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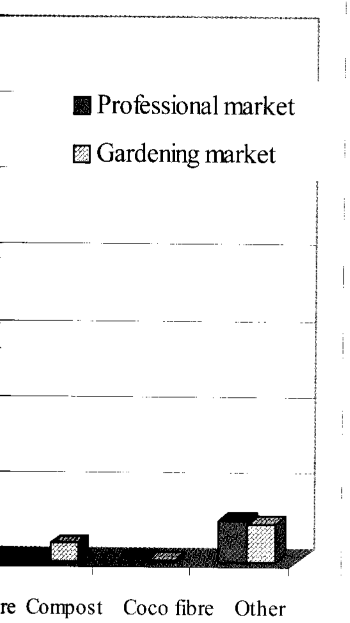

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The Use of Compost in Growing Media as Suppressive Agent against Soil-Borne Diseases

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Keywords: peat moss, suppressiveness, *Phytophthora cinnamomi*, *Fusarium* spp., *Sclerotium rolfsii, Rhizoctonia solani, Pythium* spp.

Abstract

Initially most soilless media are pathogen-free. However, an infestation during the course of the crop growing cycle is not rare. Peat moss, a common medium constituent, is especially conducive to spread of several soil-borne pathogens. Unlike peat, many compost types suppress a large range of soil-borne diseases such as those caused by *Sclerotium, Rhizoctonia, Pythium* and *Fusarium.* Compost is a term describing all organic matter that has undergone long, thermophilic, aerobic decomposition a.k.a. composting. Composts vary according to the raw material(s) used and to the nature of the composting process. Compost serving as a component of container media must be stable in order to avoid competition between microorganisms and plant roots for oxygen and nitrogen. Composts can be produced using numerous organic wastes and combinations thereof, such as sewage sludge, MSW, animal excreta, wastes of food industry, etc. Animal excreta are of special value for co-composting because they contain large, diverse populations of microorganisms, which accelerate the process. Compost disease suppressiveness is clearly linked with its degree of maturity, although excessively stabilized composts with low content of organic matter have lower suppressiveness capacity (SC). The suppressiveness causal agents are complexes of microbial and fungal populations, which invade the pile during the curing stage. Sterilization largely eliminates compost suppressiveness, suggesting that most of it results from biological activity, although some residual activity is probably related to fungistatic compounds occurring in the composts. The use of composts as constituents of growing media is discussed in relation to the nature of the raw materials, methods of compost production and practical application methods. Methods to assess microbial maturity are evaluated, as related to their SC. Examples of compost suppressiveness against several types of wilt diseases caused by *Fusarium oxysporum* are described.

GENERAL AND HISTORICAL BACKGROUND

Although many soilless media are originally free of pathogens, an infestation during the course of the growing cycle is not rare. The spread of soil-borne diseases may be epidemic in nature (especially in closed, recirculated systems) and they can inflict considerable yield or even plant losses, resulting with severe economical damage. Peat moss, a most widely-used medium constituent, is especially conducive to the rapid spread of a wide variety of soil-borne pathogens, even if sterilized before use (Hoitink et al., 1977).

About three decades ago, Hoitink and Poole (1976) published for the first time that hardwood bark compost suppresses *Fusarium oxysporum* f. sp. *chrysanthemi*, the causal agent of chrysanthemum root rot. Soon after this finding, Hoitink's group and later, few other groups, demonstrated that other compost types suppress additional soil-borne diseases such as those caused by the soil fungi genera *Sclerotium, Rhizoctonia*, *Pythium*, *Phytophthora* and others (Daft et al., 1979; Nelson and Hoitink, 1982; Lumsden et al., 1986; Hadar and Mandelbaum, 1986). The subject of using compost as a soil amendment and as a part of growing media was most recently reviewed by Noble and Coventry (2005).

Compost is a general term, describing all organic matter that has undergone long, thermophilic, aerobic decomposition a.k.a. composting. Composts can vary according to the raw material(s) used and according to the nature of the composting process.

The objectives of the current review are to describe application of compost as a practical tool for controlling soil-borne diseases of container-grown plants in a reproducible manner and to highlight the constraints to this method.

SUPPRESSIVENESS MECHANISMS

Many stable composts that undergo a proper curing stage, suppress a large range of phytopathogenic organisms (Hoitink and Kuter, 1986; Kuter et al., 1988; Mandelbaum and Hadar, 1990; Hadar and Gorodecki, 1991). Compost disease suppressiveness is clearly linked with their degree of maturity (Grebus et al., 1994; Craft and Nelson, 1996; Tuitert and Bollen, 1996), although excessively stabilized composts with low content of organic matter have lower suppressiveness capacity (SC). In a long-term study, we found that compost starts losing suppressiveness against *Fusarium oxysporum* f. sp. *melonis* (FOM) one year after production, but even two years after production it retained about 50% of the initial suppressiveness (Yogev and Raviv, unpublished).

An in-depth discussion into the different possible mechanisms of compost activities against soil-borne pathogens is beyond the scope of the current review. This subject was reviewed by Hoitink and Kuter (1986), Hoitink and Fahy (1986), Hoitink and Grebus (1994), Hoitink et al. (1997); and more recently by Hoitink and Boehm (1999) and by Lazarovits (2001). Yet, the lack of more recent reviews does not suggest that the subject was fully covered by earlier research articles and reviews. Rather, the complexity of the interacting mechanisms and affecting factors calls for additional basic research.

The main known mechanisms for compost suppressiveness are of biological nature (competition, hyperparasitism, antibiosis, induced resistance, enhanced plant vigour) and of chemical nature (existence of fungistatic compounds).

The suppressiveness causal agents are complexes of microbial and fungal populations, which invade the compost pile during the curing stage. Sterilization largely eliminates compost's suppressive effect, suggesting that most of it results from microbial activity (Mandelbaum et al., 1988; Gorodecki and Hadar, 1990; Hoitink et al., 1997; Reuveni et al., 2002; Tilston et al., 2002), although some residual activity is probably related to fungistatic compounds existing in the composts (Hoitink and Fahy, 1986).

Direct hyperparasitism is the most easily detectable suppressiveness mechanisms. Elegant examples for hyperparasitism were presented by Hadar et al., as early as 1979, showing how *Trichoderma harzianum* attacks *Rhizoctonia solani* in vitro and controls dumping-off of several infested plant species in vivo. Later, it was shown that composts that prevented dumping-off caused by *Rhizoctonia solani* contain high density of *Trichoderma harzianum* and *Trichoderma hamatum* and the activity of the isolates was reaffirmed in vitro (Kuter et al., 1983; Nelson et al., 1983). Other examples for predators include different species of myxobacteria (Bull et al., 2002) and others.

Hyphal lysis, caused by microorganisms excreting extracellular hydrolytic enzymes such as chitinase and beta-1,3-glucanase, and later consuming the resulting residues is another ubiquitous form of hyperparasitism (El-Masry et al., 2002; Mandelbaum and Hadar, 1990).

The existence of antibiotic-producing actinomycetes in composts was linked to the SC of certain composts against *Pythium graminicola*, the causal agent of damping-off and root rot of creeping bentgrass (*Agrostis palustris*) but no direct evidence of antibiosis was shown (Craft and Nelson, 1996). On the other hand, *Pseudomonas fluorescens* revealed clear antibiotic activity against the take-all disease of wheat (caused by *Gaeumannomyces graminis* var. *tritici*) and its active antibiotic compounds were chemically identified (Thomashow and Weller, 1990; Raaijmakers and Weller, 1998). Both hyperparasitism and antibiosis results with a measurable decline in the number of pathogen's propagules.

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Although less visually dramatic, competition for organic compounds, for colonization sites and for nutrients, are probably the most common suppressiveness mechanisms. This is one of the main ways compost controls the damaging effects of pathogens such as different *Fusarium* species and *Pythium ultimum* (Brito-Alvarez et al., 1995; Serra-Wittling et al., 1996; Hoitink and Boehm, 1999). Ideally, if competition is the only affecting mechanism, no reduction should be expected in the short run in the number of propagules of the pathogen (Lumsden et al., 1983; Lievens et al., 2001). This, however, is not always the case, and pathogens known to be suppressed mainly by competition such as *Pythium* and *Fusarium* spp. also show actual decline in the presence of compost in the rhizosphere after artificial inoculation. Yet, the remaining number of propagules is still sufficient for plant infestation and its absence indicates that the main affecting mechanism is, indeed, competition (Mandelbaum and Hadar, 1990; Fig. 1 in this paper).

Even more complex is the mechanisms involved in the activation of pathogenesis related (PR) genes that confer induced systemic resistance to plants, attacked by micro-organisms. Zhang et al. (1996) demonstrated, using the split root technique that cucumber seedlings, germinated in peat or in bark compost that the later medium induced resistance against *Pythium ultimum* and *P. aphanidermatum* which was transmitted to the root systems growing in peat. Also, root rot in the infested peat mix was significantly less severe on roots paired with the compost-amended mixes than those paired with the peat mix. Khan et al. (2004) demonstrated that similar effect is exerted by both compost and *Trichoderma hamatum* against Phytophthora root and crown rot of cucumber caused by *Phytophtora capsici* in cucumber transplants produced in a composted cow manure-amended mix compared with those in a dark sphagnum peat mix. Moreover, inoculation with *Trichoderma hamatum* also reduced the severity of Phytophthora leaf blight in transplants produced in the compost mix compared with controls. The fact that the *Trichoderma* and/or the compost remained spatially separated from the pathogen in these bioassays suggesting that their effects were systemic in nature. Fungistatic compounds may also contribute to disease reduction (Stone et al., 2001) as can be seen by studying residual activity of sterilized composts and effects of volatile organic molecules but their contribution to the whole suppressiveness phenomenon is secondary and still questionable.

RECENT EXAMPLES FOR AFFECTED PATHOGENS

The use of composts as constituents of growing media was studied using tomato (*Lycopersicon esculentum* Mill. cv. Hazera 139), melon (*Cucumis melo* cv. Ofir), sweet basil (*Ocimum basilicum* L. cv. Peri) and cucumber (*Cucumis sativus* cv. Ringo) as test plants and different types of compost as ingredient of growing media vs. peat moss of several origins as a control medium. The tested pathogens were the causal agents of several types of wilt diseases including *Fusarium oxysporum* f. sp. *radicis lycopersici* (FORL), *Fusarium oxysporum* f. sp. *melonis* (FOM), *Fusarium oxysporum* f. sp. *basilici* (FOB) and *Fusarium oxysporum* f. sp. *radicis-cucumerinum* (FORC). Results related to the nematode *Meloidogyne javanica* were presented elsewhere (Raviv et al., 2004). Results related to the tomato ring-rot bacterium *Clavibacter michigenense* (CBM) will be published elsewhere.

Survival of macroconidia of FOB in 3 different media is shown in Fig. 1. The propagules survived for a longer period in peat moss while composts based on a mix (1:1, V:V) of the coarse fraction of separated cattle manure (SCM) and either orange peels (OP) or wheat straw (WS) had a negative effect on propagule survival. The same media prevented completely a spontaneous infestation of fusarium crown and root rot in greenhouse-grown tomatoes, while 50% of the peat-grown plants died during the growing period (data not shown). In an effort to estimate the longevity of the suppressiveness phenomenon, the OP-SCM compost was tested 2 years after it was ready to use, vs. freshly prepared compost, containing 50% of tomato plants (TP-SCM) and peat (Fig. 2). It can be seen that the fresh compost was very effective against the highly aggressive FORC, artificially inoculated with 10^5 macroconidia per cm^3, while the old OP-SCM retained some of its original SC.

Fig. 3a presents the development with time of visual symptoms of disease in melon plants, planted to naturally infested media. Similar plants were observed under the microscope, to follow Fusarium colonization of the roots (Fig. 3b) and shoots (Fig 3c). Colonization occurs well ahead of the external symptoms of the disease. Thirteen days from planting, all the peat-grown plants died, while in 2 of the composts only 2% died at the end of the experiment, 35 days from planting. Although FOM colonized many of the apparently healthy plants, it is possible that due to the short life cycle of this crop most of the compost-grown plants will survive for the whole season. Similar results were obtained with FORC and cucumber plants and, indeed, in a large-scale commercial trial, conducted in a heavily infested area, inclusion of 25% TP-SCM into perlite resulted with 0.7% dead plants at the end of the growing season, vs. 31% dead plants in the 100% perlite control.

In a growing experiment with tomato, we encountered plant death at a mature stage. Sixty percent of the peat-grown plants died, while none of the TP-SCM compost-grown plant showed any disease symptom. Dr. Giora Kritzman identified the causal agent as *Clavibacter michiganensis*. We later conducted a survival test for the bacterium in the two media. The results suggest a clear negative effect of both media on the survival of CBM. However, TP-SCM was almost 5 orders of magnitude more effective in eradicating the CBM propagules (data not shown).

REPRODUCIBLE PRODUCTION OF SUPPRESSIVE COMPOSTS

Composts serving as a component of container media must be stable, with relatively low salinity, low concentration of phytotoxic ions and organic molecules, and free of phytopathogenic organisms. Unless all these requirements are met simultaneously, the compost may fail to serve successfully as a container medium. This may be the reason why Cull stated in 1981 that "Of the nine major organic materials reviewed, not one stands out as the alternative to peat in the UK". Since then, a wide variety of materials have been composted and served successfully as components of container media, and clear criteria for the suitability of such composts have been described (Raviv et al., 1986; Inbar et al., 1993).

The absence of direct communication among compost producers and consumers is, perhaps, the highest obstacle for a more widespread use of composts. On the one hand, compost producers are not well aware to the agronomic and horticultural uses of composts and, hence, do not make efforts to control their production methods so as to meet the consumers' demands and to ensure stable and reproducible quality of the product. On the other hand, growers are not well educated as to the effect of compost quality on the horticultural performance of their growing systems. As a result, they look for cheap products and tend to ignore the unavoidable linkage between quality and cost.

The fact that not all composts show suppressiveness is one of the reasons why the use of composts is less widespread than can be expected, based on their proven potential. In order to overcome this problem, two approaches can be taken. The first is to define reproducible composting techniques (including the choice of feedstock, optimal temperatures and moisture content throughout the process and the duration of the process). This subject was most recently reviewed by Raviv (2005). The second approach is to characterize a reliable set of parameters that may help predict the SC of the tested compost. The first, a priori method is, of course, more useful as a production tool while the second, a posteriori method may provide quality control tools.

Choice of Feedstock

Composts made of hardwood or softwood bark, wood shavings, rice hulls and coconut coir are very popular as components of growing media due to their good physical properties and the low cost of the raw material. In addition to these ligneous materials, composts serving for growing media may be produced from numerous organic wastes, such as sewage sludge, municipal solid waste, animal excreta and wastes of food industry. Wastes of the food and processing industry are especially convenient for composting since they are uniform, rich in organic matter and concentrated in place. A few examples

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for such raw materials are: apple pomace (van de Kamp, 1986), sugar-cane fibre (bagasse) (Trochoulias et al., 1990), vegetable residues (Vallini et al., 1992), grape stalks and corn cobs (Accati et al., 1996), orange peels (Raviv et al., 2004) and many others.

Animal excreta are of special value for both composting and co-composting because they contain large, diverse populations of microorganisms, capable of decomposing a wide variety of organic macromolecules, including recalcitrant ones. Manures are normally generated within agricultural regions where there is wide availability of raw materials for co-composting. Typically, in rural regions, the demand for the products comes from nearby operations and does not require long-distance hauling.

Production Methods

Reproducible production methods leading to high quality compost, suitable for substrates, should yield composts of both adequate physical (high AFP, high EAW) and biological (low BOD, suppressiveness) natures. Reconciling these demands is not always easy. As a general rule, both turned windrow and in-vessel composting tend to exert a negative effect on the physical properties of the composts due to frequent mechanical grinding of the raw material. Aerated semi-static pile is a recommended composting method for growing media. In this case, the compost should be turned only rarely, in order to ensure homogeneity.

High temperatures may cause ashing, which lead to reduced porosity and increased bulk density. High temperatures during the thermophilic stage also lead to low SC which is probably linked to low organic matter content (Millner et al., 1987). Temperatures must be controlled carefully and values above 65°C must be avoided. Temperature control is relatively easy in both in-vessel systems and aerated piles in terms of both temporal and spatial uniformity. Optimal moisture content is important for both microbial activity and temperature control, since most of the energy is released in the form of latent heat. Therefore, moisture content should be carefully controlled throughout the thermophilic stage.

Ligneous materials such as bark, wood shavings, rice hulls and coconut coir are relatively resistant to decomposition. Therefore, compost operators tend to assume that they are saleable before full maturation is actually achieved. In such a case, these products may undergo secondary breakdown while in the container due to the favourable conditions for microbial activity, namely relatively high temperatures, high MC and high nutrient availability. This situation may be accompanied by high nitrogen and oxygen consumption by microorganisms. This phenomenon is bound to interfere with standard, predictable plant nutrition and results with less-than-satisfactory plant performance (Handreck, 1992a, b). It is therefore clear that these types of raw materials should be subjected to long and well-controlled composting. The composting of these raw materials may be shortened using nitrogen (usually as urea) and N-rich organic matter such as animal manures. Moreover, a well-documented composting stage, essential for SC is a curing period (Tuitert et al., 1998). The curing stage can only start once the compost is stable.

Quality Control

Several quality indices, linked with SC were suggested. Among them are availability of cellulose (Tuitert and Bollen, 1996); composts' organic matter content (Erhart and Burian, 1997) and enhanced microbial activity, functional and population diversity (Diab et al., 2003). The above proposed parameters suggest that although compost should be mature in order to possess high SC, it should not be overdone and that high microbial activity is essential for SC. This fact reiterates the importance of a strict control over temperature regime during the course of the composting process, as temperatures higher than 65–70°C cause ashing and rapid decline of organic matter content, microbial activity and diversity.

APPLICATION METHODS AND CONSTRAINTS

In addition to their well-known use for soil amendment, an increasingly popular use of composts is a constituent in container media. The two main reasons for this popularity are: (a) In many cases, non-edible crops such as ornamentals, forest and garden trees and shrubs etc. can serve as a safe outlet for composts that may be considered as non-desirable for food crop production, (b) Various composts act equally well as peat moss in growing media, while their cost is considerably lower. The fact that mature composts are also suppressive to several soil-borne pathogens, to which peat is conducive, has encouraged many growers to substitute part or all of the peat with such composts. Typical examples for the use of composts in container media include transplant production, substrates for pot plants, forest and fruit tree saplings and substrates for greenhouse-grown plants, especially ornamentals but in some cases also edible crops. Usually compost constitutes 25–50% of the substrate; however, in many cases it was found that a rate of 10–25% is sufficient to induce suppressiveness. Compost types that had been used include combination of biosolids and yard trimmings (Wilson et al., 2002); cattle manure (Raviv et al., 1998), forest waste, pine bark and yard composts (Marfa et al., 2002); spent mushroom compost (Young et al., 2002) and many others.

The main constraints to the use of composts in container media may be of chemical, biological or physical nature. Immature composts may exert strong phytotoxicity due to the existence of toxic compounds such as short aliphatic acids (Shiralipour et al., 1997), polyphenols (Garcia et al., 1992) and others. Composts serving as a component of container media must be stable in order to avoid competition between microorganisms and plant roots for oxygen and nitrogen. From the biological standpoint composts that were not prepared properly may be infested with plant pathogens. This may occur if the thermophilic stage was too short or did not reach adequate temperatures (>55°C). Physically, composts serving for growing media should have relatively low bulk density (<0.4 g cm^{-3}) and at least 10% of air at container capacity.

CONCLUSIONS AND REQUIRED FUTURE RESEARCH

In general, it can be stated that the current knowledge allows for a much wider application of composts as ingredients of container media than is now practiced. Composts can provide the root zone with an SC against a broad range of pathogens and replace the use of significant amount of pesticides, including the phased-out methyl bromide.

A better understanding of this phenomenon requires mechanistic research, aiming at a more accurate description of the factors responsible to it and especially the interactions among them. More research should be devoted to the connection among composting conditions (e.g., raw materials, procedure, degree of maturity) and the extent of the SC in terms of both efficiency and range of defense. A more practical research should be done in order to test the possibility of inoculating composts with microorganisms that can enhance the suppressiveness phenomenon.

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