Impacts of Composts on Soil and Plant Health.

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Abstract

Composts prepared from solid wastes with high concentrations of recalcitrant materials which resist decomposition in soils (bark, wood, yard wastes, etc.), can be used to provide long-term suppression of plant diseases caused by soilborne plant pathogens. Composts prepared from materials that readily decompose in soil such as food wastes and manures, especially those prepared from manure solids without bedding, are much less likely to provide long term beneficial effects. The stability of the organic fraction in composts critically affects efficacy. Fresh materials typically increase diseases for some time after their incorporation into soil, even when inoculated with biocontrol agents. In contrast, after the organic matter has been stabilized by composting, temperatures decline to below 40 C and this allows biocontrol agents to increase their populations in composts to induce disease suppression. Most composting systems, however, do not allow adequate colonization by biocontrol agents after peak heating to induce broad-spectrum disease suppression naturally. Cotrolled inoculation of composts with specific biocontrol agents can improve efficacy. The severity of diseases caused by bacteria, fungi, nematodes and even viruses can be affected by composts. Phytophthora, Pythium and Thielaviopsis root rots can be suppressed by microbiostasis (competition and antibiotic production). Mature composts typically suppress these diseases within days after the organic matter has been incorporated if nutrient loading rates are optimum for the crop and salinity guidelines are not exceeded. Controlled inoculants are not required for these diseases. *Rhizoctonia* and *Sclerotium rolfsii* are examples of sclerotium-producing soilborne plant pathogens that require parasitism for effective biological control. Unless specific inoculants are used with composts, suppression of these diseases typically does not develop until months after application. Foliar diseases only are suppressed by those composts that induce systemic resistance (ISR) in plants naturally. Fusarium wilts present a special case. Low C/N composts may aggravate these diseases. High C/N composts inoculated with specific IRS-active Trichoderma strains have been highly effective for control of Fusarium diseases, more so than chemical fungicides. Unfortunately, most composts do not naturally harbor the specific microorganisms that activate ISR in plants. Thus, several factors must be controlled to provide consistent effects against foliar and Fusarium diseases. This paper presents an overview of historical perspectives and of recent findings in this field.

Key words: Composts, biological control, biocontrol agents, plant disease, systemic induced resistance, ISR, *Trichoderma hamatum* 382.

Historical Perspectives

During the 1950's, when chemical agriculture was in its "golden age", soils typically were tilled intensively and treated at high rates with inorganic fertilizers while "organic wastes" were disposed off in landfills or applied at excessive nutrient loading rates to farmland. Unfortunately, high nitrogen applications and plow tillage practices enhance the decomposition of soil organic matter. As a result, soil quality was poor while diseases caused by soilborne plant pathogens caused major losses on sensitive crops. Organic wastes, including manures were discarded even though it was understood that they could improve soil quality and plant health (Stone et al., 2004). Nursery soils used for the production of trees and other woody ornamental plants suffered the worst problems. Fumigants such as methyl bromide and other soil fungicides were used widely in the ornamentals industry and this caused additional soil ecology and environmental pollution issues. In spite of these pesticide treatments, Phytophthora root rot caused major losses on nursery crops because this pathogen was readily reintroduced into soil after fumigation and effective fungicides were not available at the time. Breeding for resistance to these diseases was not a realistic option for woody plants either even though this was a standard practice for agricultural crops (Hoitink and Fahy, 1986). Environmental problems caused by pesticides combined with excessive use of fertilizers and inappropriate disposal of organic wastes eventually led to legislation in the US in 1971 that yielded sustainable alternatives.

The nursery industry pioneered the return to traditional soil management practices in two different ways. Sphagnum peat, which did not suppress Phytophthora root rots, was replaced with composted tree bark because it provided natural control of the disease. Thus, composted bark became a methyl bromide and soil fungicide alternative in container media as well as in ground beds used for the production of liners (Hoitink and Fahy, 1986). Unfortunately, plant growth often was variable from batch to batch in bark-amended substrates. This was due to nitrogen deficiency in plants early after planting but also to imbalances in mineral nutrition and/or allelopathy problems caused by the fresh bark from some tree species. To avoid these problems, procedures for composting of bark from several different tree species were developed in several parts of the world that solved these plant growth issues (Hoitink and Fahy, 1986). In addition, bioassays were developed that compared the relative suppressive effects of potting mixes against diseases caused by several different types of plant pathogens. As a result of both types of efforts, compost-amended container media eventually became available that suppressed root rots caused by some *Phytophthora* and *Pythium* spp. and *Thielaviopsis basicola* (Fahy and Hoitink, 1986, Hoitink and Boehm, 1999). These bark-containing media, however, did not consistently suppress diseases caused by *Rhizoctonia solani* or *Sclerotium rolfsii*. Vascular wilts and foliar diseases typically were not suppressed either on plants produced in these systems (Stone et al., 2004).

The second move towards a return to more sustainable production practices occurred during the early 1980's when composts prepared from municipal wastes and manures became available as high quality soil amendments. Initially, leaf, bark, and sewage sludge composts were incorporated into ground beds at rates as high as 100 tons per ha. These composts were used as one time mulches or amendments to improve soil quality without causing pollution of ground or surface waters with nutrients. Follow up treatments used lower rates, based on soil type, soil quality indicators and crop requirements. These compost applications effectively reduced the severity of Phytophthora, Pythium and Thielaviopsis root rots in field agriculture also if several factors which included compost quality, soil fertility, salinity, timing of application, etc., were considered (De Ceuster and Hoitink, 1999). As observed earlier in container media, diseases caused by pathogens such as *Rhizoctonia* that produce sclerotia typically were not suppressed either until several months after incorporation of the amendments into low quality field soils (Hoitink and Boehm, 1999, Stone et al., 2004).

To allow successful utilization, control must be exerted with respect to the raw materials used as feedstock, the composting process itself, the degree to which the compost has been stabilized during curing (i.e. maturity / stability), particle size, and finally, biological, chemical and physical properties of the product (De Ceuster and Hoitink 1999, Hoitink and Boehm, 1999). Composts that have been most effective are those prepared from bark and woody residues, or created from animal wastes bulked with high in carbon materials such as sawdust or straw. Least effective, and possibly problematic, are those prepared from post consumer food wastes or farm manures devoid of bedding (sawdust or straw) because such products tend to be low in recalcitrant carbon and high in salinity. These less effective products often need to be applied in the fall to allow for leaching of salts if crops sensitive to Phytophthora or Pythium root rot are planted on the amended soil (De Ceuster, et al, 1998; De Clercq, et al., 2003; Stone et al, 2004). Thus, it is not surprising that composts have not consistently provided control of diseases caused by soilborne plant pathogens (Fuchs and Larby, 2005; Scheuerell et al., 2005; Termorshuizen et al., 2006).

Organic matter mediated biocontrol

One reason for the variable effects obtained with organic treatments (OM) is lack of appreciation on the part of practitioners of the role of OM decomposition level (also known as degree of stability) of soil organic matter in biological control (Hoitink and Boehm, 1999; Stone et al, 2004; Wang et al., 2006). Fresh manures, vegetative crop residues and woody materials release soluble nutrients early during their decomposition process. These soluble nutrients stimulate the growth of resident microbes, especially that of bacterial pathogens such as Coliforms and of some fungal plant pathogens (Hoitink and Boehm, 1999; Franz et al., 2008). Although biocontrol agents such as *Pseudomonads* and *Trichoderma* also develop high populations in such fresh substrates, they initially do not suppress pathogens or provide biocontrol due to high concentrations of free nutrients which repress antibiotic production and synthesis of enzymes required for parasitism (Duffy and Defago, 1999; Hoitink and Boehm, 1999). To avoid problems associated with net pathogen stimulation by fresh OM, it must be decomposed to a stability level of 1.0 mg CO_2-C g^{-1} dw d^{-1} through composting or it must be applied to field soil in the fall to decompose further in soil before planting of the crop the following spring. In much the same way, fresh manures and crop residues in field agriculture must be adequately decomposed before planting through minimum tillage practices or plowed under to avoid pathogen stimulation and biocontrol suppression.

The other end of the decomposition scale, which implies excessively stabilized or humified organic matter, typically does not support biological control either. For example, charred or pyrolyzed particles in composts do not support the levels of microbial biomass required for suppression of root rots (Hoitink and Boehm, 1999). Charred particles are produced during composting when temperatures exceed 70^{o}C for long periods of time. This is most severe when composts are dry. Maintenance of a moisture content > 45% and adjustment of windrow height (which affects the process temperature) during composting helps to prevent charring.

Excessively humified organic matter, the other end of the decomposition spectrum, such as that in highly decomposed Sphagnum peat or as in compost after complete humification, does not support control because this stabile organic matter cannot be used as a food base by biocontrol agents (Boehm and Hoitink, 1999; Stone et al, 2004). Thus, substrate chemistry matters and the disease suppressive effects cannot be maintained indefinitely unless new organic inputs are provided!

The longevity of the suppressive effect of composts depends on many factors. Stabilized lignocellulosic substances in composts, the chemistry of which resembles particulate organic matter (POM) in soil, seem to form the basis for long-term control (Stone et al., 2004). Generally, compost-amended container media become conducive to root rot within 12-24 months after potting but this varies with the materials used and the climate. The rate of hydrolysis of fluorescein diacetate and the concentration of microbial biomass in soil seem to best reflect this suppressive effect against root rots (Hoitink and Boehm, 1999; Stone et al, 2004). Coliform populations in field soils seem to be suppressed by the same mechanism (Franz et al., 2008).

Do composts introduce biocontrol agents into soils?

Recent literature shows that few biocontrol agents with the exception of heat-tolerant bacterial biocontrol agents (*Bacillus* spp.) survive composting. Like pathogens, however, most beneficials are killed by heating during the process (Hoitink and Boehm, 1999; Termorshuizen et al, 2005). While it is possible for beneficial colonists to survive in the outer low temperature layers of compost piles, the moisture content of this layer often is too low (< 45 % (w/w) for growth of biocontrol agents. Biocontrol agents, mycorrhizae and nitrifying bacteria often do not colonize compost-amended substrates until days or weeks after the compost has been utilized (Kowalchuck et al., 2003: Hagn et al., 2008). Many studies show that biocontrol agents with efficacy against *Pythium* and *Phytophthora* colonize amended substrates within days while those that destroy sclerotium-producing pathogens (*Rhizoctonia, Slerotium*) reach effective populations much later, after weeks or months. The microorganisms that can induce systemic resistance (ISR) to disease in plants by colonizing roots and suppress foliar diseases generally are not present in composts.

For potting mixes this means that crops highly sensitive to Pythium damping-off (e.g. poinsettia) must be drenched once with an effective fungicide immediately after planting to ensure damping-off control. Thereafter, natural suppression provides control because biocontrol agents now have fully colonized the substrate and provide control (Hoitink, and Lewandowski, 2006). In field agriculture it means that composts should be applied several days and for high in salinity materials months before planting to allow beneficials to colonize the food base.

The situation can be quite different for composting plants that use small 1m tall windrows with low process temperatures, especially when a cover is used to mitigate drying during curing. After several years of operation on a site, composts produced in this manner can be expected to support higher populations of biocontrol agents in the cured product, including inoculants that can suppress foliar diseases of plants (Horst et al, 2005). The turning machines used in these small windrow systems continually facilitate dissemination of microorganisms among windrows. Turning of mature compost first, followed by turning of fresh materials last, and a clean up operation before the next turning operation, is the best strategy. However, even with composts prepared by this method, formulated media do not naturally suppress Pythium diseases adequately until several days after planting. Thus, highly sensitive crops such as begonias must be drenched at planting with a Pythium fungicide for complete control (Horst et al, 2005, Hoitink and Lewandowski, 2006). Subsequent fungicide applications typically are not required until the potting mix loses suppressiveness towards the end of its useful lifespan. Another approach is to incubate biocontrol agent-fortified potting mixes for several days in storage before potting of plants so as to allow biocontrol agents to proliferate. The best approach is to inoculate composts with specific biocontrol agents that can provide broad spectrum disease control. This is discussed further below.

Basis that underlies general disease suppression

The different responses encountered in practice with composts against diseases caused by *Phytophthora* and *Pythium* versus *Rhizoctonia* or ISR-affected diseases (includes Fusarium wilts) classically has been explained on the basis of the differences between the mechanisms that underly their suppression. Suppression of root infections by *Phytophthora* and *Pythium* can be supported by microbiostasis which implies competition and antibiotic production by competing microorganisms (Baker and Paulitz, 1996). Numerous soil microorganisms can contribute to this effect in soils. The general suppression phenomenon *sensu* Gerlach, which is soil carbon dependent, best explains this type of disease control provided by composts (Hoitink and Boehm, 1999). Other plant pathogens that produce small propagules (<200 U in diameter) seem to be suppressed by the same mechanism. Rhizoctonia and ISR (Fusarium, foliar pathogens, etc.) require much more specific activity and this is described further below under specific effects.

Recently, nucleic acid-based techniques have been used to gain a better understanding of the microbial community structure and function in disease suppressive substrates (Kowalchuck et al., 2003; Mazzola, 2004; Benitez et al., 2007; Borneman and Becker, 2007; Hagn et al., 2008). Using such approaches, very subtle shifts in community structure related to soilborne disease suppression can be observed in response to cropping history and rotation (Benitez et al 2007, Baysal et al 2008). Compost applications in the field promote dramatic transient shifts in abundance, but not in the overall structure of native microbial communities (McSpadden Gardener et al 2002). This indicates that stimulation of general suppression is mediated by enhanced growth of the microflora present in the field. Such studies generally support conclusions from earlier work based on culturing of microorganisms but also reveal that an even greater abundance of microorganisms seems to play a role in disease suppression than realized previously.

Inoculants for specific disease suppression

Specific suppression traditionally has referred to control of pathogens that produce large pathogen propagules such as sclerotia (e.g. *R. solani, S. rolfsii*). Effective control of these pathogens requires that the biocontrol agents kill these pathogens (Baker and Paulitz, 1996). This implies competition, antibiotic production as well as parasitism. Lack of consistent colonization of composts and their amended substrates by such specific microorganisms explains the inconsistent control of diseases caused by pathogens such as *Rhizoctonia* (Hoitink and Boehm, 1999). Specific strains of *Trichoderma* spp. can be inoculated into compost-amended substrates to provide a more consistent degree of control (Hoitink and Boehm, 1999; Khan et al., 2003; Horst et al, 2005; Cotxarrera et al., 2002).

We mentioned earlier that biocontrol treatments with activity against *Pythium* and *Phytophthora* do not become effective until after the introduced biocontrol agent has established itself in the substrate. The same applies to the specific introduced inoculants and it may require 5-10 days. Therefore, crops highly susceptible to Rhizoctonia damping-off such as New Guinea impatiens also must be treated with a single fungicide sprench (heavy spray) at planting to avoid losses (Hoitink and Lewandowski, 2006). Later in the cropping cycle, when the biocontrol agent has fully established it self, the inoculated mix is more suppressive to Rhizoctonia root rot of poinsettia, for example, than the most effective fungicides available for that disease. Thus, growers need to apply only one light fungicide treatment rather than the 2-4 drenches that must be applied to plants treated chemically.

In 1991 a new form of specific biological disease suppression was discovered that is effective against root and foliar diseases of plants. It is based on systemic resistance induced in plants by specific strains of biocontrol agents such as *Pseudomonas, Bacillus* and *Trichoderma* spp. that colonize roots (Pieterse, et al, 2003; Soresh et al., 2005). This systemic effect also can be induced naturally in compost-amended substrates but it is rare (Stone et al, 2003, 2004). For example, bioassays performed with container media prepared with 80 different types of composted products, which included conventional, organic and vermicomposts, revealed that only one induced systemic resistance (ISR) to foliar diseases naturally even though all suppressed Pythium damping off of cucumber and 20% of these mixes suppressed Rhizoctonia damping-off of radish (Krause et al, 2003). Several different biocontrol agents with ISR activity were isolated from the unique batch of compost that naturally induced systemic resistance in plants. In this work, *Trichoderma hamatum* 382 (T382) was identified as the most active inducer of resistance (Krause et al, 2003). Other active isolates were *Bacillus* strains, and less active isolates included strains of *Pseudomonas spp*. and others. Thus, the types of biocontrol agents isolated from the ISR-active batch of compost-amended mix agree with the spectrum of such isolates described earlier from roots in soil.

The mechanisms by which these rhizosphere microorganisms induce systemic resistance (ISR) in plants differs from SAR which is induced by chemicals and some biocontrol agents that activate the salicylic acid defense pathway in plants (Pieterse et al, 2003). The specific strains that induce ISR do not substantially activate PR protein synthesis before the pathogen invades the plant. The ethylene and jasmonic acid pathways are involved in the ISR resistance mechanism (Pieterse et al., 2003; Soresh et al, 2005) but just how pathogen populations are suppressed in plants is not fully understood. The ISR-active biocontrol agent *Trichoderma hamatum* 382 (T382) alters the expression of 45 genes in tomato (Alfano et al, 2007). These induced genes have functions associated with biotic or abiotic stress as well as RNA, DNA, and protein metabolism. Four extension and extension-like proteins in addition to PR 5 are induced. Extensin proteins have long been associated with defense mechanisms in plants (Shanmugam, 2005). Upregulation of a specific extension protein in Arabidopsis induced a high degree of resistance to bacterial spot in this plant (Wei and Shirsat, 2006).Thus, further work may show that an increase in extension gene expression induced by T382 may well account for much of the systemic benefits associated with composts inoculated with this biocontrol agent.

It is not a surprise, therefore, that many types of diseases can be reduced in severity by biocontol agents that induce the ISR mechanism in plants. Bacterial and fungal leaf spots and blights, virus diseases and nematodes all may be affected. Vascular wilts such as those caused by various forma specialis of *Fusarium oxysporum* can be suppressed more effectively by ISR than by commercial fungicides (Hoitink et al., 2006). However, the degree of control of Fusarium wilt provided by ISR depends on fertility factors. High ammonium nutrition is known to aggravate the severity of Fusarium wilts. In general high nitrate and low ammonium N nutrition reduces the severity of Fusarium wilts (tomato, celery, cyclamen, etc). This may explain why T382 provided a high degree of control of radish or cyclamen Fusarium wilt in bark compost amended mixes whereas it had no effect on the disease in low C/N composted sewage sludge-amended mixes even though the biocontrol agent colonized the substrate (Hoitink and Boehm, 1999).

Both field trials and potting mix data shows that suppression of foliar diseases with natural composts is a rare phenomenon in commercial practice. Thus, growers cannot rely on this approach to foliar disease control. On organic farms it may take years to develop. This may explain why compost-induced foliar disease control was not discovered by growers under commercial conditions whereas suppression of Phytophthora root rots with composts was practiced by growers for 20 years before plan pathologists began to study this natural suppression phenomenon! The question is whether the inconsistent ISR effect in composts can be remedied with controlled inoculants as has been accomplished for suppression of Rhizoctonia and Sclerotium diseases with biocontrol agent-fortified composts.

Interactions between soil organic matter and ISR.

Amendment of peat mixes with composts has enhances systemic effects induced by ISR-active rhizosphere microorganisms in plants. 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 papermill sludge (Pharand et al., 2002). Light peat harvested from the surface layers in peat bogs is more effective than the more decomposed dark peat which is harvested from deeper, older peat layers. Furthermore, amendment of a light peat mix with composted dairy manure enhanced suppression of Phytophthora leaf blight of cucumber induced by *T. hamatum* 382 and increased resistance of the plant to the disease (Khan et al, 2004). Finally, greenhouse tests performed with T382 in a high in microbial carrying capacity light Sphagnum peat potting mixes 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 (Horst et al, 2005). In conclusion, soil organic matter quality seems to affect the activity of ISR-active biocontrol agents just as was observed years ago for suppression of root rots (Heyl, 1999, Stone et al, 2004). A question that remains is whether the degree of resistance induced by ISR useful to growers.

To answer this question, commercial scale demonstration trials were performed with T382 in nursery container media (Hoitink et al, 2006). In a trial with rooted cuttings of *Myrica pennsylvanica*, a severe outbreak of Botryosphearia dieback caused by *Botryosphaeria dothidea* developed on the branches of this woody plant. 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 control batch of natural compost-amended mix did not provide control of the dieback disease whereas the mix inoculated with T382 provided effective control of Botryosphaeria dieback, a disease for which effective fungicides are not available!

On Rhododendron “Roseum Elegans”, a natural dieback epidemic caused by *Phytophthora citrophthora* developed (Hoitink et al., 2006). T382 significantly (P=0.05) reduced the severity of this disease. In a test with *Pieris japonica*, the percentage plants killed by *Phytophthora parasitica* was reduced by inoculation of the mix with T382 from 26 % in the treated to 4 % in the control. The reduction in Phytophthora dieback severity occurred in these tests even though the foliage of the crops had been treated repeatedly at three week intervals with Subdue and Aliette, systemic fungicides with activity against *Phytophthora*. In vitro analysis revealed that the *Phytophthora* isolates that caused these epidemics were resistant to 100 mg ml^{-1} metalaxyl, the active ingredient in Subdue. Thus, the ISR.active biocontrol agent had a marginal effect against Phytophthora blights.

Recent work shows that efficacy induced by T382 against Botrytis blight of geranium is comparable to that provided by chemical fungicide under mild disease pressures which prevail under standard greenhouse conditions when growers vent houses to reduce the relative humidity. Under high moisture conditions, the fungicide was more effective and the biocontrol agent was not effective (Olson and Benson, 2007).

In conclusion, inoculation of container media which offer the potential to naturally suppress Pythium and Phytophthora root rots with ISR-active biocontrol agents such as T382 can significantly increase the spectrum of soilborne diseases suppressed and have an impact on control of foliar diseases as well. This holistic approach to disease control is particularly useful for Fusarium wilts, powdery mildews and Botrytis blight under low disease pressures and for stress diseases such as those caused by *Botryosphaeria dothidea* because effective fungicides are not available for the latter. For control of damping-off diseases of highly susceptible floricultural crops, an initial fungicide treatment is required. However, the degree of protection provided by ISR against foliar diseases caused by aggressive *Phytophthora* species is limited. The best strategy against these diseases apart from clean stock production is to utilize irrigation strategies that minimize pathogen dissemination and leaf wetness periods in addition to fungicide applications (Hoitink and Lewandowski, 2006).

Future Outlook and how does this information apply to banana production?

Several new technologies developed during the past decade promise to significantly increase utilization of disease suppressive composts in the United States. A novel method for production of plants, known as the “pot-in-pot system”, allows trees to be produced in disease suppressive containers buried in soil (Struve, 1996). In this system, the root system is protected from winter and high temperature summer impacts and the effect last after transplanting in field soil.

The pot-in-pot system is being adopted rapidly across the U.S. Therefore, the quantity of organic matter required for such systems is beginning to exceed the supply of composted bark and rice hulls. Thus, the nursery industry increasingly is testing alternatives for these basic ingredients in potting mixes. Composted yard wastes and other types of composts high in recalcitrant materials are beginning to fill this market but typically cannot be incorporated at rates that exceed 25% (v/v). Because pots used in these systems tend to be tall (30-60 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 as long as nutrient levels do not exceed limits.

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 in disease suppressive systems. In this technology, liners of trees can be produced from seed into 1.5-2.0 m whips within one growing season. The liner then is transplanted into soil and mulched to suppress the pathogens present in the field. In a third development, the nursery industry incorporates composts and green manures between nursery crops into field soil on a 3-5 year production plan basis. Within three months after application of composted yard wastes or mixtures of composted bark and manures, a forest horizon develops in the treated soil.

The dynamics of nutrient uptake and plant growth in these mulched systems resembles that in organic agriculture under the best conditions and in natural hardwood forest ecosystems. Root rots and feeding by leaf chewing insects are suppressed on such mulched trees relative to in the fertilized non amended control (Lloyd et al., 2002). As long as yearly fertilizer inputs take into account crop fertility needs and the quantity of nutrients available to the plant in the soil and soil type, this approach to mulching 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.

Banana production could benefit from many of the practices adopted recently by the nursery industry. New banana plantations should be planted with pathogen-free plants produced from clones produced in biocontrol agent-fortified compost-amended substrates. During outplanting, composted mulches should be applied near the base of transplants to support the activity of the biocontrol agents. It may be possible to produce cultivars susceptible to Fusarium wilt with this approach that have better taste characteristics than resistant cultivars in use today. Systemic nematodes as well as systemic bacterial and viral diseases should be reduced in severity as well by these methods especially if partial resistance is available. Whether diseases such as Sigatoka can be impacted by ISR remains to be shown.

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