmitthenner and L.J. Herr. 1975. Composted bark for control of root rot in ornamentals. *Ohio Report Res. Devel.* 60(2):25-26.

Hoitink, H.A.J. 1980. Composted bark, a lightweight growth medium with fungicidal properties. *Plant Dis.* 64(2):142-147.

Hoitink, H.A.J., G.A. Kuter and C.E. Kipp, Jr. 1984. Optimum process parameters for composting sludge. *Ohio Report* 69(3):35-36.

Hoitink, H.A.J. and P.C. Fahy. 1986. Basis for the control of soilborne plant pathogens with composts. *Ann. Rev. Phytopathol.* 24:93-114.

Hoitink, H.A.J., Y. Inbar and M.J. Boehm. 1991. Status of compost-amended potting mixes naturally suppressive to soilborne diseases of floricultural crops. *Plant Dis.* 75(9):869-873.

Howard, A. 1940. *An Agricultural Testament.* Oxford University Press, London. 243 pp.

Howard, A. 1947. *The Soil and Health: a Study of Organic Agriculture*, Devin-Adair, New York. 307 pp.

Ingham, E.R. 2000. Brewing compost tea. *Kitchen Gardener*: Oct./Nov.:16-19.

Ingham, E.R. 2001. Making compost. www.soilfoodweb.com

Kuter, G.A., E.B. Nelson, H.A.J. Hoitink and L.V. Madden. 1983. Fungal populations in container media amended with composted hardwood bark suppressive and conducive to *Rhizoctonia* damping-off. *Phytopathol.* 73:1450-1456.

Kuter, G.A., H.A.J. Hoitink and L.A. Rossman. 1985. Effects of aeration and temperature on composting of municipal sludge in a full-scale vessel system. *J. Water Pollution Control Federation* 57(4):309-315.

Long, C. 2001. Compost roulette. *Organic Gardening* 48(3):11.

Lopez, R.J. and M. Foster. 1985. Plant pathogen survival during the composting of agricultural organic wastes. In: J.K.R. Gasser, *Composting of Agricultural and other Wastes*, Elsevier, Barking, UK, pp. 291-300.

NOP (National Organic Program). 2000. Final Rule. *Federal Register* 65(246), December 21, 2000.

Olkowski, H., W. Olkowski and T. Javits. 1975. *The Integral Urban House.* Sierra Club Books, San Francisco. 494 pp.

Paul, E.A. and F.E. Clark. 1989. *Soil Biology and Biochemistry.* Academic Press, San Diego. 273 pp.

Quarles, W. 1993. Alternatives to methyl bromide: *Trichoderma* seed treatments. *IPM Practitioner* 15(9):1-7.

Quarles, W. and J. Grossman. 1995. Alternatives to methyl bromide in nurseries—disease suppressive media. *IPM Practitioner* 17(8):1-13.

Quarles, W. 1999a. Plant disease biocontrol and VAM fungi. *IPM Practitioner* 21(4):1-9.

Quarles, W. 1999b. Plant disease biocontrol and ectomycorrhizae. *IPM Practitioner* 21(9):1-10.

Quarles, W. 2000. Least-toxic control of plant diseases. In: B. Hanson, ed. *Natural Disease Control*, Brooklyn Botanic Garden, Brooklyn, New York. 111 pp.

Reich, L. 2001. Making compost. *Fine Gardening* 81:44-47.

Rodale, J.I. 1955. *Organic Gardening.* Hanover House, Garden City, New York. 224 pp.

Rodale, J.I. 1960. *The Complete Book of Composting.* Rodale Books, Emmaus, PA. 1007 pp.

Sullivan, D. 2001. Compost 101. *Organic Gardening* 38(3)36-37.

Tee, E., K. Wilkinson, S. Tymms and V. Hood. 1999. Overview of green waste recycling research conducted by the Institute for Horticultural Development. *Plant Protection Quarterly* 14(3):104-107.

Waksman, S.A. 1932. *Principles of Soil Biology*, 2nd ed. Williams and Wilkins, Baltimore. 894 pp.

Waksman, S.A. 1938. *Humus*, 2nd ed. Williams and Wilkins, Baltimore. 526 pp.

Waksman, S.A., W.W. Umbreit and T.C. Cordon. 1939a. Thermophilic actinomycetes and fungi in soils and in composts. *Soil Sci.* 47:37-61.

Waksman, S.A., T.C. Cordon and N. Hulpoi. 1939b. Influence of temperature upon the microbiological population and decomposition processes in composts of stable manure. *Soil Sci.* 47:83-113.

Waksman, S.A. and T.C. Cordon. 1939c. Thermophilic decomposition of plant residues in composts by pure and mixed cultures of microorganisms. *Soil Sci.* 47:217-225.

Waksman, S.A. 1952. *Soil Microbiology.* John Wiley, New York. 356 pp.

Yuen, G.Y. and R.D. Raabe. 1984. Effects of small-scale aerobic composting on survival of some fungal plant pathogens. *Plant Dis.* 68(2):134-136.

Can Composts Suppress Plant Disease?

By William Quarles

Composts provide organic matter, improve soil structure, supply nutrients, and boost beneficial microbial activity in the soil (Rodale 1955; Hoitink and Grebus 1994). All of these aspects contribute in some degree to disease suppression. For instance, lettuce drop caused by *Sclerotinia minor* was nearly eliminated when compost was added to lettuce fields. In this case, disease suppression was due to improved soil structure (Lumsden et al. 1986). Nutrients present in compost can also strengthen plants, reducing the incidence of disease (Rodale 1955; Menzies and Calhoun 1976).

However, the microbial content of compost may be the key factor in its suppression of plant disease. When added to soil, microbials in composts compete with pathogens for nutrients or act as antagonists, producing antibiotics that destroy the pathogens, or directly attacking them, rendering them ineffective (Quarles 1993; Quarles and Grossman 1995; Hoitink and Grebus 1994).

Disease suppression by composts often depends on the kinds, the numbers, and the metabolic activity of the microbes present. The microbial spectrum and activity depends on how the compost is made, stability or maturity of the compost, and other factors (de Ceuster and Hoitink 1999). Because experimental conditions are easier to control in container growth media, much of the early published work described compost use in container production (Hoitink et al. 1977; Hoitink et al. 1975).

Container Media

Use of compost to replace some of the peat in container mixes spares the natural product peat, and provides a use for resources that would otherwise end up in landfills. The suppressive nature of the product also means that fungicide use can be reduced (see Quarles and Grossman 1995). (See Box A for a description of container mixes.)

Early container experiments showed that composted hardwood bark was suppressive to *Phytophthora* probably due to microbial activity in the compost (Hoitink et al. 1977). The microbial nature of the suppression was subsequently confirmed. These results have been summarized in a number of reviews (Hoitink 1980; Hoitink and Fahy 1986; Hoitink et al. 1991; Hoitink and Grebus 1994; 1997). More than 600 fungal, bacterial, and actinomycete cultures antagonistic to *Pythium ultimum* have been isolated from composted bark (Hoitink 1980). Diseases suppressed are those caused by *Fusarium*, *Pythium*, *Phytophthora*, *Thielaviopsis*, *Verticillium* and other pathogens (Hoitink 1989; Hoitink and Kuter 1985).

Other researchers have found similar results. Pot mixes amended with composted bark were suppressive to Fusarium wilt of radish (Trillas et al. 1986). Addition of 20% bark compost to potting soil infested with *Fusarium oxysporum* reduced mortality of carnations planted in the soil (Filippi and Pero 1989). Composted pine bark suppressed root rot caused by *Phytophthora* spp. in an ornamental planting (Spencer and Benson 1981), but composted hardwood bark was more effective than pine bark (Spencer and Benson 1982). These experiments by Hoitink and others led to commercial use of composted bark in growth media for floricultural crops (Hoitink et al. 1991; Hoitink et al. 1997ab).

Although composted bark is a favorite for container production, composts of yard waste, biosolids, and other materials have also been used (Quarles and Grossman 1995). In India, 5 different composts were used to suppress Fusarium wilt of tomatoes growing in pots. The composts enhanced microbial activity, reduced disease incidence by 44-96%, and reduced mortality by 75-100% (Harender and Kapoor 1997). In another experiment, when pot mixes amended with compost were inoculated with *Pythium*, only 10% of the plants became diseased. Cucumbers planted in the infested potting soil without compost showed 85% infection (Hadar and Mandelbaum 1983).

Composts produced and tested in England from various sources of organic waste suppressed a number of pathogenic species in pot trials. Largest effects were seen with wheat-take-all, *Gaeumannomyces graminis*, and red core of strawberries, *Phytophthora fragariae*. However clubroot of brassicas, *Plasmodiophora brassicae*, and root rot of peas, *Phoma medicaginis* were also suppressed (Pitt et al. 1998).

Composted chicken manure, when incorporated at 25% by volume into a potting mix suppressed root rot, dieback and plant death caused by *Phytophthora cinnamomi* on *Lupinus albus* seedlings. The chicken manure was composted for 5 weeks before incorporation. It contained actinomycetes, fluorescent pseudomonads, fungi, and especially endospore-forming bacteria (Aryantha et al. 2000).

Mechanism of Suppression

Disease suppression of composts depends on the microbial composition of the compost, the composting process, stability or maturity of the compost, quantity of available plant nutrients, loading rates, time of application to soil and other factors (de Ceuster and Hoitink 1999). The type of microbes, microbial competition and antagonism are very important factors (Dinelli 2000; Quarles and Grossman 1995).

The type of microbes present in compost can influence its effectiveness in disease suppression, and is one of the indicators of compost quality. A microbial

Box A. Container Mixes

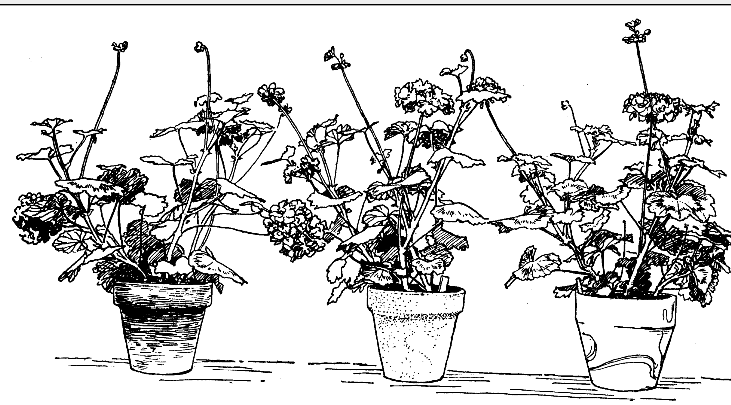
When nurseries became large, centralized businesses, standardization and quality control became an important part of the production method. Partly for this reason, growers moved away from soil for production of container media to use of mixes of various growth media. Container media usually consist of an organic component, such as peat or bark, plus inert elements. The organic component holds moisture and provides cation-exchange capacity. A typical commercial growing medium might contain some combination of sphagnum peat moss, horticultural vermiculite or perlite, composted hardwood or pine bark, shredded polystyrene, composted peanut hulls, sand, and starter fertilizer with trace elements and a wetting agent (Pro-Gro 1995). Since peat moss, like many natural elements, is becoming scarcer and more expensive, the tendency has been to replace it with the less expensive composted material such as bark, municipal green waste, or composted sewage sludge (Hoitink et al. 1991).

Most growers now use a 4:1 (v/v) mixture of composted bark and peat as the organic component of the media. Similar percentages of composted green waste might be used to replace composted bark, but no more than 25% of the organic component should be sewage sludge (Logan et al. 1984). Inert components are used to adjust bulk density and provide air spaces to 15-25% of the total volume (Hoitink 1980).

Peat

Peat is used as a component of container media because of its desirable physical properties and "relatively inert" biological properties. Light peat harvested near the top of peat bogs is rich in antagonists, and is suppressive. In fact, both in North America and in Finland batches of sphagnum peat have been identified that suppress Rhizoctonia and Pythium damping-off and also Fusarium wilt of tomato and other crops. The effect, at least in part, is due to antagonists of these pathogens naturally present in these peat sources. However, the suppressive effect of such peats lasts for up to six to seven weeks only. In theory, the short term nature of suppressive peats makes them particularly attractive for use in plug mixes or in propagation. Such media would not have to be drenched with fungicides during macropropagation and seedling production, thus avoiding potential phytotoxic responses to fungicides on these juvenile plants.

There is also tremendous variability among batches of sphagnum peat in terms of disease suppressive qualities (Hoitink 1989). Dark peat harvested at lower depths is conducive to *Phytophthora*, *Pythium*, *R. solani* and *Fusarium*. Peat can be rendered suppressive by steam sterilization and addition of antagonists, addition of suppressive soil, or addition of suppressive compost (Hoitink and Fahy 1986).



Compost in container media helps suppress disease.

Composts can protect carnation crops against the pathogen *Fusarium* sp.

profile of compost can be obtained by sending samples to laboratories such as BBC Labs or Soil Food Web (see Resources). This profile gives the quantity of aerobic and anaerobic bacteria, fungi, actinomycetes, pseudomonads and nitrogen-fixing bacteria (Bess 1999; Dinelli 2000). Large concentrations of pseudomonad bacteria may be important for disease suppression, and are often specific antagonists. Aerobic bacteria and fungi can effectively compete with pathogens for nutrients (Dinelli 2000). (See Box B).

The microbial composition can vary with the compost starting materials and other factors. For instance, when municipal biosolid compost was compared with brewery sludge, the highest populations of fungi and antibiotic producing actinomycetes were found in brewery sludge compost (Craft and Nelson 1996). Composted biosolids are often high in antagonists such as bacterial pseudomonads (Dinelli 2000).

Competition is greatest in composts with large numbers of microorganisms with active metabolism, but a low concentration of available nutrients. Active competition will effectively suppress *Pythium* spp. damping off (Chen et al. 1988a). For example, *Pythium graminicola* suppression in creeping bentgrass increased with microbial activity of the compost that was applied to turf (Craft and Nelson 1996).

Although microbial activity is a key player in disease suppression, it does not explain some cases of suppression. A turkey litter compost had low microbial activity and low suppression in bioassays, but became suppressive after it was applied in the field. The authors believed that ammonia in the compost slowed microbial activity in bioassays, but the compost became suppressive in the field after the ammonia had dissipated (Craft and Nelson 1996). Erhart et al. (1999) found that microbial activity in their composts did not correlate with *Pythium* suppression. They speculated that the high microbial activity and low suppression was due to compost immaturity.

Maturity of Compost

Maturity of the compost is another factor in disease suppression, but care must be used in interpreting the literature, since different authors have slightly different definitions of maturity. After the hot phase of composting, most of the readily available nutrient sources have been used, and the compost slowly cools. As it cools, it is recolonized by microbials that thrive at moderate temperatures (mesophilic organisms) (Waksman 1932; Gotaas 1956). Once recolonization has occurred, the finished compost can be used to suppress *Pythium* and some other pathogens. Although different researchers use different words, the compost at this point is finished, stabilized, or matured (Hoitink et al. 1997ab; Gotaas 1956; Waksman 1932). As it sits, the compost continues to cure or mature and becomes even more effective as populations of beneficial microbes continue to increase (Chen et al. 1987; Chen et al. 1988ab). Finally, a point is reached where most of the available nutrients have been used, many organisms have gone dormant, and the fully mature compost is well on its way to becoming humus (Waksman 1932). (See Box B).

Composts are most effective for disease suppression in the window of time between recolonization and development of full maturity. For example, composts from brewery sludge or muncipal biosolids were not initially suppressive to *Pythium* sp. but became so as they aged (Craft and Nelson 1996). Compost produced from liquorice roots was not suppressive to Pythium damping off in the thermophilic stage. Suppression occurred only after the compost had aged (Hadar and Mandelbaum 1986). When organic matter was incorporated into soil, populations of *R. solani* and its antagonist *T. hamatum* developed to high levels. As the organic matter aged, the pathogen population dropped (Chung et al. 1988). Composted municipal sludge was initially conducive to *Pythium* and *Rhizoctonia*. However, pot mixes amended with 25% compost

***Brassica* crops with added compost have fewer problems with clubroot caused by *Plasmodiophora* sp.**

Box B. Composts and Biological Control

During the hot phase of composting, most pathogens, as well as many beneficial organisms, are killed. As the temperature cools the compost is recolonized by bacteria and fungi, including both pathogens and antagonists (biological control agents). It is during this "curing" phase of the compost process that compost becomes suppressive to pathogens. Compost is suppressive to *Pythium* spp., *Phytophthora* spp. and other pathogens partly due to competition for the available food supply. Compost at this point contains hundreds of microbial species, many of which are metabolizing nutrients needed for the development of the pathogens. This process is called "general suppression" or "microbiostasis" (Cook and Baker 1983; Chen et al. 1988a; Chen et al. 1987; Hardy and Sivasithamparam 1991; Mandelbaum and Hadar 1990; Boehm et al. 1993). Composted yard waste, composted municipal sludge, in fact most any compost that is properly produced has these qualities (Grebus et al. 1994; Hoitink and Grebus 1994).

General suppression is a kinetic phenomenon. Though full of microbials, compost that has been through the pasteurization phase, but not the curing phase, is not suppressive. The raw compost still contains too much glucose and other easily metabolized products for competition to be important. *Pythium* and *Phytophthora* suppression occurs as the compost matures. At this point, sugars are gone but enough carbohydrates such as cellulose remain to sustain high microbial activity. Hard to metabolize carbohydrates support microbial growth but foster competition. As the compost ages further, a point is reached where all available food is eaten by microbes, and only humic substances incapable of further microbial degradation remain. At this point, when the medium can no longer support microbial growth, suppressiveness is lost (Chen et al. 1988a).

Pythium suppression can be predicted by chemical and physical assays. Suppression occurs when there is an abundance of microbial activity in the midst of a relatively difficult food supply (cellulose). Microbial activity can be monitored by an enyzme assay measuring hydrolysis rates in the compost (see Resources). The amount of available food left in the compost can be measured by a nuclear magnetic resonance technique (Chen et al. 1988b; Inbar et al. 1989).

Use of these sophisticated assay techniques have been especially useful in predicting the suppressive characteristics of different kinds of commercial peat. Light peat is harvested near the surface, shows high microbial activity and is suppressive to *Pythium*. Dark peat, harvested lower in the ground, has little microbial activity because most of the available food supplies are depleted. As the decomposition level and food supply changes, so do the associated microbes. Light peat has higher levels of pseudomonads, dark peat higher levels of *Bacillus* spp. (Boehm et al. 1993). These assays can also predict how long a substrate will remain suppressive. Light peat seldom remains suppressive for more than a few weeks because after this time the "carrying capacity" of the compost is exceeded. All the available carbohydrates are gone, leaving humic substances stable to further degradation (Hoitink et al. 1991; Boehm and Hoitink 1992; Boehm et al. 1993).

Specific Antagonists

Some pathogens such as *Rhizoctonia* spp. are not stopped by competition and general suppression, and require the presence of a specific microbial antagonist in the compost. Whether or not the right antagonist finds its way into the compost depends partly on where the compost is cured. For instance, muncipal sludge compost that was cured near a forest area was suppressive to *Rhizoctonia*, but that which was cured away from this source of microbial diversity was conducive (Kuter et al. 1983).

During the curing phase many composts in an open environment are colonized by antagonists such as *Bacillus* spp., *Enterobacter* spp., *Flavobacterium balustinum*, *Pseudomonas* spp., *Streptomyces* spp., *Trichoderma* spp. and *Gliocladium virens* (Chung and Hoitink 1990; Hardy and Sivasithamparam 1991; Hoitink and Fahy 1986; Phae et al. 1990; Hoitink et al. 1991). The most important *Rhizoctonia* antagonists isolated from lignocellulosic wastes are *Trichoderma* spp., including *T. hamatum* and *T. harzianum* (Kuter et al. 1983; Nelson et al. 1983). These biocontrol agents interact with a number of bacterial species to suppress Rhizoctonia damping-off and Fusarium wilt (Kwok et al. 1987; Alabouvette 1990; Grebus et al. 1993).

Antagonists Plus Maturity

Mere presence of a known antagonist in the compost, however, does not automatically mean *Rhizoctonia* suppression (Chung and Hoitink 1990). Specific suppression is also dependent on the age of the compost. For instance, raw compost emerging from the pasteurization phase has overabundant nutrients. Antagonists such as *Trichoderma* sp. utilize the food supply in the compost and grow saprophytically (Nelson et al. 1983). As the compost matures, and the available carbohydrates are metabolized, *Trichoderma* begins to "starve." At this point it becomes a hyperparasite, secreting lytic enzymes and attacking *Rhizoctonia* (Chen et al. 1988a). Mature compost that contains the proper antagonists, then, is suppressive to *Rhizoctonia* and *Fusarium*, as well as *Pythium* and other pathogens (Hoitink and Grebus 1994).

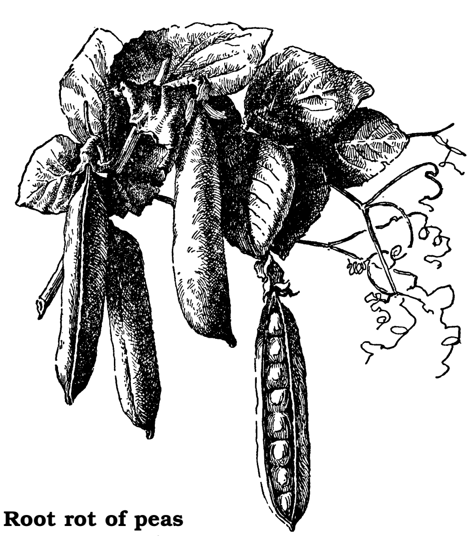
Table 1. Diseases Controlled by Composts*

Pathogen	Disease	Crop	Site	Compost	Reference
?	leafspot	peanuts	field	various	Choi et al. 1988
Aphanomyces sp.	root rot	peas	containers	manure	Walter et al. 1995
F. oxysporum	Fusarium wilt	carnations	containers	bark	Filippi and Pero 1989
Fusarium	Fusarium wilt	radish	containers	bark	Trillas et al. 1986
Fusarium	wilt	Chinese yam	field	compost bark	Hoitink and Kuter 1985
Fusarium	wilt	cucumber	greenhouse	mushroom	Seo et al. 1986
Fusarium	wilt	pigeonpea	field	compost	Goudar et al. 1998
Fusarium oxysporum	root rot	cucumbers	containers	dairy solids	Kannanagara et al. 2000
Fusarium udum	pigeonpea wilt	pigeonpea	field	neemcake	Goudar et al. 1998
Fusarium wilt	Fusarium wilt	tomato	containers	various	Harender and Kapoor 1997
Gaeumannomyces graminis	wheat take all	wheat	containers	organic waste	Pitt et al. 1988
Phoma medicaginis	root rot	peas	containers	organic waste	Pitt et al. 1988
Phytophthora	rot	flowers	containers	hardwood bark	Hoitink et al. 1977
Phytophthora	root rot	ornamentals	landscape	bark	Spencer and Benson 1981
Phytophthora cinnamomi	root rot	lupin	containers	chicken manure	Aryantha et al. 2000
Phytophthora cinnamomi	rot	lupin, cucumber	field	green waste	Tuitert et al.1996
Phytophthora fragariae	red core	strawberry	containers	organic waste	Pitt et al. 1988
Phytophthora fragariae	rot	raspberry	field	various	Neuweiler et al. 2000
Phytophthora infestans	late blight	potatoes	greenhouse	------	Clulow et al. 1995
Phytophthora sp.	rot	tomato	field	compost	Workneh et al. 1993
Plasmodiophora brassicae	clubroot	brassicas	containers	organic waste	Pitt et al. 1988
Pythium	root rot	cucumbers	containers	various	Hadar et al. 1983
Pythium	root rot	various	containers	green waste	Schueler et al.1989 a
Pythium	root rot	peas	field	green waste	Erhart et al. 1999
Pythium sp.	rot	sugarcane	field	cotton trash	Dissanayake and Hoy 1999
Rhizoctonia	rot	flowers	containers	biosolids	Kuter et al. 1988
Rhizoctonia	rot	cucumbers	containers	green waste	Tuitert et al.1998
Rhizoctonia solani	rot	peas, beets, beans	containers	green waste	Schueler et al. 1989b
Rhizoctonia sp.	wilt	bean	field	compost	Logsdon 1993; Ozores-Hampton al. 1994
Sclerotinia minor	lettuce drop	lettuce	field	biosolids	Lumsden et al. 1986
Sclerotinia sp.	dollarspot	turf	golfcourse	various	Nelson and Craft 1992
Soft Rot	soft rot	onion	field	various	Navarro and Umana 1997; Maynard and Hill 2000
Various	various	cucumbers and peppers	field	biosolids	Hoitink et al. 1991
Verticillium dahliae	early dying	potato	field	mushroom	La Mondia et al. 1999

***This is a partial list**

became suppressive after storage for another 4 week period (Kuter et al. 1988).

Hointink et al. (1997ab) believe that immature composts are not effective for disease suppression and may even stimulate the growth of pathogens. Composts must not be allowed to age too long, however. Widmer et al. (1998) found that only freshly prepared samples of composted municipal waste were able to suppress *Phytophthora nicotianae* in the soil of 5-week old citrus seedlings. Incidence of infection was reduced from 95% to as low as 5%. Material that was aged more than 3 months before use was not effective.



Root rot of peas caused by *Aphanomyces* sp. is suppressed by compost.

When various animal manures were composted with leaves, the resulting composts were suppressive to damping off from *Pythium* and *Rhizoctonia*. Composts from dairy manure were more effective than those from horses or from chickens. There was no correlation between compost age and disease suppression (Ringer et al. 1997). These composts were probably all used in the period between recolonization and microbial dormancy seen at full maturity, so no age effect was noted.

Ineffective Against *R. solani*

Though many properly prepared composts will suppress *Pythium* and other pathogens, *Rhizoctonia solani* poses a more difficult problem. In China, 3 commercial composts from mushroom culture and paper waste suppressed Fusarium wilt of watermelon, cabbage clubroot, root-knot nematodes on watermelon, tomato and pepper, and Pythium root rot of tomato and watermelon. These composts were unable to suppress Rhizoctonia damping off (Chiu and Huang 1997).

High microbial activity in a compost is a necessary, but not sufficient condition for suppression of *Rhizoctonia* sp. In addition, the presence of a specific antagonist such as *Trichoderma* spp. may be needed (Kuter et al. 1983; Nelson et al. 1983).

Inoculation with Antagonists

Inoculation of compost made from grass clippings with *Bacillus subtilis* increased suppressiveness to *Rhizoctonia solani* that causes large-patch disease in turfgrass. Pasteurized compost was inoculated at 40°C (104°F), leading to *B. subtilis* concentrations of 10^8 cfu/gram of compost (Nakasaki et al. 1998; Nakasaki et al. 1996).

Hoitink et al. (1997ab) were able to produce a more reliably suppressive compost by using the inoculants *Flavobacterium balustinum* and *Trichoderma hamatum*. In another experiment, *Trichoderma viride* was used as an inoculant in coconut coir pith compost. The inoculated compost reduced damping off by *Rhizoctonia solani* by 95% in field tests of eucalyptus plantings (Kumar and Marimuthu 1994).

Citrus reshni grown in pot mixes was monitored for effects that the various mixes had on growth and disease suppression. Inoculation of composted pine bark with *Trichoderma aureoviride* and with the VAM fungus *Glomus intraradices* produced the largest positive effects on growth and disease suppression. Inoculation of a mixture of sand, perlite, and peat also produced increased growth (Camprubi et al. 1995). Biocontrol inoculants and VAM fungi are commercially available (Quarles 1999)(see Resources).

Additives

Sometimes additives can make compost even more effective in disease suppression. Chitin from shrimp and crab shells when added to soil stimulates the enzyme chitinase. Chitinase then attacks pest nematodes and pathogenic fungi. Roy et al. (1997) prepared a two-phase compost with chitin. First, they composted peat moss, sawdust and cow manure through the thermophilic phase. As the compost started to cool, 30% shrimp waste was added, which triggered a further thermophilic compost phase.

Additives are also sometimes used to improve composting performance. When a compost pile does not heat up properly, it might need addition of nitrogen. Soybean meal or other organic fertilizer can be used (Reich 2001; Gotaas 1956).

Type of Compost

The kind of compost can be a factor in disease suppression. In one experiment, dairy solids were composted either by windrow or vermicomposting. Flower pots amended with these composts were planted with cucumber and inoculated with the pathogen *Fusarium oxysporum* that causes root and stem rot. Compost produced by the windrow method suppressed cucumber disease symptoms, but vermicompost did not. [Vermicompost is castings and organic waste of a worm colony.] Since the same waste was used in both cases, the authors concluded that the method of composting must have an effect on disease suppression (Kannangara et al. 2000).

Composts stop soft rot of onion better than fungicides.

Composts made either from muncipal sludge or from fallen leaves were

Table 2. Diseases Suppressed by Compost Extract (Tea)*

Pathogen	Disease	Crop	Reference
?	downy mildew	cucumber	Ma et al. 1996
Alternaria sp.	early blight	tomato	Tsror and Bieche 1999
Botrytis sp.	gray mold	bean	McQuilken et al. 1994
Botrytis spp.	gray mold	beans, strawberries	Weltzien 1990
Botrytis spp.	gray mold	tomato, pepper	Elad and Shtienberg 1994
Botrytis spp.	gray mold	various	Ketterer et al. 1992
Colletotrichum sp	anthracnose	cucumber	Zhang et al. 1998b
Erysiphe polygoni	powdery mildew	bean	Ketterer and Schwager 1992
Erysiphe sp.	powdery mildew	barley	Budde and Weltzien 1988
Erysiphe sp.	powdery mildew	barley, sugar beet	Weltzien 1989
Leveillula taurica	powdery mildew	tomato	Elad and Shtienberg 1994
Phytophthora infestans	blight	tomato, potato	Weltzien 1990; 1989
Phytophthora infestans	blight	tomato	Ketterer and Schwager 1992
Plasmopara viticola	downy mildew	grape	Weltzien et al. 1987; 1989
Pseudomonas sp.	bacterial speck	Arabidopsis	Zhang et al. 1998a
Pseudopeziza sp.	leaf blight	grape	Weltzien 1989
Sphaerotheca sp.	powdery mildew	cucumber	Ma et al. 1999; Weltzien 1989
Uncinula necator	powdery mildew	grape	Weltzien 1989

*This is a partial list.

suppressive to cucumber damping off caused by *Pythium* spp. Compost from leaves was effective at 80 mg/cm3 whereas composted sludge was effective at half that rate. The different composts had different thermal profiles. The leaf compost was more suppressive against *Pythium* at higher temperatures, 28-32°C (82-90°F). The composted sludge was more effective at 20-24°C (68-75°F)(Ben-Yephet and Nelson 1999). Composts containing manure were more suppressive to Aphanomyces root rot of peas than those produced from tree bark (Walter et al. 1995).

Potatoes grown in a greenhouse in wet compost were more resistant to late blight than those grown in dry compost. Tubers grown in the wet compost had larger numbers of bacteria on the surface. About 17% of the bacterial isolates were antagonistic to the late blight pathogen, *Phytophthora infestans* (Clulow et al. 1995).

Household Waste

Many readers of *Common Sense Pest Control Quarterly* are interested in small-scale composting of kitchen, yard and garden waste. Composts from these sources can be effective in preventing plant diseases in the garden. Hot garden compost is also a convenient way of getting rid of weeds and pathogens that can be easily deactivated by heat. However, results are sometimes inconsistent because there are no uniform standards on compost production (see Quarles and Grossman 1995).

Composted household waste in pot experiments effectively suppressed diseases caused by *Pythium ultimum* or *Rhizoctonia solani* in a number of plants (Schueler et al. 1989a). However, experiments in Austria showed that of 17 composts made from household waste, only 9 were suppressive to *Pythium* in pea production. The majority of the samples were mildly phytotoxic to cress. Microbial biomass, and other measures of microbial activity did not correlate with suppression. These composts may have been tested before they had matured (Erhart et al. 1999).

Mature compost from house and garden waste when added to potting soil suppressed the effects of the pathogen *Rhizoctonia* in cucumbers (Tuitert et al. 1998). In pot experiments, composted household waste controlled soilborne diseases of peas, beans, and beetroots caused by *R. solani* and *P. ultimum* (Schueler et al. 1989b).

Tuitert and Bollen (1996) found that composts prepared from vegetable, fruit and garden waste was suppressive to *Phytophthora cinnamomi*. However, only long-matured compost was suppressive to *Rhizoctonia*. As the compost sits, the likelihood of antagonist growth in the compost increases. The test plants were lupin and cucumber.

Field Soil

Although much of the published information on suppressive composts comes from container experiments, composts can help prevent plant diseases in field soils also. In Connecticut, application of 1-inch of compost to fields each year over a 3-year period led to larger onions, larger yields of onions, and a lower incidence of soft rot disease (Maynard and Hill 2000). In Costa Rica, compost applied at 25 tons/acre was more effective than the fungicides captan and benomyl or 4 weeks of solarization in preventing soilborne rot of onion seedlings (Navarro and Umana 1997).

Addition of 10% compost to topsoil infested by *Phytophthora fragariae* var. *rubi* increased the health of young raspberry plants, increasing cane lengths by 128%. These effects were not seen with sterilized compost, and effects were probably due to microbial activity. Over a 3-year period composts applied in the spring and fall gave plants where the number of disease free canes were 97% higher than untreated controls (Neuweiler et al. 2000).

Raspberry yields were increased in fields infested by *Phytophthora* sp.

Composted trash from cotton gins, filterpress cake, and biosolids suppressed disease caused by *Pythium arrhenomanes* and increased the growth of sugarcane. Level of microbial activity correlated with degree of suppression (Dissanayake and Hoy 1999). Composted sugarcane residues were also effective (Theodore and Toribio 1995)

Spent mushroom compost was added to potato fields infested with *Verticillium dahliae* or *Pratylenchus penetrans*. These pathogens cause potato early dying and typically depress yields 22-44%. Compost application resulted in increased yields of marketable potatoes (La Mondia et al. 1999).

Topdressings of sand and compost (70:30) applied to putting greens of creeping bentgrass and annual bluegrass effectively suppressed dollarspot caused by *Sclerotinia homoeocarpa* for at least 1 month. Applied monthly as a preventive over a 3-year period, results were comparable to use of the fungicide propiconazole (Nelson and Craft 1992).

Substitution of compost for inorganic fertilizers reduced disease in cucumbers and peppers during two consecutive seasons in the U.S. (Huelsman and Edwards 1998). A combination of solarization and composting gave better disease suppression in California than solarization alone (Gamliel and Stapleton 1993).

Deep tillage and addition of compost plus magnesium lime increased the yield of peanuts in a field operation, mainly due to suppression of leaf spot disease. The combined treatment increased the bacteria:fungi and the actinomycetes:fungi ratios (Choi et al. 1988).

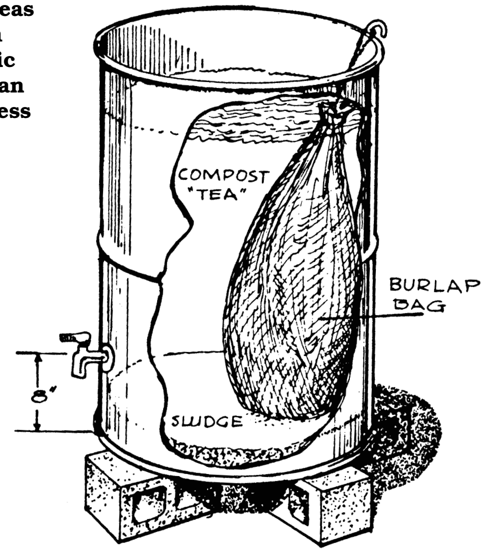
Effects are not always clearcut. Composted sewage sludge worsened *Fusarium* on carnations and pea and *Thielaviopsis* of bean, though it decreased *Fusarium* on cucumber and *Phytophthora* on pepper and soybeans (Hancock 1994; Isakeit et al. 1991; 1992; Lumsden et al. 1983; Logsdon 1993). *Rhizoctonia* has been suppressed in field-grown beans (Logsdon 1993; Ozores-Hampton et al. 1994). Workneh et al. (1993) showed that organic farms using compost had less *Phytophthora* and tomato corky root disease than conventional farms that did not use compost. Composted pine bark controlled *Fusarium* on Chinese yam in field soil as well as methyl bromide (Hoitink and Kuter 1985; Hoitink 1980). Soil amendents of mushroom compost and chicken manure reduced Fusarium wilt of cucumber by 30-35% in greenhouse tests (Seo 1986). Fusarium wilt of basil, flax, and eggplant was also suppressed by compost (Raviv et al. 1998; Serra et al. 1996; Sheela et al. 1995).

In India, pigeonpea wilt caused by *Fusarium udum* was best suppressed by a soil amendment of neemcake. Compost was the next most effective soil amendment (Goudar et al. 1998). Composted sewage sludge, when added to soil of lettuce fields reduced the incidence of lettuce drop caused by *Sclerotinia minor*. Survival of the pathogen and pathogen populations were unaffected. Disease suppression in this case was probably due to improved soil structure produced by the compost (Lumsden et al. 1986).

Compost Tea

Water extracts of properly prepared aerobic compost are also suppressive to disease (see Quarles 2000). [Note: More complete information on compost teas will follow in a later article.] Effects are probably due to a combination of added nutrients and microbials (Riggle 1996; Ingham 2001). For example, extracts of compost effectively suppressed grey mold on beans and strawberries and blight of tomatoes and potatoes caused by *Phytophthora infestans*. Addition of selected microbes to the extracts improved their efficacy (Weltzien 1990). Compost tea when sprayed on the primary leaves of barley gave a further reduction of powdery mildew over that seen with compost soil amendments (Budde and Weltzien 1988).

Compost teas made from hot, aerobic compost can also suppress diseases.



Lab and greenhouse experiments showed that compost teas reduced blight caused by *Phy. infestans* on potato and tomato, mildews of sugarbeets and barley caused by *Erysiphe* spp., gray mold of bean, *Botrytis fabae*; and grape disease caused by *Plasmopara viticola* (Weltzien et al. 1987).

Extracts of composted cattle manure and from grape waste were tested in growth chamber experiments for suppression of grey mold on tomato and pepper plants. After fermentation for at least 10 days, the extracts reduced disease by 56-100%. The extracts also suppressed powdery mildew of tomato, *Leveillula taurica*. Addition of nutrients to the fermenting mass did not improve disease control (Elad and Shtienberg 1994).

Resources

Test Kits and Labs

Compost Assays—BBC Laboratories, 1217 North Stadem Drive, Tempe, AZ 85281; 480/967-5931, Fax 480/967-5036; www.bbclabs.com

Compost Assays—Soil Foodweb, 980 NW Circle Blvd., Corvallis, OR 97330; 541/752-5066; Fax 541/752-5142; www.soilfoodweb.com

Maturity Test Kit (Solvita)—Woods End, PO Box 297, Mt. Vernon, ME 04352; 207/293-2457; Fax 207/293-2488; www.woodsend.org

Biocontrol Inoculants

Trichoderma sp.—Bioworks (Rootshield)—122 N. Genesee St., Geneva, NY 14456; 800/877-9443; 315/781-1703; Fax 315/781-1793. Ag Tech Corporation (Plant Helper), 4720 W. Jennifer Ave., Suite 105, Fresno, CA 93710; 559/271-2458, 559/271-2417.

Bacillus subtilis (Serenade)—AgraQuest, 1530 Drew Avenue, Davis, CA 95616; 530/750-0150.

Streptomyces grieseoviridis (Mycostop)—AgBio Development, 9915 Raleigh St. Westminister, CO 80030; 303/469-9221; Fax 303/469-9598.

VAM Fungi—BioOrganics, 53606 Bridge Drive, La Pine, OR 97739; 888/332-7676; Fax 541/536-1583; Plant Health Care, 440 William Pitt Way, Pittsburgh, PA 15238; 800/421-9051.

Compost Tea Equipment

Growing Solutions, 160 Madison St., Eugene, OR; 888/600-9558; 541/343-8727; Fax 541/343-8374, www.growingsolutions.com. Peaceful Valley Farm Supply, PO Box 2209, Grass Valley, CA 95945; 530/272-4769; Fax 530/272-4794.

When compost teas were produced and tested as sprays against grey mold, effectiveness varied with the length of extraction. The best results, 90-95% suppression, came with an 8-day extract. The largest number of bacteria in the extract were found after 7 days. Extracts mixed with 0.5% casein and 0.05% pine needle oil were just as effective as chemical fungicides (Ketterer et al. 1992). In another experiment, 7-day extracts with 0.5% casein controlled powdery mildew of bean, *Erysiphe polygoni* and tomato blight, *Phytophthora infestans*, just as well as sulfur or the fungicide propineb (Antracol™)(Ketterer and Schwager 1992).

Extracts of horse, pig and cow manure suppressed powdery mildew of cucumber (Ma et al. 1999). Extracts from composted horse or cow manure gave good control of downy mildew when sprayed on cucumber under greenhouse conditions. Disease suppression was about 66-67%. The effect may not have been due directly to microbials, as sterilized extracts of composted horse manure were more effective (Ma et al. 1996).

Compost and compost extracts triggered systemic acquired resistance in *Arabidopsis thaliana* plants against bacterial speck caused by *Pseudomonas syringae* (Zhang et al. 1998a). The same materials induced resistance in cucumber against anthracnose caused by *Colletotrichum orbiculare*. Heating destroyed the effects of the compost, but inoculation of the sterilized compost by unheated compost restored activity. This effect suggests that protection was microbial in nature (Zhang et al. 1998b).

In field tests, 'Brigade' tomatoes were inoculated with *Alternaria solani*, which causes early blight. After inoculation tomatoes were sprayed with compost extracts, and the results were compared to sprays of the fungicide metalaxyl. A compost tea that had been soaked in compost for 14 days gave disease suppression comparable to metalaxyl. An average yield increase of 20.9% was seen with metalaxyl and 19.9% with compost extract. A 7-day compost extract was not quite as effective, showing a yield increase of 13.9% (Tsror and Bieche 1999).

Conclusion

Properly made aerobic composts can suppress plant diseases in containers, gardens and field soils. Disease suppression comes through improved soil structure, added nutrients, and microbial activity. Microbial composition and maturity of the compost are important factors. Suppression of some pathogens may require inoculation of the compost with commercially available biocontrol agents.

References

Alabouvette, C. 1990. Biological control of *Fusarium* wilt pathogens in suppressive soils. In: Hornby, p. 27-43.

Aryantha, I.P., R. Cross and D.I. Guest. 2000. Suppression of *Phytophthora cinnamomi* in potting mixes amended with uncomposted and composted animal manures. *Phytopathol.* 90(7):775-782.

Ben-Yephet, Y. and E.B. Nelson. 1999. Differential suppression of damping-off caused by *Pythium aphanidermatum*, *P. irregulare* and *P. myriotylum* in composts at different temperatures. *Plant Dis.* 83(4):356-360.

Bess, V. 1999. Evaluating microbiology of compost. *BioCycle* 40(5):62-64.

Boehm, M.J. and H.A.J. Hoitink. 1992. Sustenance of microbial activity in potting mixes and its impact on severity of *Pythium* root rot on poinsettia. *Phytopathol.* 82:259-264.

Boehm, M.J., L.V. Madden and H.A.J. Hoitink. 1993. Effect of organic matter decomposition level on bacterial species diversity and composition in relationship to *Pythium* damping-off severity. *Appl. and Environmental Microbiol.* 4171-4179.

Budde, K. and H.C. Weltzien. 1988. [Phytosanitary effects of compost extracts and substrates in the host pathogen system barley-powdery mildew]. *Med. Facul. Landbouwweten. Rijksuniv. Gent* 53(2a):363-371. [CAB Abstracts]

Camprubi, A., C. Calvet and V. Estaun. 1995. Growth enhancement of citrus reshni after inoculation with *Glomus intraradices* and *Trichoderma aureoviride* and associated effects on microbial populations and enzyme activity in potting mixes. *Plant and Soil* 173(2):233-238.

Chen, W., H.A.J. Hoitink and A.F. Schmitthenner. 1987. Factors affecting suppression of *Pythium* damping-off in container media amended with composts. *Phytopathol.* 77:755-760.

Chen, W., H.A.J. Hoitink, A. F. Schmitthenner and O.H. Tuovinen. 1988a. The role of microbial activity in suppression of damping-off caused by *Pythium ultimum*. *Phytopathol.* 78:314-322.

Chen, W., H.A.J. Hoitink and L.V. Madden. 1988b. Microbial activity and biomass in container media for predicting suppressiveness to damping-off caused by *Pythium ultimum*. *Phytopathol.* 78:1447-1450.

Chiu, A.L. and J.W. Huang. 1997. Effect of composted agricultural and industrial wastes on the growth of vegetable seedlings and suppression of their root diseases. *Plant Pathol. Bull.* 6(2):67-75. [CAB Abstracts]

Choi, S.Y., J.S. Na, N.Y. Hwang and D.H. Kim. 1988. Effect of soil conditioner application on some growth characters and yield of peanut in continuous cultivation in upland soil. *Res. Rep. Rural Dev. Admin. Korea Repub.* 30(2):11-20. [CAB Abstracts]

Chung, Y.R., H.A.J. Hoitink and P.E. Lipps. 1988. Interactions between organic matter decomposition level and soilborne disease severity. *Agric. Ecosys. Environ.* 24(1-3):183-193.

Chung, Y.R. and H.A.J. Hoitink. 1990. Interactions between thermophilic fungi and *Trichoderma hamatum* in suppression of *Rhizoctonia* damping-off in a bark compost-amended container medium. *Phytopathol.* 80:73-77.

Clulow, S.A., H.E. Stewart, E.P. Dashwood and R.L. Wastie. 1995. Tuber surface microorganisms influence the susceptibility of potato tubers to late blight. *Ann. Appl. Biol.* 126(1):33-43. [CAB Abstracts]

Cook, R.J. and K.F. Baker. 1983. *The Nature and Practice of Biological Control of Plant Pathogens.* American Phytopathological Society, St. Paul, MN. 539 pp.

Craft, C.M. and E.B. Nelson. 1996. Microbial properties of composts that suppress damping off and root rot of creeping bentgrass caused by *Pythium graminicola. Appl. Environ. Microbiol.* 62(5):1550-1557.

de Ceuster, T.J.J. and H.A.J. Hoitink. 1999. Prospects for composts and biocontrol agents as substitutes for methyl bromide in biological control of plant diseases. *Compost Sci. and Util.* 7(3):6-15.

Dinelli, D. 2000. Composts to improve turf ecology. *IPM Practitioner* 22(10):1-6.

Dissanayake, N. and J.W. Hoy. 1999. Organic material soil amendment effects on root rot and sugarcane growth and characterization of the materials. *Plant Dis.* 83(11):1039-1046.

Elad, Y. and D. Shtienberg. 1994. Effect of compost water extracts on grey mould, *Botrytis cinerea. Crop Prot.* 13(2):109-114.

Erhart, E., K. Burian, W. Hartl and K. Stich. 1999. Suppression of *Pythium ultimum* by biowaste composts in relation to compost microbial mass, activity and content of phenolic compounds. *J. Phytopath.* 147(5):299-305.

Filippi, C. and A. Pero. 1989. The role of telluric microflora in the control of Fusarium wilt in carnations grown in soils with bark compost. *Biol. Wastes* 27(4):271-279. [CAB Abstracts]

Gamliel, A. and J.J. Stapleton. 1993. Effect of chicken compost or ammonium phosphate and solarization on pathogen control, rhizosphere microorganisms and lettuce growth. *Plant Dis.* 77(9):886-891.

Gotaas, H.B. 1956. *Composting: Sanitary Disposal and Reclamation of Organic Wastes.* World Health Organization, Geneva. 205pp

Goudar, S.B., K. Srikant and S. Kulkarni. 1998. Effect of organic amendments on *Fusarium udum*, the causal agent of wilt of pigeonpea. *Karnataka J. Agric. Sci.* 11(3):690-692. [CAB Abstracts]

Grebus, M.E., K.A. Feldman, C.A. Musselman and H.A.J. Hoitink. 1993. Production of biocontrol agent-fortified compost-amended potting mixes for predictable disease suppression. *Phytopathol.* 83:1406 (Abstract).

Grebus, M.E., M.E. Watson and H.A.J. Hoitink. 1994. Biological, chemical and physical properties of composted yard trimmings as indicators of maturity and disease suppression. *Compost Sci. and Util.* 2(1):57-71.

Hadar, Y. and R. Mandelbaum. 1983. Suppression of Pythium damping-off in compost containing horticultural substrates. In: K.M. Schallinger, ed. *Peat in Agriculture and Horticulture*, pp. 379-382. [CAB Abstracts]

Hadar, Y. and R. Mandelbaum. 1986. Suppression of *Pythium aphanidermatum* damping-off in container media containing composted liquorice roots. *Crop Prot.* 5(2):88-92.

Hancock, J. 1994. Pers. Comm. Professor Plant Pathology, UC Berkeley, CA.

Hardy, G.E. St. J. and K. Sivasithamparam. 1991. Suppression of *Phytophthora* root rot by a composted *Eucalyptus* bark mix. *Aust. J. Botany* 39:153-159.

Harender, R. and I.J. Kapoor. 1997. Possible management of Fusarium wilt of tomato by soil amendments with composts. *Indian Phytopathol.* 59(3):387-395. [CAB Abstracts]

Hoitink, H.A.J., A.F. Schmitthenner and L.J. Herr. 1975. Composted bark for control of root rot in ornamentals. *Ohio Report Res. Devel.* 60(2):25-26.

Hoitink, H.A.J., D.M. van Doren and A.F. Schmitthenner. 1977. Suppression of *Phytophthora cinnamomi* in a composted hardwood bark potting medium. *Phytopathol.* 67(4):561-565.

Hoitink, H.A.J. 1980. Composted bark, a lightweight growth medium with fungicidal properties. *Plant Dis.* 64(2):142-147.

Hoitink, H.A.J. and G.A. Kuter. 1985. Effect of composts in container media on diseases caused by soilborne plant pathogens. *Acta Hort.* 172:191-197.

Hoitink, H.A.J. and P.C. Fahy. 1986. Basis for the control of soilborne plant pathogens with composts. *Ann. Rev. Phytopathol.* 24:93-114.

Hoitink, H.A.J. 1989. Disease suppressive properties of container media. *Ornamental Plants: A Summary of Research 1989.* Ohio State Univ./OARDC special circular 123, pp. 20-22.

Hoitink, H.A.J., Y. Inbar and M.J. Boehm. 1991. Status of compost-amended potting mixes naturally suppressive to soilborne diseases of floricultural crops. *Plant Dis.* 75(9):869-873.

Hoitink, H.A.J. and M.E. Grebus. 1994. Status of biological control of plant diseases with composts. *Compost Sci. Util.* 2(2):6-12.

Hoitink, H.A.J. and M.E. Grebus. 1997. Composts and the control of plant diseases. In: M.H.B. Hayes and W.S. Wilson, eds., *Humic Substances in Soils, Peats and Waters.* Royal Society of Chemistry, Cambridge, UK, pp. 359-366. [CAB Abstracts]

Hoitink, H.A.J., A.G. Stone and D.Y. Han. 1997a. Suppression of plant diseases by composts. *HortScience* 32(2):184-187.

Hoitink, H.A.J., W.H. Zhang, D.Y. Han and W.A. Dick. 1997b. Making compost to suppress plant disease. *BioCycle* 38(4):40-42.

Hornby, D., ed. 1990. *Biological Control of Soilborne Plant Pathogens.* CABI, Wallingford, UK. 479 pp.

Huelsman, M.F. and C.A. Edwards. 1998. Management of disease in cucumbers and peppers by using composts as fertility inputs. *Brighton Crop Prot. Conf., Pests and Diseases*, Vol. 3, pp. 881-886.

Inbar, Y., Y. Chen and Y. Hadar. 1989. Solid-state carbon-13 nuclear magnetic resonance and infrared spectroscopy of composted organic matter. *Soil Sci. Soc. Am. J.* 53:1695-1701.

Ingham, E. 2001. Composts and microbials. www.soilfoodweb.com

Isakeit, T., S. Tjosvold, A.R. Weinhold, M.N. Schroth and J.G. Hancock. 1991. Evaluation of several soil amendments added after fumigation with methyl bromide to control Fusarium wilt of carnation, 1989-1990. *Biol. Cult. Tests for Control of Plant Diseases* 6:105.

Isakeit, T., S. Tjosvold, M. Ferri, A.R. Weinhold, M.N. Schroth and J.G. Hancock. 1992. Evaluation of several soil amendments added after fumigation with methyl bromide to control Fusarium wilt of carnation, 1990-1991. *Biol. Cult. Tests for Control of Plant Diseases* 7:116.

Kannangara, T., R.S. Utkhede, J.W. Paul and Z.K. Punja. 2000. Effects of mesophilic and thermophilic composts on suppression of Fusarium root and stem rot of greenhouse cucumber. *Can. J. Microbiol.* 46(11):1021-1028. [CAB Abstracts]

Ketterer, N. and L. Schwager. 1992. Effect of compost extracts on the disease incidence and the phyllosphere flora of bush bean and tomato leaves. *Med. Facul. Landbouwweten Univ. Gent* 57(2b):411-421. [CAB Abstracts]

Ketterer, N., B. Fisher, H.C. Weltzien. 1992. Biological control of *Botrytis cinerea* on grapevine by compost extracts and their microorganisms in pure culture. In: K. Verhoeff, N.E. Malathrakis and B. Williamson, eds. *Recent Advances in Botrytis Research*, Pudoc Scientific, The Netherlands.

Kumar, A. and T. Marimuthu. 1994. Biological control of damping off of *Eucalyptus camaldulensis* caused by *Rhizoctonia solani* with *Trichoderma viride* and decomposed coconut coir pith. *Plant Dis. Res.* 9(2):116-121.

Kuter, G.A., E.B. Nelson, H.A.J. Hoitink and L.V. Madden. 1983. Fungal populations in container media amended with composted hardwood bark suppressive and conducive to Rhizoctonia damping off. *Phytopathol.* 73(10):1450-1456.

Kuter, G.A., H.A.J. Hoitink and W. Chen. 1988. Effects of municipal sludge compost curing time on suppression of *Pythium* and *Rhizoctonia* diseases of ornamental plants. *Plant Dis.* 72(9):751-756.

Kwok, O.C.H., P.C. Fahy, H.A.J. Hoitink and G.A. Kuter. 1987. Interactions between bacteria and *Trichoderma hamatum* in suppression of *Rhizoctonia* damping-off in bark compost media. *Phytopathol.* 77:1206-1212.

LaMondia, J.A., M.P.N. Gent, F.J. Ferrandino, W.H. Elmer and K.A. Stoner. 1999. Effect of compost amendment or straw mulch on potato early dying disease. *Plant Dis.* 83(4):361-366.

Logan, T.J., W.R. Faber and E.M. Smith. 1984. Use of composted sludge on different crops. *Ohio Report* May/June:37-40.

Logsdon, G. 1993. Using compost for plant disease control. *Biocycle* 34(10):33-36.

Lumsden, R.D., J.A. Lewis and P.D. Miller. 1983. Effect of composted sewage sludge on several soilborne pathogens and diseases. *Phytopathol.* 73(11):1543-1548.

Lumsden, R.D., P.D. Millner and J.A. Lewis. 1986. Suppression of lettuce drop caused by *Sclerotinia minor* with composted sewage sludge. *Plant Dis.* 70(3):197-201.

Ma, L.P., F. Gao, Y.P. Wu and X.W. Qiao. 1996. The inhibitory effects of compost extracts on cucumber downy mildew and the possible mechanism. *Acta Phytophylacica Sinica* 23(1):56-60. [CAB Abstracts]

Ma, L.P., Y.P.Wu, F. Gao and X.W. Qiao. 1999. Effects of compost extracts of livestock manure on cucumber powdery mildew and its mechanisms. *Acta Phytophylacica Sinica* 26(3):285-286. [CAB Abstracts]

Mandelbaum, R. and Y. Hadar. 1990. Effects of available carbon source on microbial activity and suppression of *Pythium aphanidermatum* in compost and peat container media. *Phytopathol.* 80:794-804.

Maynard, A.A. and D.E. Hill. 2000. Cumulative effect of leaf compost on yield and size distribution in onions. *Compost Sci. and Util.* 8(1):12-18.

McQuilken, M.P., J.M. Whipps and J.M. Lynch. 1994. Effects of water extracts of a composted manure-straw mixture on the plant pathogen *Botrytis cinerea. World J. Microbiol. Biotechnol.* 10(1):20-26.

Menzies, S.A. and J. Calhoun. 1976. Control of Phoma root rot of chrysanthemums by the use of fertilizers. *Trans. Brit. Mycol. Soc.* 67(3):455-462. [CAB Abstracts]

Nakasaki, K., M. Kubo, H. Kubota. 1996. Production of functional compost which can suppress phytopathogenic fungi of lawn grass by inoculating *Bacillus subtilis* into grass clippings. In: M. de Bertoldi, P. Sequi, B. Lemmes and T. Papi, eds. *The Science of Composting*, part 1. Blackie Academic and Professional, Glasgow, UK, pp. 87-95.[CAB Abstracts]

Nakasaki, K., S. Hiraoka and H. Nagata. 1998. A new operation for producing disease-suppressive compost from grass clippings. *Appl. Environ. Microbiol.* 64(10):4015-4020.

Navarro, J.R. and G. Umana. 1997. Control of root pathogens in onion seedling nurseries. *Agronomia Mesoamericana* 8(2):107-111. [CAB Abstracts]

Nelson, E.B. and C.M. Craft. 1992. Suppression of dollar spot on creeping bentgrass and annual bluegrass turf with compost-amended topdressings. *Plant Dis.* 76(9):954-958.

Nelson, E.B., G.A. Kuter and H.A.J. Hoitink. 1983. Effects of fungal antagonists and compost age on suppression of Rhizoctonia damping-off in container media amended with composted hardwood bark. *Phytopathol.* 73(10):1457-1462.

Neuweiler, R., W. Heller and U. Niggli.2000. In:T. Alfoldi and W. Lockeretz, eds. *Proc. 13th Intl. IFOAM Scientific Conf.*, Basel, Switzerland, 28-31 August, 2000.

Ozores-Hampton, M., H. Bryan and R. McMilan, Jr. 1994. Suppressing disease in field crops. *BioCycle* July:60-61.

Paul, E.A. and F.E. Clark. 1989. *Soil Microbiology and Biochemistry.* Academic Press, San Diego. 273 pp.

Phae, C.G., M. Saski, M. Shoda and H. Kubota. 1990. Characteristics of *Bacillus subtilis* isolated from composts suppressing phytopathogenic organisms. *Soil Sci. Plant Nutr.* 36:575-586.

Pitt, D., E.L. Tilston, A.C. Groenhof and R.A.K. Szmidt. 1998. Recycled organic materials in the control of plant disease. *Acta Hort.* 469:391-403.

Quarles, W. 1993. Alternatives to methyl bromide: *Trichoderma* seed treatments. *IPM Practitioner* 15(9):1-7.

Quarles, W. and J. Grossman. 1995. Alternatives to methyl bromide in nurseries—disease suppressive media. *IPM Practitioner* 17(8):1-13.

Quarles, W. 1999. Plant disease biocontrol and VAM fungi. *IPM Practitioner* 21(4):1-9.

Quarles, W. 2000. Least-toxic control of plant diseases. In: B. Hanson, ed. *Natural Disease Control*, Brooklyn Botanic Garden, Brooklyn, New York. 111 pp.

Raviv, M., A. Krasnovsky, S. Medina, R. Reuveni, L. Freiman, A. Bar and R.A.K. Szmidt. 1998. Compost as a controlling agent against Fusarium wilt of sweet basil. *Acta Hort.* 469:375-381.

Reich, L. 2001. Making Compost. *Fine Gardening* 81:44-47.

Riggle, D. 1996. Compost teas in agriculture. *BioCycle* 37(12):65-67.

Ringer, C.E., P.D. Millner, L.M. Teerlinck and B.W. Lyman. 1997. Suppression of seedling damping-off disease in potting mix containing animal manure composts. *Compost Sci. and Util.* 5(2):6-14.

Rodale, J.I. 1955. *Organic Gardening.* Hanover House, Garden City, New York. 228 pp.

Roy, S., P. Leclerc, F. Auger, G. Soucy, C. Moresoli, L. Cote, D. Potvin, C. Beaulieu and R. Brzezinski. 1997. A novel two-phase composting process using shrimp shells as an amendment to partly composted biomass. *Compost Sci. Util.* 5(4):52-64.

Schueler, C., J. Biala and H. Vogtmann. 1989a. Antiphytopathogenic properties of biogenic waste compost. *Agric. Ecosys. Environ.* 27(1-4):477-482.

Schueler, C., J. Biala, C. Bruns, R. Gottschall, S. Ahlers and H. Vogtmann. 1989b. Suppression of root rot on peas, beans, and beetroots cause by *Pythium ultimum* and *Rhizoctonia solani* through the amendment of the growing medium with composted organic household waste. *J. Phytopath.* 127(3):227-238.

Seo, I.S. 1986. Effect of organic matter on the occurrence of Fusarium wilt in cucumber. *Korean J. Plant Pathol.* 2(1):43-47. [CAB Abstracts]

Serra, W.C., S. Houot and C. Alabouvette. 1996. Increased soil suppressiveness to Fusarium wilt of flax after addition of municipal solid waste compost. *Soil Biol. Biochem.* 28(9):1207-1214.

Sheela, J., K. Sivaprakasam and K. Seetharaman. 1995. Biological control of Fusarium wilt of eggplant. *Madras Agric. J.* 82(3):199-201. [CAB Abstracts]

Spencer, S. and D.M. Benson. 1981. Root rot of *Aucuba japonica* caused by *Phytophthora cinnamomi* and *P. citricola* and suppressed with bark media. *Plant Dis.* 65(11):918-921.

Spencer, S. and D.M. Benson. 1982. Pine bark, hardwood bark compost and peat amendment effects on development of *Phytophthora* spp. and lupine root rot. *Phytopathol.* 72(3):346-351.

Theodore, M. and J.A. Toribio. 1995. Suppression of *Pythium aphanidermatum* in composts prepared from sugarcane factory residues. *Plant and Soil* 177(2):219-223.

Trillas-Gay, M.I., H.A.J. Hoitink and L.V. Madden. 1986. Nature of suppression of Fusarium wilt of radish in a container medium amended with composted hardwood bark. *Plant Dis.* 70(11):1023-1027.

Tsror, L. and B.J. Bieche. 1999. Biological control of early blight in tomatoes. *Acta Hort.* 487:271-273.

Tuitert, G.and G.J. Bollen. 1996. The effect of composted vegetable, fruit and garden waste on the incidence of soilborne plant diseases. In: M. de Bertoldi, P. Sequi, B. Lemmes and T. Papi. *The Science of Composting*, part 2. Blackie Academic and Professional, Glasgow, UK pp. 1365-1369. [CAB Abstracts]

Tuitert, G., M. Szczech and G.J. Bollen. 1998. Suppression of *Rhizoctonia solani* in potting mixtures amended with compost made from organic household waste. *Phytopathol.* 88(8):764-773.

Waksman, S.A. 1932. *Principles of Soil Biology*, 2nd ed. Williams and Wilkins, Baltimore. 894 pp.

Walter, M., C.M.A. Frampton, P.A.G. Elmer, R.A. Hill and A.J. Popay. 1995. Pathogenicity and control using composts of *Aphanomyces euteiches* pea root rot. *Proc. 48th New Zealand Plant Prot. Conf.*, Hastings, New Zealand, August 8-10, 1995, pp. 308-315.

Weltzien, H.C., N. Ketterer, C. Samerski, K. Budde and G. Medhin. 1987. Studies on the effects of compost extracts on plant health. *Nachricht. Deutschen Pflanzenschutz.* 39(2):25-28. [CAB Abstracts]

Weltzien, H.C. 1989. Some effects of composted organic materials on plant health. *Agric. Ecosys. Environ.* 27:439-446.

Weltzien, H.C. 1990. The use of composted materials for leaf disease suppression in field crops. Monograph No. 45, *Brit. Crop Prot. Council*, pp. 115-120. [CAB Abstracts]

Widmer, T.L., J.H. Graham and D.J. Mitchell. 1998. Composted municipal waste reduces infection of citrus seedlings by *Phytophthora nicotinanae.* 1998. *Plant Dis.* 82(6):683-688.

Workneh, F., A.H.C. van Bruggen, L.E. Drinkwater and C. Shennan. 1993. Variables associated with corky root and *Phytophthora* root rot of tomatoes in organic and conventional farms. *Phytopathol.* 83:581-589.

Zhang, W., D.Y. Han, W.A. Dick, K.R. Davis and H.A.J. Hoitink. 1998a. Compost and compost water extracted induced systemic acquired resistance in cucumber and *Arabidopsis. Phytopathol.* 88(5):45-455.

Zhang, W., W.A. Dick, K.R. Davis, J.C. Tu, and H.A.J. Hoitink. 1998b. Systemic acquired resistance induced by compost and compost water extract in *Arabidopsis. Bull. OILB/SROP* 21(9):129-132. [CAB Abstracts]