**H. A. J. Hoitink, Y. Inbar, and M. J. Boehm**
The Ohio State University, Ohio Agricultural Research and Development Center, Wooster

# Status of Compost-Amended Potting Mixes Naturally Suppressive to Soilborne Diseases of Floricultural Crops

During the 1960s, the nursery industry across the United States explored the possibility of using wood industry wastes as peat substitutes in container media to reduce production costs. Procedures for aging or composting of tree bark were developed to avoid nitrogen immobilization and allelopathy toxin problems associated with fresh bark (11). The wettability of bark also was improved by this process. The best technology was developed for pine bark, and composted pine bark is the most widely used peat substitute in container media today. During the past decade, similar procedures have been developed for composts produced from food industry and agricultural wastes and from municipal sewage sludges. At present, emphasis is on composting of yard wastes—that fraction in municipal solid waste consisting of leaves, brush, and grass clippings.

Early during the utilization of composts, improved plant growth and decreased losses caused by Phytophthora root rots were observed as side benefits (7,11). In practice, control of this and other diseases is at least as effective as that obtained with fungicides. In many parts of the world, the nursery industry relies heavily on composts for control of diseases caused by soilborne plant pathogens of crops produced in containers.

Composts must be of consistent quality and maturity to be used successfully in container media. Variability in quality is the principal factor limiting use of compost for this purpose. In ground bed or field agriculture, maturity is less important as long as composts are applied well ahead of planting to allow for additional stabilization.

Maturity of composts, as related to the potential for improved plant growth, can now be predicted (13). In addition, as a result of increased research on biological control during the 1980s, information is now available that facilitates formulation of container media capable of suppressing several soilborne diseases, including those caused by *Fusarium* spp., *Phytophthora* spp., *Pythium* spp., *Rhizoctonia solani* Kühn, and other pathogens. To maintain quality related to both plant growth and disease control, producers of compost must understand the processes involved in this method of biological control.

## The Composting Process

The composting process can be divided into three phases. The first is during the first 24–48 hours as temperatures gradually rise to 40–50 C and when sugars and other easily biodegradable substances are destroyed. During the second phase, when temperatures of 40–65 C prevail, cellulose and other substances that are less biodegradable are destroyed. Lignins, the darker components in plant tissues, break down even more slowly, but the rate varies among plant species. Plant pathogens, weed seeds, and biocontrol agents—with the exception of *Bacillus* spp.—also are killed by the heat generated during this high-temperature phase of the process (2,11). Compost piles must be turned frequently to expose all parts to high temperatures and produce a homogeneous product.

The third, or curing, phase of composting begins as the concentrations of readily biodegradable components in wastes decline. As a result, rates of decomposition and heat output, as well as temperatures, decline. At this time, mesophilic microorganisms recolonize the compost from the outer, low-temperature layer into the pile. By this time, humic substances are accumulating in increasing quantities. Mature composts consist largely of lignins, humic substances, and biomass and have a dark color.

Biocontrol agents that recolonize composts after peak heating include *Bacillus* spp., *Enterobacter* spp., *Flavobacterium balustinum* Harrison, *Pseudomonas* spp., other bacterial genera, and *Streptomyces* spp., as well as *Trichoderma* spp., *Gliocladium virens* J.H. Miller, J.E. Giddens, & A.A. Foster, and other fungi (4,8,11).

## Mechanisms of Biological Control in Composts

Two mechanisms of biological control, based on competition, antibiosis, and hyperparasitism, have been described for compost-amended substrates. Propagules of nutrient-dependent plant pathogens, including *Pythium* and *Phytophthora*

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Dr. Hoitink's address is: Department of Plant Pathology, Ohio Agricultural Research and Development Center, The Ohio State University, 1680 Madison Avenue, Wooster, OH 44691-4096.

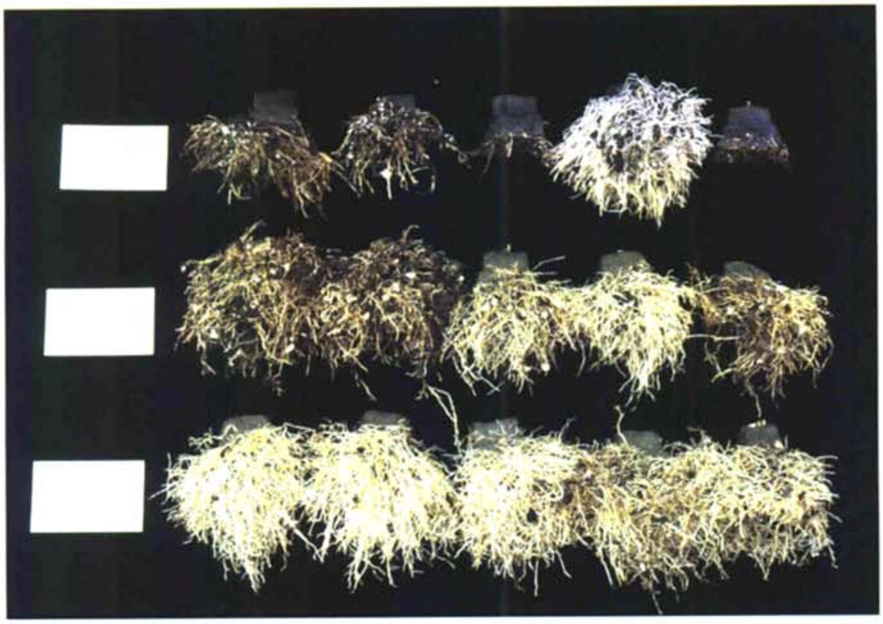

Fig. 1. Root rot severity of poinsettia plants 32 days after planting in potting mixes prepared with (top) dark decomposed sphagnum peat and perlite, (middle) light, less decomposed sphagnum peat and perlite, and (bottom) a blend of composted pine bark, dark sphagnum peat, vermiculite, and perlite. All mixes were infested with the same population of *Pythium ultimum* at potting.

Fig. 2. Pine bark composting plant using the windrow process.

Fig. 3. Mechanized composting plant using process control. Process temperatures are maintained through forced aeration under feedback control.

Fig. 4. Production of cyclamen in a potting mix amended with composted pine bark naturally suppressive to Fusarium wilt in an ebb-and-flow production system in which *F. oxysporum* f. sp. *cyclaminis* can be disseminated in a recycled nutrient solution.

spp., are suppressed through a mechanism known as "general suppression" (3,5,8,16). Many different kinds of microorganisms present in compost-amended container media function as biocontrol agents for diseases caused by *Phytophthora* and *Pythium* spp. (3,8). Propagules of these pathogens, if inadvertently introduced into container media, do not germinate in response to nutrients released in the form of seed or root exudates. The high microbial activity and biomass in these mixes prevent germination of sporangia, presumably through microbiostasis (3,16). A simple biochemical assay that determines microbial activity on the basis of the rate of hydrolysis of fluorescein diacetate predicts suppressiveness of potting mixes to *Pythium* diseases (3) and can be used to predict the need for fungicide drenching to control Pythium damping-off and root rots.

Sphagnum peat typically is included as a component in container media. Both the microflora and the organic matter in peat can affect suppression of soilborne diseases. Organic matter in sphagnum peat generally does not support high microbial activity because peat resists decomposition. Dark decomposed sphagnum peat is low in activity and is consistently conducive to Pythium root rot (Fig. 1), whereas light sphagnum peat harvested from the surface of peat bogs is less decomposed and has a higher microbial activity. The suppressive effect of light peat on Pythium root rots, if the peat is colonized by biocontrol agents, is of short duration (1,20,21). Light peats, therefore, can be used most effectively for short production cycles, such as in plug and flat mixes used in the bedding plant industry.

The "slow-release" nature of the organic nutrients tied up in mature composts and in light peat supports activity of microflora and thus sustains biocontrol. This is thought to be the essence of biological control associated with "organic farming." Nondestructive direct spectroscopic (NMR and FT-IR) procedures are now being used to predict the level of organic matter decomposition and the maturity of compost. These techniques also are used to determine the amount of undecomposed biodegradable organic matter remaining in compost (13). This approach to the analysis of maturity promises to yield a technology that can assess the "carrying capacity" or the potential for a soil or potting mix to support sustained microbial activity and thus "general suppression."

The mechanism for biological control of such plant pathogens as *R. solani* is entirely different from that for biological control of *Pythium* and *Phytophthora* spp. *R. solani* produces large nutrient-independent propagules known as sclerotia. In compost-amended substrates, a much narrower group of microorganisms is responsible for suppressing or eradicating this pathogen (4). We refer to this type of suppression as "specific suppression."

Variability in suppression of Rhizoctonia damping-off encountered in substrates amended with mature composts is due in part to random recolonization after peak heating of compost by a microflora that varies in efficacy against *R. solani*. Composts produced in the open near a forest—an environment with many microbial species—are more consistently suppressive than those produced from the same materials in facilities that are partially enclosed, where microbial species are fewer (11). Container media amended with composts prepared from municipal sewage sludges are consistently conducive to *R. solani* because care is taken to kill fecal pathogens and parasites by heat exposure. This process kills most beneficial microorganisms as well. These compost-amended container media may have to be incubated for a month before they can be used in nurseries to suppress *R. solani* (14); in field soil, several months may pass before suppression is induced (15). Selected strains of *Trichoderma* and *Gliocladium* spp. are examples of fungi found in composts prepared from tree barks or mixtures of wood wastes and municipal sludge and identified as biocontrol agents of *R. solani* (4). Several bacteria may interact with *Trichoderma* isolates to eradicate this pathogen, and some of these interactions are synergistic (4).

To solve the problem of variability in suppressiveness of compost to *R. solani*, specific microbial inoculants have been developed in our laboratory that, when introduced into compost after peak heating but before recolonization has reached significant levels, induce consistent levels of suppression. This process has been patented (9).

*R. solani* is highly competitive as a saprophyte. It can utilize cellulose and colonize fresh bark but cannot colonize the low-in-cellulose mature bark compost. On the other hand, isolates of *Trichoderma* that function as biocontrol agents for *R. solani* are capable of colonizing mature compost. Biological control does not occur in fresh, undecomposed organic matter because both fungi grow as saprophytes and *R. solani* remains capable of causing disease. In mature compost, on the other hand, sclerotia of *R. solani* are killed by the hyperparasites, and biological control prevails (4,11). Because the degree of organic matter decomposition is important, composts must be stabilized adequately to reach that decomposition level where biological control is possible. In practice, this occurs in wood-waste composts that no longer immobilize nitrogen during plant growth and that have been colonized by the appropriate specific microflora.

Knowledge developed during the past decade on mechanisms of biological control of *Pythium, Phytophthora*, and *Rhizoctonia* diseases in nurseries producing woody ornamentals encouraged us to expand the concepts of natural biological control to the much more demanding field of floriculture. During the past decade our aim has been to produce potting mixes with composted pine bark for production of high-quality plants on a predictable schedule and to consistently suppress Pythium damping-off and root rots. We also have determined whether pine bark composts produced on a large scale consistently suppress *Rhizoctonia* and thus whether addition of biocontrol agents for control of the pathogen is needed in practice.

## Composting Pine Bark on a Commercial Scale

Pine bark is first hammer-milled and screened so that all particles are <1.25 cm in diameter. The raw pine bark used for the formulation of potting mixes typically contains <20% "wood" by volume. Because components other than cellulose in pine bark harvested from mature stands resist decomposition, only a small amount of nitrogen (0.6 kg/m$^3$ of bark), mostly as ammonia or urea, is added with water as the first step in the composting process. This amendment raises the total moisture content of the bark to 65–70% (w/w) and the pH from 5.0 to 7.4. The low pH of fresh bark (4.5–5.0) inhibits growth of thermophilic bacteria during composting, a problem that is avoided by using ammonium nitrogen (12). Some producers compost pine bark without added nitrogen. This type of a compost can be used at incorporation rates of up to 25% (v/v) without causing significant levels of nitrogen immobilization.

Figure 2 shows the general layout of a typical windrow composting facility. The wet and nitrified bark is stored in windrows on a concrete pad and turned several times during an 8- to 11-week period. During composting, free water must not accumulate in the base of windrows and the free air space must be sufficient (35–50%) to avoid fermentation. Temperature is monitored daily. Electrical conductivity, pH, and moisture levels are monitored weekly to follow the rate of composting. Adjustments are made to maintain optimum conditions for the process (12). During prolonged dry weather, water must be added to maintain moisture levels above 50% and thus ensure a high rate of decomposition.

Because of its resistance to decomposition, pine bark harvested from large trees is low in specific heat output when compared with a substrate such as municipal sludge. When ambient temperatures are high, windrows must be low enough (<3 m) to maintain internal process temperatures below 60–65 C. During the winter, when heat losses are high, windrows must exceed this height to maintain the same temperatures. During curing, when temperatures in the pile decline to below 40–50 C, composts produced in rainy climates must be stored out of the weather to maintain total moisture levels below 50% (w/w). Traffic patterns in the composting area must be such that soils harboring pathogens are not introduced into the compost. Weeds around the site must be controlled with a herbicide that does not leave residues.

Figure 3 shows an in-vessel, computer-controlled composting system. Optimum process parameters for composting of bark in such a system differ from those for the windrow system (12).

**Formulation of potting mixes.** Components used in potting mixes are composted pine bark, horticultural grades of perlite, vermiculite, and, typically, dark-colored Canadian sphagnum peat (H3–H4 on the von Post decomposition scale) that is conducive to *Pythium* and *Rhizoctonia* diseases. Some industries incorporate silica sand to reduce pore space and increase water retention and bulk density of the mix. All ingredients are first passed through a 12-mm screen. Ratios of ingredients used in potting mixes ideally are such that physical properties related to aeration and water retention conform to guidelines developed to suppress Phytophthora root rot (6,18). The pH is maintained above 5.5 with calcium carbonate. Fertilizer—typically 0.5 kg of $KNO_3$, 0.5 kg of superphosphate, 1.2 kg of gypsum, and 0.5 kg of epsom salts per cubic meter of mix—and an appropriate amount of micronutrients are added during formulation. At full-scale formulation plants, mixes typically are blended continuously for 3 minutes or less.

Water added during blending serves several purposes. Dust generation, mixing efficiency, final bulk density, and wettability of the mix at planting are all recognized as important factors. The effect of water potential in a mix on biological properties often is overlooked, however. Particularly during a drought, when the water content of compost in windrows may reach values below 30% (w/w), regrowth of mesophilic bacteria in compost after peak heating is inhibited. A free film of moisture must be present on the surface of organic matter in compost (≥40%, w/w) for bacteria to recolonize (17). During the drought of 1988, batches of potting mix with final moisture contents below 30% were formulated at several points in the United States. These mixes were predominantly recolonized by fungi and conducive to Pythium damping-off. Addition of water to such dry mixes, to raise the moisture level to 40–50%

(w/w), results in recolonization by mesophilic bacteria.

Growers occasionally complain about mushrooms appearing in pots of flowering plants being produced in compost-amended mixes. This problem is associated with mixes formulated with low moisture content, which enhances recolonization by fungi. High moisture content enhances recolonization by bacteria as well as by fungi.

After formulation, mixes typically are stored in 100-L perforated polyethylene bags or in 2-$m^3$ nylon bags from days to months before their use. At least 4 days must be allowed for recolonization of high-temperature (40–50 C) compost with a mesophilic microflora to induce the natural suppression of Pythium damping-off (3).

**Amount of compost required to induce suppression in potting mixes.** Mixes containing more than 20% (v/v) composted pine bark support a significant level ($P = 0.05$) of suppression to Pythium damping-off. Interestingly, a much lower volume (as low as 2.5%) of composted municipal sludge, which is much higher in microbial biomass and activity, has the same effect as a high volume (>20%) of composted pine bark. This low specific microbial activity in composted pine bark compared with composted sludge is advantageous because a large volume can be used in potting mixes without depleting oxygen for the root system. This is the principal reason why pine bark is used so widely in container media.

In the western United States, barks of fir and western hemlock, which also resist decomposition, are the preferred substitutes for peat. Bark composts also tend to be lower in salinity than sludge or manure composts. The potting mix industry, therefore, may use up to 55% (v/v) composted pine bark in mixes. The nursery industry utilizes up to 80% pine bark in container media. Manure and sludge composts, on the other hand, typically are used at up to 15% (v/v) (11).

**Spectrum and consistency of natural suppression.** During the past 3 years we have surveyed suppressiveness of commercial batches of composted pine bark mix to Pythium and Rhizoctonia damping-off. With the exception of some batches produced during the drought of 1988, mixes were consistently suppressive to Pythium but varied in suppressiveness to Rhizoctonia damping-off. Industry has learned to irrigate compost piles during dry weather to avoid conduciveness to *Pythium* diseases. Consistent suppressiveness to both Rhizoctonia and Pythium damping-off among batches of mix was not found in full-scale production plants. This demonstrates that mechanisms of suppression of these diseases in commercial composted pine bark mixes indeed differ, as do mixes prepared with composted hardwood bark (11) or composted municipal sludge (14), including field-applied composted municipal sludge in vegetable production (15). We conclude, therefore, that controlled addition of biocontrol agents indeed is necessary to induce consistent levels of suppression to Rhizoctonia damping-off.

Very little is known about mechanisms of suppression of Fusarium wilts in compost-amended mixes. In spite of this, growers in the eastern United States have consistently suppressed Fusarium wilt of cyclamen for over a decade by using composted pine bark mixes (10). Effective fungicides and "pathogen-free" plant production techniques are not yet widely available for control of this disease, so this procedure of biological control has become very important to the industry.

Nutritional as well as biological factors are involved in suppression of Fusarium wilts. Suppressiveness is not limited to high-pH mixes, suggesting that siderophore production is not essential. Although treatments with single biocontrol agents have had little if any effect, combinations of any of several *Trichoderma* and bacterial biocontrol agents have proved effective in mixes amended with bark compost (10). Biocontrol agents that induce protection against *Fusarium* pathogens have yet to be described from compost-amended substrates.

Bark composts immobilize nitrogen, preferentially as ammonia. Nitrogen available for plant growth, therefore, is in predominantly nitrate form. Sludge composts release ammonia upon mineralization and enhance Fusarium wilts, even when recolonized by biocontrol agents capable of inducing suppression (10). This impact of bark composts on nutrition therefore affects severity of Fusarium wilt.

During the past decade, a new method of irrigation for potted greenhouse crops has been introduced in the United States to reduce pollution of groundwater. In this system, known as ebb and flow, the nutrient solution is pumped onto benches and drains back into storage tanks after a short flooding period. Water is taken up into mixes through capillary activity. Composted pine bark mixes used to suppress Fusarium wilt (45% compost, v/v) cannot be used in the ebb-and-flow system because of their low capillary activity. In the Netherlands, where temperatures in greenhouses are predominantly low (18–24 C), dissemination rates of *F. oxysporum* f. sp. *cyclaminis* Gerlach in the nutrient solution of this system are low enough so that transmission is not a major problem (19). In the United States, however, where temperatures in the summer are much higher, cyclamen losses to Fusarium wilt can be severe enough (20–80%) in peat mixes to render production uneconomical. A mix formulation developed in 1988 with composted pine bark (25% v/v), light sphagnum, and perlite effectively suppresses the disease and performs well in the ebb-and-flow system (Fig. 4).

## Future Opportunities

Consistent success with biological control of diseases caused by *Fusarium, Pythium*, and *Phytophthora* spp. is possible only if all factors involved in the production of ingredients and in the formulation of potting mixes are defined and kept constant. Most composts produced in the United States cannot meet these criteria because quality control in general is still inadequate. In the eastern states, therefore, composted pine bark and sphagnum peat remain the principal organic components used for preparing potting mixes naturally suppressive to soilborne plant pathogens.

Natural suppression, according to present concepts, at best covers those diseases caused by pathogens suppressed through microbiostasis. Microbial activity in a mix, determined by the rate of hydrolysis of fluorescein diacetate, is one procedure that now can be used effectively to determine suppressiveness of a mix to Pythium root rot. This procedure by itself, however, does not predict how long the effect will last. The potential for biodegradable carbon in a mix to support an active biomass determines that phenomenon. Practical procedures that quantify this effect have yet to be developed.

Composts are not consistently recolonized after peak heating by biocontrol agents capable of suppressing *R. solani.* Controlled inoculation of composts with biocontrol agents is a procedure that must be developed on a commercial scale, therefore, to induce consistent levels of suppression to this nutrient-independent pathogen.

Recycling through composting is increasingly being chosen as the preferred strategy for waste treatment, and composts are becoming available in greater quantities. Peat, on the other hand, is a limited resource that cannot be recycled. For these reasons, future opportunities for both natural and induced suppression of soilborne plant pathogens, using composts as the foodstuff for biocontrol agents, appear bright.

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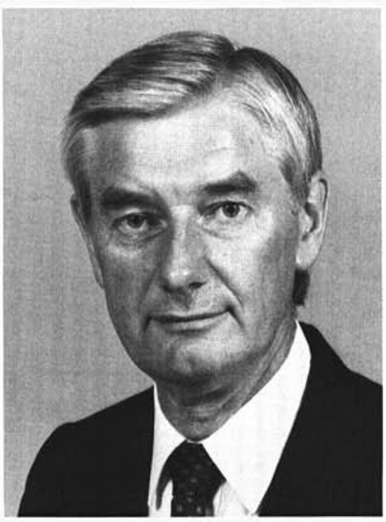
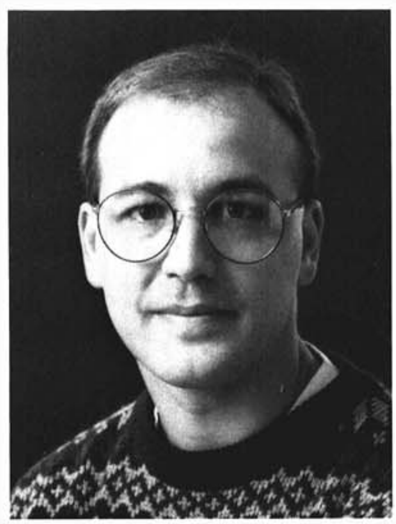


**H. A. J. Hoitink**

Dr. Hoitink is a professor in the Department of Plant Pathology at The Ohio State University (OSU) and the Ohio Agricultural Research and Development Center (OARDC). His primary research interests involve mechanisms of biological control of soilborne plant pathogens of ornamental plants in compost-amended container media. He received his B.Sc. and M.Sc. degrees from MacDonald College and McGill University in Montreal in 1963 and 1964, respectively, and his Ph.D. degree in plant pathology from the University of Wisconsin, Madison, in 1967.

**Y. Inbar**

Dr. Inbar has completed a postdoctoral research leave in the Department of Plant Pathology at OSU/OARDC, where he worked on characterization of organic fractions in potting mixes that sustain microbiostasis. He has M.S. and Ph.D. degrees from the Hebrew University of Jerusalem, Rehovot, where he worked on physical and chemical characterization of organic matter transformations during composting of agricultural wastes.



**M. J. Boehm**

Mr. Boehm is a graduate research associate in the Department of Plant Pathology at OSU/OARDC. He has developed procedures for characterizing sphagnum peats suppressive to Pythium root rot and is continuing his research in this field.