DISEASE SUPPRESSION WITH COMPOST: HISTORY, PRINCIPLES AND FUTURE

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Introduction

Composts have been used for centuries to maintain soil fertility and plant health. Even so, the mechanisms by which diseases are controlled by composts are just now being elucidated. This paper reviews the recent history on control of plant diseases with composts. Furthermore, the present state of knowledge in this field is reviewed. Finally, potential future opportunities for control of plant diseases with inoculants of specific biocontrol agents are discussed. The focus of the discussion is on utilization of composts in container media.

Historical Perspectives

Soils low in organic matter content and microbial activity tend to be conducive to root diseases of plants (1, 59). Pathogens thrive in such mineralized soils in the presence of host plants. During the 1950's, methyl bromide and other pesticides were introduced to control fungal pathogens and plant pathogenic nematodes. After treatment, these sterilized soils were even more conducive to disease. *Phytophthora* and *Pythium* spp. that cause root rots on many plant species often were reintroduced with new planting stock or with irrigation water within days after planting. Therefore, infections occurred on susceptible crops. On Rhododendron in particular, the disease spread rapidly, and losses were high while the quality of surviving plants was poor. As a result, susceptible woody plants such as azalea, rhododendron, and taxus frequently died from Phytophthora root rot in the landscape. On rhododendron, death might occur within weeks after planting in high temperature regions and losses could reach 100% (38).

To address this soil quality problem, the nursery industry used green manures. Often two crops were planted between each nursery crop. This approach was not effective by it self in the nursery industry. It did not prevent the decline of soil quality probably because newly planted woody ornamentals do not shade the soil for several years after out planting. This results in high soil temperatures and high rates of organic matter decomposition (59). Disease and erosion posed problems in these highly mineralized soils from which top soil continued to be sold with harvested trees and shrubs.

In the 1970's, composts first became available to the nursery industry in the U.S. Compost was applied just before planting and this solved the soil quality problem. Massive compost loading rates as high as 100 tons per ha were used without causing pollution of ground or surface waters with nutrients (9, 58). These compost amendments also reduced the severity of diseases caused by soilborne plant pathogens (3, 10, 17, 21, 22, 42, 51, 72, 73). Stone et al., 2004, presents a detailed overview of the effects of composts on the severity of diseases of plants in field agriculture. Suppression of root diseases with composts has been most successful in container-produced plants. This paper therefore focuses on that aspect of compost-induced disease control.

Early during the development of container media, it was learned that peat mixes generally did not suppress Pythium or Phytophthora root rots, or if they were suppressive initially, the effect was short term in nature (8, 65). Fungicides such as metalaxyl that can effectively control these root rots were not available until the mid 1970's. Phytophthora root rot therefore posed serious problems in this industry because the pathogens of this disease spread readily with irrigation water. In the absence of control procedures, nurserymen decreased fertility inputs to reduce disease pressures during the highest temperature season of the year. This resulted in less growth. Another problem was that high quality peat was not available at low cost in all locations. Therefore, the nursery industry began to develop alternatives to peat.

The U.S. and Australian nursery industries began to introduce bark from several different tree species as peat substitutes into container media during the 1950's (35). Nurserymen observed that bark-amended potting mixes seemed to naturally suppress Phytophthora and Pythium root rots. Unfortunately, plant growth often was variable from batch to batch in part due to nitrogen deficiency in plants early after potting but also due to other mineral nutrition and allelopathy problems. To overcome these issues, procedures were developed for composting of bark from several tree species (11, 35, 43, 56). Bioassays that allowed careful analysis of the relative suppressive effects of potting mixes against several different types of plant pathogens were developed (6). Eventually, procedures were developed for production of nursery crops in composted bark and sawdust-amended media that also supported predictable control of plant parasitic nematodes and of Phytophthora and Pythium root rots (18, 21, 25, 33, 57).

Almost immediately after these disease suppressive media became available, nurseries increased fertility inputs in the high temperature part of the summer to shorten production cycles because root rots no longer posed a threat. The net result of high fertility was increased susceptibility of some crops to foliar diseases such as fire blight and Phytophthora leaf and shoot blights. Rhododendron cultivars became highly susceptible to *Phytophthora* spp. that cause shoot blight and dieback (39). Thus, although free of root rot, susceptible crops still had to be sprayed on the foliage with fungicides, particularly in humid climates or where overhead irrigation was used and leaf wetness periods were long enough to allow infections to develop. Taxus has been produced for decades in suppressive container media without fungicide applications. It is highly susceptible to Phytophthora root rot but resistant to Phytophthora needle blight and stem dieback diseases. This crop must be transplanted on an 18 month basis to maintain suppressiveness and avoid the production of deformed root systems (64). Crops such as these clearly established that natural suppression of root rots caused by *Phytophthora* spp. is a highly effective approach to disease control. It is also clear, however, that composts do not naturally suppress foliar diseases. Based on observations at growers, the suppressive effect supplied by composts seems to be limited to diseases of roots.

Present Status

Many factors contribute to successful utilization of composts in container media. During the early seventies, problems caused by solid wastes throughout the western world eventually produced pollution abatement regulations. Industrial as well as municipal solid wastes were removed from effluent water by treatment plants. This allowed composting to emerge as an industry and it eventually became a better understood process. A recent review presents an overview of the role that composting now plays in treatment of solid wastes in the U.S. (36). Environmental safety regulations have been adopted for treatment of each of these wastes. Thus, several different types of composted products now are available that have reproducible performance characteristics during their utilization. Toxicology issues also have been addressed. Even so, some unregulated composted products still fit the "muck and magic" category and they must be avoided in container media at all cost.

Compost quality impacts: Properties of composts that must be controlled to allow successful utilization in container media include the raw materials used as feedstock, the sizing of materials during and after composting, the composting process it self, the degree to which the compost has been stabilized during the process and curing (maturity/stability), and finally, biological, chemical and physical properties of the end product. Several of these factors are reviewed briefly here. More details for each can be garnered from review articles (20, 32) and from books and proceedings on these topics cited below.

The decomposition level of the organic fraction in composts (maturity/stability) critically affects biological control (31). For example, most fresh wood residues release glucose and other sugars during the decomposition process and these substances support growth of *Rhizoctonia solani*. Biocontrol agents such as *Trichoderma* spp. reach high populations in such substrates but they do not provide disease control, probably due to glucose-induced repression of enzyme synthesis required for parasitism of the pathogen (16). *Sclerotium rolfsii* and other pathogens that produce sclerotia and are controlled by parasitism, probable are affected the same way (27). Antibiotics produced by biocontrol agents also are affected in this manner (23). Thus, it is not surprising that high in wood content products do not suppress Pythium and Phytophthora root rots since biocontrol agents which produce these antibiotics including *Trichoderma* spp, and *Bacillus, Pseudomonas and Pantoea* spp., contribute to suppression of these pathogens in container media (3, 7, 8, 47).

To avoid lack of stability problems, composts must be stabilized to reach a stability level of at least 1.0 mg CO_2-C g^{-1} dw d^{-1} (71). However, excessively stabilized, charred or pyrolyzed particles in composts do not support an adequate concentration of microbial biomass for biological control (13, 14). Charred particles are produced when compost temperatures exceed 70^{o}C for long periods of time. This material does not support the activity of biocontrol agents. Finally, excessively humified organic matter such as in highly decomposed Sphagnum peat or as in composts after they have been utilized in potting mixes for more than their "useful life time" (more than two years) does not support control (8, 60). Thus, substrate chemistry matters!

The longevity of the suppressive effect of properly produced and cured composts in container media depends on many factors. Stabilized, protected from decomposition, lignocellulosic substances in composts, the chemistry of which resembles particulate organic matter (POM) in soil, seem to form the basis for long-term control (59, 60). Generally, compost-amended container media become conducive to root rot within 12-24 month after potting, but this varies with the materials used and the climate. The rate of hydrolysis of fluorescein diacetate seems to best reflect this suppressive effect against root rots (31, 59).

The type of bedding blended with a particular type of manure on farms obviously affects the composting process (12). It also affects the length of time of composting required to reach an appropriate degree of stability. Manures must be composted and cured until toxic concentrations of ammonia have been converted to nitrate to avoid crop failure immediately after planting due to ammonia toxicity (71). Thus this variable must be considered in compost quality. Typically, several tests must be performed on composts to predict the potential for plant growth. The U.S. Composting Council provides guidelines for testing and utilization of composts in various applications including container media (66).

Salinity is another property of composts that must be considered in compost quality control (32). Phytophthora root rots, for example, are stimulated by high salinity (24). Composted sewage sludge when brought to a constant stability level before marketing and when utilized at an optimum fertility amendment rate does not pose salinity problems because salt (NaCl) typically remains in the water that is discharged at sewage treatment plants. Manures can vary considerably in salinity. Farms in dry regions typically produce high in salinity composted manures. In contrast, composts produced on farms that dispose of liquid manures separately tend to be low in salinity (71). Thus, amendment rates for these manure products may range from 5- 20%.

Composted swine as well as cow manures now can be used successfully for suppression of Phytophthora root diseases (4, 26, 41). Failures were common before it was realized that these products must be produced on a consistent basis. It is now clear that essentially all composts can be used predictably and with great success for the production of high value crops as long as the entire process used to produce and cure the product is kept constant.

Value-added properties of composts: The quality of composts produced from a particular material varies widely and depends often on marketing opportunities. Several factors contribute to this effect. Apart from location effects, the “peat substitute” aspect of composts used in potting mixes typically is the most valuable property. Pine bark, rice hulls, shredded coconut fiber (coir) and other recalcitrant lignocellulosic materials that decompose slowly over time, are the most sought after composted products for use in container media. They may be used up to 60-80% by volume in potting mixes (34). These materials can maintain desirable physical properties of container media related to aeration and drainage over several years if the right ratio choices of ingredients are made. This is explained in more detail below.

Cost savings associated with reduced pesticide use has become the second most value-added benefit associated with compost utilization for crops susceptible to root rot. Readily biodegradable materials such as composted biosolids, food wastes and manures are major sources of essential major and minor nutrients. Such composts serve as substitutes for mineral slow release fertilizers. They produce fulvic acids while they decompose (15). These compounds function as chelates which maintain trace elements in solution and available to the plant even at high potting mix pH values. Fulvic acids undoubtedly also contribute to biological control of disease because of known effects of chelates on this process. Unfortunately, no information is available on this topic to our knowledge. This property of composts prepared from sewage sludge and manures is not supplied by recalcitrant materials such as composted tree bark. It represents the third most valuable property of composts used in container media. In field soils and in the landscape, other factors such as impacts on erosion, water use, soil compaction, winter and drought injury protection, etc., must be considered.

Since 1990, nurserymen have begun to recycle their own prunings and diseased plants through composting. These wastes are ground and then composted for 5-6 months. This product often is high in density due to the decomposed nature of old recycled potting mixes and the eventual concentration of mineral medium additives (sand, etc.). Therefore, temperatures often remain low in piles of these materials. Thus, the compost must be steamed to kill heat tolerant weed seeds and pathogens before it can be utilized in container media.

Formulation of container media: The nursery industry increasingly uses mixtures of composted materials in container media to take full advantage of the beneficial properties associated with different types of products (37). On a volume basis, a typical container medium used in the Midwestern and Northeastern U.S. may contain: 60% pine bark (composted or "aged" in piles or windrows for 3-6 months to remove resins, waxes and cellulose to avoid N immobilization and prepare a wettable as opposed to water repelling material), 20% composted hard wood bark, yard waste trimmings, rice hulls, or light fibrous Sphagnum peat, depending upon specific requirements of some plant species, 8-12% composted sewage sludge or composted cow or swine manure to provide nutrients and buffer capacity against high pH-induced iron deficiency, 5-10% silica sand and/or expanded shale, a high or a lower bulk density mineral amendment that increases the bulk density of the mix, and finally, lime and other mineral additives, depending on pant species requirement or irrigation water quality.

Physical properties of container media relative to aeration and drainage must be ideal for plant growth and biological control of root rots and this requirement typically determines the volumetric ratio of major recalcitrant ingredients (pine bark, rice hulls, etc.) used in container media. The air-filled pore space after saturation and drainage must exceed 25% in 20 cm tall container medium columns for most crops (52). When this value drops below 15-20%, growth of many species is impaired and root rot begins to develop. In taller containers such as those used fro trees, values can be different due to the taller water column (63). Root rot becomes a major issue even in compost-amended media when the airspace declines to below 15% in 20 cm tall pots. The percolation rate of container media often exceeds 2 cm min^{-1} to avoid puddle formation. *Phytophthora* spp. can release zoospores within minutes in free standing water (24). Thus, puddles must be avoided at all times.

Water must be added during formulation of container media from high temperature ingredients such as composts which typically are dry to adjust the total moisture content of the mix within the range of 50-55% on a weight basis. This allows colonization of the mix by beneficial microorganisms which include fungi, bacteria and actinomycetes that induce microbiostasis within days after formulation (7, 13, 14, 48). Without added water, dry potting mixes do not become colonized adequately and the medium remains conducive to Pythium and Phytophthora root rots. When all these precautions are taken, microbiostasis is induced but this natural process still does not result in consistent suppression of pathogens suppressed by parasitism. Examples of pathogens not suppressed in such natural media are: Fusarium wilt pathogens, *Rhizoctonia solani* and *Sclerotium rolfsii* (27, 47, 68, 69).

Specific microbial inoculants: Although compost-amended media prepared according to guidelines reviewed above consistently suppress Pythium and Phytophthora root rots within days after their formulation, only 20% of several hundred different batches of such compost-amended media tested naturally suppressed Rhizoctonia damping-off (46). Inoculation of such media with specific biocontrol agents of these plant pathogens has provided more predictable control of these diseases (46, 47, 53). Without such specific inoculants, fungicides must be applied on a preventative basis.

All of the work reported above on the activity of biocontol agents in disease suppressive composts has been based on culturing of biocontrol agents on selective media. Recently, nucleic acid based techniques have been used to eventually gain a better understanding of the microbial community structure and function in these substrates (44, 49, 67). These studies support conclusions from earlier work based on PLFA analysis (70) which showed that many different types of microbial consortia seem to contribute to disease suppression.

Even though it has not been observed at growers, composts occasionally suppress foliar diseases of plants (1, 61, 74, 75). Bioassays performed with container media prepared from 1997-2001 with 80 different types of composted products revealed that only one of these induced systemic resistance to foliar diseases naturally even though all 80 natural compost-amended media suppressed Pythium root rot (45). The systemic effect was expressed more consistently in the foliage than in the roots of plants (74, 75). This showed that suppression of foliar diseases with natural composts is a rare phenomenon and that growers cannot rely on this approach to disease control. It also may explain why compost-induced foliar disease control was not discovered by growers under commercial conditions.

Several different biocontrol agents were isolated from the unique batch of compost that induced systemic resistance in plants. *Trichoderma hamatum* 382 (T382) was identified as the most active inducer of resistance. Other active isolates were *Bacillus* strains (45). Less active isolates included strains of *Pseudomonas* spp. and *Pantoea agglomerans* (28, 46).

The mechanisms by which beneficial rhizosphere microorganisms induce systemic resistance in plants differ (29, 55). It is not known how T382 induces systemic resistance in plants but like many other such biocontrol agents, it does not substantially activate PR protein synthesis before the pathogen invades the plant (28). Most of the activation occurs after infection. The population of the pathogen as well as the severity of the disease is reduced (28, 41, 45, 75) suggesting that the mechanism is ISR.

Role of substrates in compost in ISR-activity: Recently it was shown that amendment of peat mixes with composts enhances the systemic effect induced by ISR-active rhizosphere microorganisms in plants. Zhang et al., 1996 showed that dark, decomposed Sphagnum peat mixes do not induce ISR naturally. This has been confirmed several times (45, 54, 61, 75). Suppression of Fusarium crown and root rot of tomato induced by the biocontrol agent *Pythium oligandrum* was enhanced by amending a Sphagnum peat mix with composted paper mill sludge (54). Similar data has been reported for suppression of Fusarium wilt of tomato induced by several isolates of *Trichoderma asperellum* (19). Furthermore, suppression of Phytophthora leaf blight of cucumber induced by *T. hamatum* 382 was enhanced by amendment of a peat mix with composted dairy manure. It increased resistance of the plant to the disease (41). Finally, greenhouse tests performed with T 382 in a high in microbial carrying capacity (8) light Sphagnum peat potting mix revealed that powdery mildew and Botrytis blight of begonia were suppressed as effectively as provided by bi-weekly foliar sprays with the fungicides piperon and clorothalonil, respectively (40). The powdery mildew data is presented in Table 1. Addition of compost to the peat mix in this case did not enhance activity of the biocontrol agent, probably because the crop was mature (in full bloom) before the suppressive effect of the light peat used in this test declined to below critical levels for this short term crop (55 days). In conclusion, soil organic matter quality affects the activity of biocontrol agents that induce systemic resistance in plants as observed years ago for suppression of root rots. Heyl, 1999, and Stone et al, 2004 present an overview of these ecological interactions in disease control.

Table 1: Systemic resistance induced against powdery mildew in Begonia (*Begonia hiemalis* cv *Barbara*) by *Trichoderma hamatum* 382 in a peat versus a composted cow manure-amended potting mix.

Potting[1] Mix	Control[2] Treatment 1	Disease Severity[3] (AUDPC)	Dry Weight[4] (gm)	Salability[5]
peat	control	1402.8 a	4.6 c	2.6 c
peat	Piperon[4]	363.2 bc	7.1 ab	3.7 b
peat	T382	100.3 c	7.5 a	4.4 a
SD compost	control	347.3 bc	5.7 bc	3.9 ab
SD compost	Piperon	216.8 bc	7.6 a	4.1 ab
SD compost	T382	521.4 b	7.0 ab	3.8 ab

1) Peat mix (Sphagnum peat, perlite; 7:3, vol./vol.). SD compost represents 5% of peat replaced with sawdust-bedded composted cow manure.
2) Piperon applied biweekly as a topical spray to the foliage, T382 was incorporated into the potting mix at 120 g of a granular preparation of T382 per $^{-3}$ of mix.
3) Area under the disease progress curve based on mean disease severity ratings (n=9); values followed by the same letters do not differ significantly based on Fisher's LSD test.
4) Mean dry wt. (g) per plant (n=9) determined 55 days after potting.
5) Mean salability (n=9) at flowering based on the following rating scale: 5= healthy with 1 or more flower stalks with at least 1 flower open; 4= with buds or flower stalks with minimal damage to leaves; 4=no flowers or flowers with minimal damage; 2= no flowers, small and/or damaged plants; 1= dead plant.

Is the degree of resistance induced by ISR useful to growers? To answer this question, commercial scale demonstration trials were performed with T382 in nurseries. The container medium used in these trials contained the following ingredients: 65% aged pine bark (all particles <20mm diam), 15% light fibrous sphagnum peat, 10% composted municipal sewage sludge, 7% expanded shale, and 3% sharp silica sand, all on a volume basis. Chemical additives were dolomitic lime stone (2 kg per m^3), gypsum (1 kg per m^3) and slow release fertilizer at the recommended rates for crops used in this work. The container medium was inoculated during its formulation with T382 by adding 120 g per m^3 medium of a granular preparation of *T. hamatum* 382 produced by Sylvan Bioproducts, Inc., West Hills Industrial Park, Kittanning, PA. The entire medium was blended 3 min in a mixer, and water was then added as the medium was removed from the mixer to adjust its total water content to within the range of 50-55%. The control medium was not inoculated with T382. The population of T382 in the medium was monitored by dilution plating on a Trichoderma selective medium as described in Khan et al., 2004. The identity of presumptive isolates of T382 was verified with a PCR assay (2).

In a trial on rooted cuttings of *Myrica pennsylvanica*, a severe outbreak of Botryosphearia dieback occurred. Diseased plants were discarded and symptomless plants were divided into two equal batches and planted into 3.8 L containers filled with the control container medium or the medium inoculated with T382. The disease continued to develop after repotting of the crop. *Botryosphaeria dothidea* was identified as the causal agent. In the control medium, 20.8% of the plants were killed and only 25.0% of the plants remained symptomless. Most were stunted in growth. In contrast, only 6.3% of the plants in the T382-inoculated medium were killed whereas 66.7% of the plants remained symptomless. In conclusion, this batch of natural compost-amended mix did not provide control of the disease. In contrast, inoculation of the mix with T382 provided effective control of Botryosphaeria dieback, a disease for which effective fungicides are not available.

Table 2. Suppression of Botryosphaeria dieback of *Myrica pennsylvanica* by *Trichoderma hamatum* 382 (T382) in a compost-amended container medium.

Container Medium[1]	Mean Dieback Severity[2]	Mean %Plants Killed[2]	Mean %Symptomless Plants
Control	2.4	20.8	25.0
T382	1.5	6.3	66.7
LSD 0.05	0.4	14.1	20.4

1) Apparently healthy, symptomless liners were potted on March 20, 2002 in 1 gal pots in a container medium consisting of a) “aged” pine bark, sphagnum peat, composted biosolids, expanded shale and sand (9:1.5:0.75:1:0.33; vol./vol.) (control) or b) the same medium but inoculated with 120 g of T382 granular inoculum per m^{-3} of mix (T382).
2) Mean dieback severity based on four blocks of 12 plants per treatment (n = 48) in a randomized complete block design, determined on May 16, 2002 using a scale in which 1 = symptomless, 2 = slight stunting, 3 = severe stunting, and 4 = dead plant.

In another demonstration trial that was performed under commercial scale conditions during the summers of 2003 and 2004, a natural Phytophthora dieback epidemic developed on Rhododendron “Roseum Elegans”. The pathogen was identified as *Phytophthora citrophthora*. Four blocks of 120 plants were produced in each the control and the T382-inoculated container medium (n = 480). A randomized complete block design was used.

Plants were rated for disease severity in both growing seasons and the area under the disease progress curve (AUDPC) was determined. A comparison of AUDPC values after ANOVA showed that T 382 significantly (P=0.05) reduced the severity of Phytophthora dieback. This reduction in disease severity occurred even though the crop had been treated repeatedly at three week intervals with Subdue and Aliette, systemic fungicides with activity against *Phytophthora*. In vitro analysis revealed that the isolates of *P. citrophthora* that caused the epidemic were resistant to 100 mg ml^{-1} metalaxyl, the active in gradient in Subdue.

In the demonstration trials described above, the biocontrol agent T382 was recovered from the inoculated container medium and from roots of plants in the medium but not from above ground plant parts. It was not isolated from the control mix although the total population of *Trichoderma* recovered from both media (2-4 x 10^6 cfu g^{-1} medium) did not differ. Wild type *Trichoderma* isolates typically colonize these types of container media within 10-14 days after formulation (50).

Suppression of Phytophthora dieback of rhododendron Roseum Elegans with T382 verified an earlier report which showed that inoculation of nursery container media with T382 reduced the severity of Phytophthora dieback of *Pieris japonica* caused by *Phytophthora parasitica* (37). In that test, inoculation with T382 reduced the percentage of plants killed from 26 to 4%. In conclusion, inoculation of container media which naturally suppress Phytophthora root rots with ISR-active biocontrol agents such as T382 reduces foliar diseases caused by *Phytophthora*. This approach to disease control on woody plants may prove most useful for stress diseases because effective fungicides are not available for these disease problems.

Future Outlook

Several new technologies developed during the past decade promise to significantly increase utilization of disease suppressive composts in the U.S. A novel method for production of plants known as the “pot-in-pot system” allows trees to be produced in containers buried in soil. In this system, the root system is protected from winter and high temperature summer impacts. Large trees can now be produced as effectively in these systems as in field soil. Thus, trees now can be produced in the absence of plant pathogens such as *Verticillium* spp. that survive as microsclerotia in infested soils. Because the pot-in-pot system is being adopted rapidly across the U.S., the quantity of organic matter required for such systems in beginning to exceed the supply of bark and rice hulls. Thus, the nursery industry increasingly is testing alternatives for these basic ingredients of potting mixes. Composted yard wastes and other types of composts high in recalcitrant materials are beginning to fill this market. Because pots used in these systems tend to be deep (40-80 cm) depending upon tree type and size, water retention and aeration requirements are different as well. Thus, larger quantities of composts that predominantly contain small particles can be utilized successfully in these media.

A second development which is a natural spin off from this new tree technology is rapid production of nursery liners from seed or rooted cuttings (62). For example, liners of trees can now be produced from seed into 1.5-2.0 m whips within one season. This avoids production of bare root field trees (whips) in pathogen or insect-infested soils and guarantees better products.

A third development is incorporation of massive doses of composts and green manures between nursery crops into field soil on a 3-5 year production plan basis. This system is designed to mimic placement of a forest litter horizon on nursery land. As long as yearly fertilizer inputs take into account crop fertility needs and the quantity of nutrients available to the plant in the soil, this approach does not lead to environmental insults. This still is a controversial topic, however, because our ability to predict N release from compost still is poor unless several factors for each specific compost type are considered (71).

It is too early to predict the role that microbial inoculants will play in disease control. However, based on impacts of recent epidemics caused by *Phytophthora ramorum* on nursery stock in the U.S., coupled with the desire of the industry to decrease pesticide use due to increased costs, re-entry regulations, and environmental issues for some pesticides, it would seem that ISR-active inoculants will increasingly be used by growers in the future.

In conclusion, the future for utilization of composts as substitutes for pesticides seems bright. It is clear also, however, that much remains to be learned if specific disease suppression for control of foliar diseases is ever to be applied as successfully as the general suppressive effect practiced so effectively today for root rot control.

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