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Composted Bark, A Lightweight Growth Medium

Root rots of container-produced ornamentals traditionally have been controlled by various media sterilization techniques, proper use of soil fungicides, and sanitation procedures. Meristem-tip culture has been used increasingly to eliminate vascular pathogens, thus further reducing the incidence of some soilborne diseases. During the past decade, composted tree bark has partially replaced peat in container media. This had added a new dimension to control, since composted tree bark is suppressive to many pathogens.

Container media generally consist of

with Fungicidal Properties

an organic component, such as peat or bark, and various inert fractions. The organic component holds moisture and provides cation-exchange capacity. Inert components, such as sand, Styrofoam, perlite, pumice, or expanded shale, are used to adjust bulk density and percentage air-filled pore space at container moisture capacity to optimum levels. Numerous articles have discussed physical and nutritional aspects of container media, but little attention has been paid to the suppressive effect of organic components on root rot pathogens.

Grower examining poinsettia roots in a medium consisting of composted hardwood bark, Canadian peat, and perlite (4:3:2, v/v). The medium was not sterilized, and no soil fungicides were applied.

During the late 1960s, observations made in nurseries indicated that Phytophthora root rot of rhododendron was less severe on plants produced in media amended with composted tree bark than in those amended with peat. At that time, bark was ammoniated before use to avoid nitrogen deficiency on plants produced in the media. The excessive quantities of ammonia added in this process, however, resulted in ammonia kill of the microflora. The time required for decomposition was increased because decomposition did not occur until after excessive quantities of ammonia had dissipated. In the early 1970s, a process calling for addition of ammonium nitrate nitrogen was developed for decomposition of bark. The process was slow, however, and occasionally yielded phytotoxic bark. A project was therefore initiated to develop a system for mass production of composted tree bark that killed pathogens in the bark and yielded a nontoxic but disease-suppressive product. This system has been adopted widely for production of nursery stock. It eliminates the need for sterilization of container media and reduces frequency of soil fungicide application. Research on the development of the bark composting process was reviewed recently (9).

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The Composting Process

Composting has been defined as "the biological decomposition of organic constituents in wastes under controlled conditions" (6). An important term in this definition is "controlled," which distinguishes composting from natural rotting or putrefaction such as occurs in open dumps, manure heaps, or field soil. Basically, the process can be divided into three phases: 1) an initial phase of 1–2 days during which easily degradable compounds are decomposed, 2) a thermophilic phase (possibly lasting several months) during which high temperatures occur (40–80 C) in which primarily cellulose is degraded, and 3) stabilization, a period during which the rate of decomposition decreases, temperatures decline, and mesophilic microorganisms, some of which are antagonistic to plant pathogens, recolonize the compost.

Thermokill of plant pathogens occurs during the thermophilic phase (8). *Phytophthora cinnamomi, Pythium irregulare, Rhizoctonia solani, Botrytis cinerea,* and *Erwinia carotovora* var. *chrysanthemi* could not be recovered from infected plant parts that had been buried in a compost pile (internal temperature 40–60 C) for 10–12 wk (8). In a similar study, tobacco leaves and stems infected with tobacco mosaic virus (TMV) were buried in compost piles (three separate trials). Extracts prepared from all samples after exposure to 50–75 C for 6 wk were infective (D. T. Gordon and H. A. J. Hoitink, *unpublished*). This suggests that TMV may not be inactivated during composting of tree bark.

Bark generally is composted in windrows (4–5 m wide, 2.5–3 m high). Because the process is aerobic, windrows should be covered by a roof in areas of high rainfall, not with polyethylene. Optimum physical and chemical factors for maximum rates of decomposition (CO_2 evolution) during thermophilic composting are oxygen levels of 5–12%, a

Fig. 1. Compost being removed from an aerated bioreactor tank and placed onto conveyor belt (arrow). The compost is aerated by fans through perforated floors and turned frequently to expose all organic matter to thermophilic conditions. Tank (4 × 7 × 150 m) on left is filled with cow manure and tank on right is filled with hardwood bark.

temperature of 40–50 C, and a moisture content of 50–65% (on a wet weight basis). Optimum pH ranges from 6.5 to 8.5. Rates of decomposition are higher with addition of ammonia nitrogen than with nitrate nitrogen, largely due to the pH effect of the ammonium ion. Added phosphorus also increases the decomposition rate. Other additives, including microbial starter cultures, have not significantly decreased the duration of the thermophilic phase observed during composting of either hardwood or softwood tree barks.

The duration of the thermophilic process is dictated by the cellulose content of bark being composted. This varies with tree age and species. Most pine barks (long leaf, short leaf, loblolly, and slash pines) contain less than 5% readily degradable carbon (cellulose). Barks from most hardwoods used in the Midwest (mostly oak, maple, and poplar species) may contain up to 40%. In addition, the proportion of wood chips (cellulose) in bark removed from trees during the debarking process may range from 10 to 30%. Because of its low wood content (less than 10%), pine bark utilized in the southeastern United States can be stabilized by windrow composting in 4 mo or less. In contrast, hardwood bark, which usually contains 20% wood chips or more, will self-heat up to 1 yr because of the high total cellulose content.

In practice, the duration of the thermophilic phase has been reduced most effectively by using bark low in wood content and by controlling aeration, moisture level, pH, amount and form of added nitrogen, and particle size distribution. This has been accomplished in mechanized aerobic tanks (Fig. 1) and in aerated windrows known as the Beltsville system (4).

Generally, chemical additives for composting of both softwood and hardwood tree bark are 1 kg of nitrogen and 0.3 kg of P_2O_5/m^3 of bark. To bark composted in windrows not aerated with fans, urea is added as the nitrogen source. Parts of the nitrogen may be substituted with poultry manure. Where windrows are aerated, part of the nitrogen is added as ammonia and the remainder as ammonium nitrate or poultry manure to avoid a pH above 7.4. This pH reading is within the optimum range for composting but is low enough to avoid ammonia loss during aeration.

Grower Experience

Substitution of all or the major portion of Canadian or German peat in container media with composted hardwood bark eliminated rhododendron root rot as a problem in many nurseries. This was accomplished without the use of soil fungicides. Media consisting of only bark and sand, however, needed to be irrigated frequently because the amount of readily available water (held between negative tensions of 5 and 50 mb) and the water buffer capacity (between negative tensions of 50 and 100 mb) were too low. Growers, therefore, incorporated Canadian or German sphagnum peat, which increased the amount of water held at negative tensions between 5 and 100 mb to suitable levels for plant growth (3). Most growers now use a 4:1 (v/v) mixture of bark and peat in the organic component of media. Various neutral aggregates are used to adjust the air-filled pore space to 15–25% in 10–15-cm tall containers. In practice, root rots have not occurred in media with this 4:1 bark-peat ratio. Survey results indicate that the apparent suppressive effects are lost when the volume of peat is equal to or exceeds that of bark.

During the development of this process, several problems were encountered by growers. Suppliers of hardwood bark screened out coarse particles to be marketed as landscape mulch. This decreased the percentage of particles in the 12–18 mm range and resulted in inadequate aeration of media and unacceptable rates of plant growth. Another problem was caused when paper mills replaced ring and drum debarkers with whole-tree chippers and increased the wood content of "bark" to as high as 60%. Rhododendrons produced in media amended with this compost became affected by Phytophthora root rot. Also, chronic nitrogen deficiency occurred on plants because of immobilization of nitrogen in the medium for decomposition of the wood.

Commercially produced composted pine and hardwood bark frequently is distributed before it is adequately stabilized. During shipment of such compost in polyethylene bags, covered trucks, or railroad cars, decomposition becomes frementative and phytotoxic products accumulate. These problems do not occur with composts that are adequately stabilized before distribution.

The use of composted tree bark has reduced incidence of soilborne diseases not only in nursery crops but also in floricultural crops and in foliage plants. It is not in general use in the bedding plant industry, perhaps because of effects of allelopathotoxins present in bark (16). In Ohio, composted pine bark is most widely used for floricultural crops and is supplied as preformulated media from the southeastern United States. Ohio nurseries utilize large volumes of bark and usually either prepare their own compost from hardwood bark supplied by sawmills or use a premixed, partially stabilized compost.

Spectrum of Suppressive Effect

The first report on suppression of a soilborne disease by application of tree bark was from Oregon State University in 1962 (13). Ammoniated Douglas fir bark incorporated into *Phytophthora fragariae*-infested Willamette Valley clay soil at rates of 90–225 tons/ha provided a high degree of control for strawberry red stele for the first and second years after treatment. By the fourth year, however, the disease was again as severe in bark-amended as in nontreated soil. Douglas fir sawdust incorporated into soil, on the other hand, increased losses (17). This is consistent with losses observed in Ohio on rhododendron produced in bark media with a high wood content.

The first report on suppression of a plant pathogen in container media by incorporation of tree bark was from the University of Georgia (7). Fresh root weights of Japanese holly 'Helleri' increased with a higher percentage of pine bark in the container medium. This increase occurred irrespective of high *P. irregulare* populations. In various Ohio nurseries during the 1969–1970 growing seasons it was observed that rhododendron root growth was significantly better in a composted hammermilled-bark-sand medium than in various peat-sand media. Furthermore, Phytophthora root rot did not occur in bark media, as it did in peat media (10).

Rhizoctonia and Pythium crown and root rots of poinsettia 'Annette Hegg Dark Red' were suppressed in composted hardwood bark amended with sphagnum peat but not in a peat medium. At low inoculum levels, suppression was equivalent to that obtained in an aerated steam-treated peat medium drenched twice with Dexon 35% WP (*p*-dimethylaminobenzene diazo sodium sulfonate) and Terraclor 75% WP (pentachloronitrobenzene) at rates of 60 and 30 g per hectoliter, respectively. High inoculum levels overcame the suppressive effect (2). In addition to these poinsettia pathogens, *Thielaviopsis basicola* was suppressed by composted hardwood bark (D. F. Schoeneweiss, *personal communication*).

Rhizoctonia damping-off on celosia (Fig. 2) was suppressed in media containing 50% or more composted hardwood bark. Higher ratios of peat reduced or eliminated the suppression. However, batches of fresh or composted pine bark from Arkansas, North Carolina, and Alabama did not suppress *R. solani* (C. T. Stephens, E. B. Nelson, and H. A. J. Hoitink, *unpublished*). Additional research may show that barks from other tree species also do not suppress *Rhizoctonia.*

Fusarium spp. also may be suppressed by tree bark. Fusarium wilt of Chinese yam was controlled by incorporation of pine bark (30 ton/ha) into field soil. Control was similar to that obtained with methyl bromide fumigation and better than that obtained with benomyl (15). Furthermore, Fusarium wilt of chrysanthemum was suppressed in media amended with composted hardwood bark but not in a peat medium (1).

Several reports have indicated that root rot of tomato is reduced after incorporation of tree bark or other organic amendments. The incidence of tomato root knot caused by *Meloidogyne hapla* and *M. incognita* was lower on plants in composted hardwood bark than on those in a peat container medium. Also, population development of *Pratylenchus penetrans* and *Trichodorus christiei* was inhibited in composted bark but stimulated in peat (14).

Mechanisms of Suppression

Three types of mechanisms have been suggested as playing a role in suppression of plant pathogens in media amended with tree bark. First, bark particles

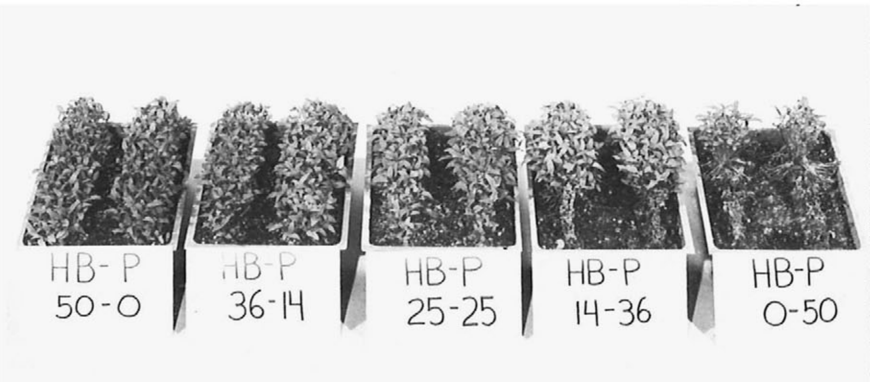

Fig. 2. Suppression of Rhizoctonia damping-off of celosia in media consisting of 50% organic components, 30% perlite, and 20% silica sand (v/v). The relative percentages (v/v) of composted bark and Canadian peat in the organic components were 50–0, 36–14, 25–25, 14–36, and 0–50, respectively; pH and nutrient levels were similar. Note the increase in damping-off with an increase in Canadian peat in the media.

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generally are coarser than peat, resulting in improved aeration. Second, composts support high levels of antagonists and phagous organisms, whereas peat does not. Finally, water extracts prepared from bark appear to have fungicidal properties.

To investigate the role of aeration and related physical factors on the suppression of rhododendron root rot, hardwood bark was hammermilled, screened, and amended with sand before composting. The resulting container medium had moisture-holding and percentage air-volume characteristics not significantly different from those of a peat-sand medium (11). Four inoculum levels of *P. cinnamomi* were added to each medium. Significantly more lupine seedlings ('Sweet Frost') were killed in peat than in bark at all inoculum levels. This suggested that suppression of *P. cinnamomi* in composted hardwood bark was, at least in part, due to biological and/or chemical characteristics rather than physical factors related to drainage.

The role of antagonists in bark compost has been examined in Japan (12). After peak heating when temperatures return to below 40 C, populations of thermophilic microorganisms decline in compost. At this point, the mesophilic microorganisms recolonize this "biological vacuum." In the mushroom industry, elaborate efforts are made at this stage to eliminate weed fungi, hyperparasites, and undesirable antagonists from the food base. In theory at least, however, composts for use in container media should be recolonized with the highest possible levels of desirable antagonists. The Japanese report indicates that the suppressive effect of bark compost was improved by controlled addition of specific antagonists to compost before temperatures declined below 40 C. Untreated compost suppressed cucumber damping-off caused by *Corticium rolfsii* but not that caused by *Fusarium oxysporum, P. aphanidermatum,* or *R. solani.* The same bark compost amended just after peak heating with an antagonistic *Pachybasium* sp. suppressed damping-off caused by all the above organisms (12). Based on these data, a commercial process was developed in Japan. Six microorganisms were added to windrows at different times during and after peak heating. In several field trials in Japan, however, this fortified compost was no more effective for control of Fusarium wilt of cucumber than was compost not amended with the antagonists.

In our laboratory, more than 600 fungal, bacterial, and actinomycete cultures antagonistic to *P. ultimum* were isolated directly from composted bark and from roots and vascular tissues of plants produced in bark compost obtained from a variety of sources (A. M. Moustafa, *unpublished*). Hyperparasitic *Trichoderma* isolates were present only in the outer 10 cm of windrows, even after peak heating. Antagonistic actinomycetes were isolated after thermophilic temperatures ceased from all parts of windrows. Cultures of an antagonistic *Pseudomonas* sp. were isolated from all locations in windrows after heavy rains, during peak heating when temperatures declined temporarily, and after peak heating, when temperatures declined below 40 C. All three types of antagonists were isolated consistently from container media prepared from stabilized compost.

In trials with the antagonists, 12 of the most antagonistic cultures (based on in vivo assays) were added separately to composted hardwood bark at the end of the thermophilic phase. The suppressive effect of this antagonist-amended compost was compared with that of compost that had been recolonized naturally. A *Trichoderma* sp., a fluorescent *Pseudomonas* sp., and a *Streptomyces* sp. added to compost reduced tomato damping-off over the control in three trials. In another four trials, however, differences were not significant (A. M. Moustafa, *unpublished).* Although antagonists are probably important for suppression, the foregoing seems to indicate that controlled recolonization with these antagonists may not consistently improve the suppressive effect of bark compost prepared in exposed outdoor windrows.

Evidence has been reported indicating that chemical inhibitors play a role in suppression of Phytophthora root rots in media amended with hardwood bark (11). Sterile filtrates prepared from composted hardwood and pine bark leachates inhibited sporangium production and lysed zoospores of *P. cinnamomi* (5,11; S. Spencer and D. M. Benson, *unpublished*). Viability of chlamydospores was not affected by the extracts. Several inhibitory components have now been purified from composted hardwood bark in a cooperative effort with R. W. Doskotch, Department of Pharmacognosy and Natural Products Chemistry, Ohio State University, Columbus. Research on the isolation and characterization of these components is in progress.

Suppression in bark appears not to be a result of a reduction of inoculum. Death rates of *F. oxysporum* f. sp. *chrysanthemi* propagules in peat and composted hardwood bark media were not significantly different over a 100-day period (1). Suppression of *P. cinnamomi* in pine bark media compared with peat apparently also is not due to differences in death rate of chlamydospores (D. M. Benson, *personal communication*).

Summary

Composted tree bark has been used successfully for control of some soilborne diseases. The system has been most widely adopted for production of containerized nursery stock. It has eliminated the need for sterilization of media and reduced the need for application of soil fungicides. These effects were most noticeable in commercial production of azalea, Easter lily, ferns, poinsettia, and rhododendron.

The tree species from which the bark is removed affects the spectrum of pathogens that are suppressed. For instance, compost prepared from bark of a mixture of hardwood species and inoculated in greenhouse trials suppressed Phytophthora, Pythium, and Thielaviopsis root rots, Rhizoctonia damping-off and crown rot, Fusarium wilt, and some nematode diseases. Composted pine bark suppressed Phytophthora and Pythium root rots but not Rhizoctonia damping-off. The wood content of bark, which is largely determined by the debarking method, also affects suppression. Compost prepared from hardwood bark contaminated with

60% wood chips did not suppress Phytophthora root rot of rhododendron in nurseries.

The bark-peat ratio in the organic component of container media affects suppression. Growers who substituted more than 50% of the composted hardwood bark with Canadian peat experienced root rots in nursery as well as greenhouse crops.

Little is known about the mechanisms of the suppressive effect. Inhibitors with fungicidal activity have been found in media amended with composted hardwood bark as well as in those amended with pine bark. The nature of the chemicals involved is being investigated.

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