Effects of Municipal Sludge Compost Curing Time on Suppression of *Pythium* and *Rhizoctonia* Diseases of Ornamental Plants

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ABSTRACT

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Composts prepared from municipal sewage sludge and formulated into container media initially were conducive to both Pythium and Rhizoctonia damping-off. Sludge composts cured 4 mo, when temperatures in the center of piles were < 60 C, consistently suppressed Pythium damping-off but not Rhizoctonia damping-off. Additional storage of media prepared with 4-mo-cured sludge compost for a 4-wk period consistently rendered them suppressive to both diseases. The levels of suppressiveness induced in such media amended with 25% (v/v) sludge compost were adequate to avoid plant losses caused by *Rhizoctonia solani* or *Pythium* spp. in greenhouse and nursery crops over 5-mo and 2-yr production cycles, respectively.

During the past decade, composts prepared from a variety of organic wastes have been utilized successfully in container media for suppression of soilborne diseases of ornamental plants. Examples are composts prepared from tree barks, licorice root waste, grape pomace, separated cattle manure, and municipal sewage sludge (3,8,15,16). The mechanisms of suppression that are involved vary with the pathogen, the source or type of compost, and the level of decomposition achieved during the composting process (8,9). Suppression of Rhizoctonia and Pythium damping-off is due to the activity of microbial antagonists (3,4,13,17).

Composting has become a common practice for treatment of municipal sewage sludges. Long-term high temperature treatment (> 55 C) is an integral part of this process to ensure fecal pathogen and parasite destruction (1). After composting, the product is cured in large piles, during which self-heating still occurs. As temperatures decline, mesophilic microorganisms recolonize the compost. The fate of the beneficial microflora involved in suppression of *Rhizoctonia* and *Pythium* diseases during this composting and curing process for municipal sludge has not been determined.

In this paper we show that the curing time of compost affects the suppression of Pythium and Rhizoctonia damping-off. Furthermore, storage of media after their formulation affects suppressiveness. Finally, the length of time that media remain suppressive under production conditions was investigated.

MATERIALS AND METHODS

Compost and container media. Composted municipal sludge was obtained from the Southwesterly Composting Facility, Columbus, OH 43215. It was prepared from polymer-dewatered, aerobically-digested municipal sewage sludge by the static positive-pressure-aerated pile composting process (6). In this process, wood chips and attached tree bark are used as bulking agents. After a minimum of two 21-day periods of composting in these piles, compost was screened to remove wood chip particles > 1.8 cm in diameter. Thereafter, to reduce chances of reintroducing fecal pathogens into the compost, it was cured in isolated locations on a concrete pad in windrows of various heights (up to 6 m high) for up to 1 yr before utilization. Temperatures > 70 C may occur in such large curing piles (11). In some experiments, composted municipal sludge was prepared in 100 m^3 pilot-scale aerated bioreactor vessels operated with a mean retention time of 12.6 days (11). Bark, sawdust, and recycled compost were used as bulking agents. Compost was cured 4 mo without turning in approximately 35 m^3 piles. These curing piles were stored directly adjacent to bark compost piles amended with mineral nitrogen instead of municipal sludge (13).

A sludge compost container medium was prepared by mixing composted municipal sludge, Canadian sphagnum peat, and perlite (1:2:1, v/v, pH 5.5). This medium was not amended with plant nutrients because sludge compost media release adequate amounts for plant growth for at least 6 wk after potting (2). A peat container medium was prepared from Canadian sphagnum peat and perlite (1:1, v/v) and adjusted to pH 5.5 with a 2:1 (w/w) mixture of dolomitic and hydrated lime. Slow-release fertilizer was added as described previously (13).

Bioassays to detect suppression of Pythium and Rhizoctonia damping-off. Suppression of Pythium damping-off was determined with a cucumber bioassay (3). Inoculum of isolate 211 of *Pythium ultimum* Trow, originally obtained from a diseased poinsettia plant at the Plant Disease Clinic, Department of Plant Pathology, The Ohio State University, Columbus, was prepared in Ko and Hora's chopped potato soil medium (10), dried, and screened as described previously to yield 1–2 mm diameter inoculum pieces (13). Suppressiveness to Rhizoctonia damping-off was determined with a radish (*Raphanus sativus* L. 'Early Scarlet Globe', 97% germination) bioassay (13,17). Soil inoculum of *Rhizoctonia solani* Kühn also was produced in Ko and Hora's chopped potato soil mixture, air-dried, and screened to yield 1–2 mm soil inoculum pieces, as described above.

Unless specified otherwise, 0.5 g of either soil inoculum was added per liter container medium (200 g dry weight) in polyethylene bags. Bags were shaken vigorously to ensure uniform distribution of inoculum and contents were then distributed into five pots (400 ml/pot). For the *Pythium* bioassay, cucumber

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seeds (*Cucumis sativus* L. 'Straight Eight', 90% germination) were planted in disposable styrofoam pots (eight seeds/10 × 10 cm diameter pot) with a perforated base containing approximately 400 ml of container medium. Plants were grown at a constant temperature of 20 C under 16-hr illumination (225 μE m^{-2} sec^{-1}) per day, and were watered daily. In the *Rhizoctonia* bioassay, radish seeds were planted at a mean distance of 1.4 cm from each other in pots containing approximately 400 ml of container medium (32 seeds/10 × 10 cm diameter pot). Pots were watered and incubated in a growth chamber at 25 C under continuous illumination (225 μE m^{-2} sec^{-1}).

A disease severity rating was made 10 days after planting for cucumber and after 7 days for radish, according to the following scale: 1 = symptomless; 2 = diseased but not damped-off; 3 = postemergence damping-off; and 4 = preemergence damping-off. Diseased seedlings and nongerminated seeds were surface-sterilized in 1% sodium hypochlorite (30 sec), rinsed in sterile distilled water three times, and placed on SA-PBNC (19), a semiselective medium for *Pythium* spp., or on acidified Difco potato-dextrose agar (PDA) for *R. solani* to reisolate the pathogens.

Unless specified otherwise, bioassays were set up within 24 hr after samples were collected and media were prepared. Completely randomized designs with five replicates per treatment were used in both bioassays. One way analysis of variance was performed using a MINITAB computer program. Separations of means were based on least significant difference (LSD) at $P = 0.05$.

Effect of compost curing time on suppressiveness of container media. Freshly screened compost received from the Southwesterly Composting Facility was cured in 25 m^3, 2.2 m high piles on a concrete pad adjacent to, but separated from, bark compost piles. Curing piles were not turned following procedures practiced during curing and storage at composting plants for municipal sludge. Temperatures in the center of piles were monitored daily during the first week of curing, and weekly thereafter.

At various times, samples of compost were removed from both the edge and the center of piles. Sampled areas were marked so the same location was sampled only once. This avoided mixing compost in the pile, and made certain that conditions were similar to those used at composting plants.

Compost samples removed from the edge and center of piles were mixed separately with Canadian sphagnum peat and perlite to prepare sludge compost media, as described above. These media hereafter are referred to as edge and center sludge compost media. To avoid differences in properties among batches of peat, the same batch of steam-sterilized (60 min, 115 C) Canadian sphagnum peat-perlite was used for all samples for an entire curing trial. In these experiments, *Pythium* and *Rhizoctonia* disease severity bioassays were set up within 4 hr after samples were collected. Infested and noninfested peat media were used as controls in each bioassay. These controls were also included because emergence and growth of seedlings in inadequately cured composts can be inhibited due to the accumulation of phytotoxic concentrations of fermentation end products in the container medium (8). Data were analyzed as described above under bioassays. The entire curing trial was performed with three separate batches of composted municipal sludge.

Effect of container medium storage on suppressiveness of container media. A container medium was prepared with a mixture of center and edge compost recovered randomly from 2.2 m high piles that had cured 4 mo, to obtain a sample that represented the entire pile. This sludge compost medium (approximately 40% moisture, w/w) was stored at 25 C in polyethylene bags (30 L/bag). Self-heating did not occur in these bags during storage. Within 4 hr after formulation of this medium, and at weekly intervals thereafter, bioassays were performed to determine suppressiveness to Pythium and Rhizoctonia damping-off. The peat medium (not sterilized) was stored in bags and used as a control. Data were analyzed as described under bioassays. The experiment was performed twice with separate batches of compost.

In another approach, two batches of sludge compost medium were prepared with compost cured more than 4 mo in 5–6 m high piles at the Columbus Southwesterly Composting Facility. After their formulation, these sludge compost media were stored in 2.2 m high piles at a commercial greenhouse and monitored for suppressiveness for several months. Self-heating did not occur in these storage piles. The peat medium, also stored on the site, was used as a control. Data were analyzed as described under bioassays.

Suppressiveness of nursery sludge compost container media. In May 1984, composted municipal sludge cured in 5–6 m high piles at the Columbus Southwesterly Composting Facility was used to formulate sludge compost media at two commercial nurseries in Ohio. The nursery media consisted of sludge compost, fresh pine bark, Canadian sphagnum peat, and expanded shale (1:2:1:1, v/v, pH 5.5). Potting of plants started 3 days after medium formulation. Roots of *Cotoneaster apiculata* Rehd. E. H. Wils. and of *Taxus media* Rehd. plants produced from rooted cuttings in 4-L containers were examined throughout the 1984 and 1985 growing seasons. Samples of the sludge compost nursery media were collected on the day of potting. Soil fungicide drenches were not applied to either crop. In addition, in July and November 1984 and again in October 1985, at the end of the second growing season, samples of the container media were removed from each of 20 randomly selected plants of *C. apiculata*. Roots were carefully removed from the container medium and bioassays were then set up within 4 hr on each sample. In addition, root pieces were plated on PDA and on the selective medium for *Pythium* spp. to isolate pathogens from plants of *C. apiculata* and *T. media*. Nurserymen do not routinely use peat media for production of woody plants in containers because of severe root rot losses experienced in such media (7,20). Therefore, the peat medium, as described above, was prepared and used as a control for each bioassay. It was not sterilized before use. Data were analyzed as described under bioassays.

Suppressiveness of greenhouse sludge compost container media. Two separate batches of sludge compost were utilized in container media at a commercial greenhouse during 1984 and 1985. The compost had been cured more than 4 mo in 5–6 m high piles at the Columbus Southwesterly Composting Facility. The first batch of sludge compost medium was utilized without storage, immediately after its formulation. The peat medium and the sludge compost medium, prepared as described above, were used for production of a variety of crops including cyclamen, geranium, and chrysanthemum cultivars.

A second batch of sludge compost medium was prepared 1 mo before its utilization and stored in a 2.2 m high pile. Temperatures in the center of this storage pile did not exceed 35 C at any time. Approximately 35,000 poinsettia plants were potted (15-cm-diameter pots) in each of the sludge compost media and in a commercial peat medium. The commercial peat medium consisted of Canadian sphagnum peat and styrofoam instead of perlite. Therefore, it was essentially the same as the peat medium used in the rest of the work. Again, soil fungicide drenches were not applied.

Before potting, and at monthly intervals thereafter, container media samples were removed from just below the root zone in pots of 20 randomly selected poinsettia plants produced in each container medium. After roots had reached the bottom of the pot, they were carefully screened from the medium samples. Bioassays were set up on these media samples within 4 hr after their collection.

In December 1984, roots of flowering poinsettia plants were rated as described previously (5) for root rot severity, according to 1 = symptomless; 2 = mild root rot; 3 = severe root rot; 4 = severe root and crown rot; and 5 = dead plant.

Roots of diseased plants were plated on PDA and on the selective medium for *Pythium* spp., as described under bioassays. Root rot severity ratings were determined for four replications of 20 plants each, selected randomly from the 35,000 poinsettia plants in each container medium. One way analysis of variance was performed using a MINITAB computer program. Separations of means were based on least significant difference.

Various Easter lily cultivars also were produced on both media. Fungicide drenches were not applied. At flowering, roots of four replications of 10 plants each were rated for root rot severity, and data were analyzed as described above for poinsettias. Roots of diseased plants were plated on PDA and the selective *Pythium* medium, as described under bioassays.

RESULTS

Effect of compost curing time on *Pythium* and *Rhizoctonia* disease severity. Sludge compost media formulated with 4-mo cured compost prepared in the aerated bioreactor and stored near piles of composted hardwood tree bark suppressed both Rhizoctonia and Pythium damping-off (mean disease severity values of 2.5 and 1.8 for Rhizoctonia and Pythium damping-off, respectively). On the other hand, disease severity values in the infested peat media were 3.4 and 3.6 (Rhizoctonia $LSD_{0.05}$ = 0.4; Pythium $LSD_{0.05}$ = 0.8). Heating of the sludge compost medium (5 days, 60 C) destroyed the suppressive effect to both diseases (disease severity values >3.0).

Four days after wood chips had been screened out of compost received from the Columbus Southwesterly Composting Facility, temperatures in the center of the 2.2 m high (25 m^3) curing piles ranged from 68 to 72 C (Fig. 1). After 2 wk this temperature had declined to 60 C. Thereafter, temperatures gradually declined to 35 C after 12 wk of curing. Similar temperature profiles were obtained in two other curing piles.

Cucumber seedlings emerged without symptoms of phytotoxicity in edge sludge compost container media that were not infested with *P. ultimum*. However, emergence was significantly reduced ($P = 0.05$) in the center sludge container medium not infested with *P. ultimum* if prepared with compost cured 2 wk (Table 1). *Pythium ultimum* was not recovered from affected seedlings, so that lack of emergence could not be attributed to contamination with *Pythium* inoculum among treatments. The uninfested center sludge compost medium prepared with compost cured 4 wk or more did not reduce emergence and, therefore, was not phytotoxic to cucumber.

Severe Pythium damping-off developed in the center sludge compost medium prepared with 2-wk-cured compost (Table 1). After 4 wk of curing it was mildly suppressive (mean disease severity 2.8), and after 6 wk of curing it was highly suppressive (mean disease severity 1.4). *Pythium ultimum* was recovered from the damped-off seedlings. Disease severity values in the suppressive edge sludge compost media ranged from 1.2 to 1.5. The edge medium, therefore, suppressed Pythium damping-off at all maturity levels. The sterilized peat medium was consistently conducive. Disease severity ratings in this infested medium ranged from 3.7 to 4.0.

Radish seedlings that emerged in the center sludge compost medium prepared with compost cured 8 wk or less developed phytotoxicity symptoms. After 12 or more weeks of curing, emergence was similar to that in the peat control and edge compost media. Symptoms of phytotoxicity were not observed on radish seedlings produced in container media amended with edge compost of any of the maturity levels. High levels of Rhizoctonia damping-off were observed in the edge sludge compost medium prepared with compost cured 6 wk or less (Table 2). After 8 wk of curing, the disease severity value was 2.3 and the edge sludge compost was suppressive to Rhizoctonia damping-off. Disease severity values in center sludge compost media prepared with compost of all maturity levels, including 12 wk of curing, ranged from 3.4 to 3.6. The center sludge compost media, therefore, were consistently conducive. Disease severity values in the sterilized peat medium also were high (3.4–3.8) ($LSD_{0.05}$ = 0.4).

Effect of compost maturity on disease severity was examined with two other batches of composted municipal sludge. After 4 mo of curing, when the temperature in the center of the piles was <40 C, center sludge compost media were not phytotoxic to radish or cucumber but were conducive to Rhizoctonia damping-off. The same center sludge compost media were suppressive to Pythium damping-off, however. Edge sludge compost media were consistently suppressive to Pythium damping-off. They were initially conducive to Rhizoctonia damping-off but became suppressive with increased curing time, as described above.

On four occasions, compost samples were collected from 5–6 m high piles cured 4 mo or more at the Columbus Southwesterly Composting Facility. Radishes produced in media prepared with these samples had *Rhizoctonia* disease severity values >3.2 and these media, therefore, were consistently conducive to Rhizoctonia damping-off. The same sludge compost media, however, were consistently suppressive to Pythium damping-off.

Effects of container medium storage on suppression of Pythium and Rhizoctonia damping-off. Three separate batches of composted municipal sludge cured 4 mo or more in 2.2 m high piles and formulated into container media were suppressive to Pythium damping-off (mean disease severity levels 2.6). Batches of peat media that had not been sterilized and were used as controls were conducive (mean disease severity ratings ranging from 3.2 to 4.0; $LSD_{0.05}$ = 0.8).

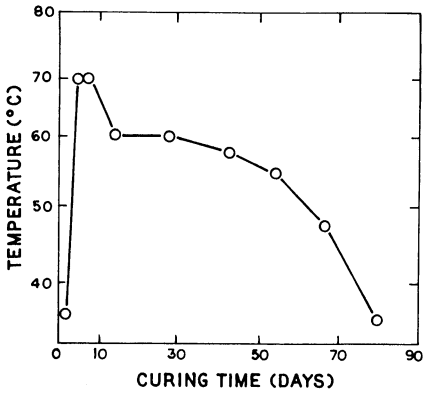

Fig. 1. Temperature (C) profile of composted municipal sludge in the center of a curing pile (mean of three readings).

Table 1. Effect of compost curing time on suppression of Pythium damping-off in container media amended with composted municipal sludge removed from the edge or center of a compost pile

Curing time (weeks)	Disease severity[a]			
	Edge compost[b]		Center compost[b]	
	Check	Infested	Check	Infested
2	1.2	1.3	2.0	3.7
4	1.2	1.4	1.3	2.8
6	1.1	1.3	1.1	1.4
8	1.1	1.2	1.4	1.8
12	1.0	1.5	1.0	1.5
$LSD_{0.05}$	0.7			

[a] Based on five replicates of eight cucumber seeds per pot determined 10 days after planting. Infested with 0.5 g of *Pythium ultimum* inoculum per liter of container medium. 1 = Symptomless; 2 = diseased but not damped-off; 3 = postemergence damping-off; 4 = preemergence damping-off.
[b] Container media prepared with compost removed from the edge or center of the compost pile.

These same sludge compost media, however, varied in effects on Rhizoctonia damping-off. An example of a bag storage test is presented in Figure 2. Initially, both the peat and the sludge compost medium were conducive, although the sludge compost medium was significantly ($P = 0.05$) less conducive. After 3 wk of storage, the mean *Rhizoctonia* disease severity in the sludge compost medium had declined to 2.5. The peat medium remained conducive, however (mean disease severity >3.0). Similar results were obtained for Rhizoctonia damping-off in bag storage trials with one other batch of composted municipal sludge.

In another approach, two batches of the sludge compost medium prepared with compost cured in 5–6 m high piles were stored in 2.2 m high piles at a commercial greenhouse. Sludge compost media collected 1 day after their formulation were suppressive to Pythium damping-off (mean disease severity ratings of 2.4 and 1.8 for two separate batches). However, both batches were conducive to Rhizoctonia damping-off at this time (disease severity values of 3.6 and 3.7). After 1 mo storage, the mean disease severity ratings had declined to 2.4. During the following 4 mo thereafter, mean *Rhizoctonia* disease severity ratings ranged from 1.9 to 2.5. Values for the peat medium used as a control in these bioassays ranged from 3.4 to 4.0 ($LSD_{0.05} = 0.4$).

Suppression of *Pythium* and *Rhizoctonia* diseases during nursery crop production. Mean *Pythium* disease severity values in the nursery sludge compost medium from the time of potting in May 1984 until the conclusion of the following growing season in October 1985 ranged from 1.8 to 2.6 (Table 3). Disease severity values for the peat medium used as a control in the bioassays ranged from 3.5 to 4.0, and were significantly ($P = 0.05$) higher. The nursery sludge compost medium remained suppressive to Pythium damping-off throughout both growing seasons. Results obtained on Pythium damping-off at another nursery were similar, but mean disease severity values ranged from 1.5 to 2.3.

At the time of potting, the nursery sludge compost medium that had been formulated 3 days earlier (not stored before utilization) was conducive to Rhizoctonia damping-off (mean disease severity value 3.7). Two months later in July and then during the 1984 and 1985 growing seasons mean disease severity values ranged from 2.6 to 2.9, and were significantly ($P = 0.05$) lower than those in the conducive peat medium used as a control in these bioassays (Table 3).

Plant losses (*C. apiculata* and *T. media*) were not observed in the sludge compost media at either location. *Rhizoctonia solani* was not recovered from plants produced in these media. However, *Pythium irregulare* Buis. was isolated in both the 1984 and 1985 seasons from roots of *T. media* and *C. apiculata* at both locations.

Suppression of *Pythium* and *Rhizoctonia* diseases during greenhouse crop production. The first batch of sludge compost medium utilized for greenhouse crop production was suppressive to Pythium damping-off (mean disease severity rating 2.2) on the third day after its formulation. It was as conducive to Rhizoctonia damping-off at that time as the peat medium (mean disease severity ratings 3.6; $LSD_{0.05} = 0.4$) *Rhizoctonia solani* was isolated from diseased cyclamen plants produced in both the peat and the sludge compost medium. Pythium root rot also developed on this crop in the peat medium, but not on plants in the sludge compost medium. *Pythium aphanidermatum* (Edson) Fitzp. was isolated from rotted roots of cyclamen plants in the peat medium.

Temperatures in the center of the second batch of sludge compost medium that was stored 1 mo after formulation in a 2.2 m high pile and was used for poinsettia and Easter lily production did not exceed 35 C. This medium was suppressive to Pythium damping-off throughout the poinsettia season (disease severity ratings of 1.8–2.2). The peat medium, on the other hand, was conducive throughout the season (disease severity ratings of 3.1–4.0; $LSD_{0.05} = 0.8$). At the time of potting, the mean Rhizoctonia damping-off severity rating in this sludge compost medium was 2.4 (Fig. 3). It remained suppressive throughout the poinsettia production season. The peat medium remained conducive to Rhizoctonia damping-off throughout the season (mean disease severity values >3.0).

Rhizoctonia solani and *P. aphanidermatum* were isolated from poinsettia plants produced in both media. At flowering, the mean root rot severity rating for the poinsettia plants produced in the peat medium was 2.8 and was

Table 2. Effect of compost curing time on suppression of Rhizoctonia damping-off in a container medium amended with composted municipal sludge removed from the edge of a compost pile

Curing time (weeks)	Disease severity[a]	
	Check	Infested
2	1.4	3.6
4	1.8	3.4
6	1.4	3.0
8	1.3	2.3
12	1.3	2.5
$LSD_{0.05}$	0.4	

[a] Based on five replicates of 32 radish seeds per pot determined 7 days after infestation with 0.5 g of *Rhizoctonia solani* inoculum per liter of container medium. 1 = Symptomless; 2 = diseased but not damped-off; 3 = post-emergence damping-off; 4 = preemergence damping-off.

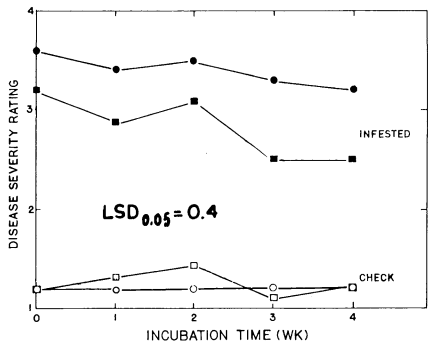

Fig. 2. Effect of container medium storage on suppressiveness to Rhizoctonia damping-off. • = Peat medium, ■ = sludge compost medium. Disease severity rating: 1 = symptomless; 2 = diseased but not damped-off; 3 = postemergence damping-off; and 4 = preemergence damping-off. Infested with 0.5 g of *Rhizoctonia* inoculum per liter of container medium. $LSD_{0.05}$ for all sampling times combined = 0.4.

Table 3. Suppressiveness of a nursery sludge compost and a peat container medium to Pythium and Rhizoctonia damping-off as determined by bioassays

Container medium	Pathogen[a] treatment	Disease severity rating[b]							
		Pythium				*Rhizoctonia*			
		May 1984	July 1984	November 1984	October 1985	May 1984	July 1984	November 1984	October 1985
Sludge compost	Check	1.1	1.0	1.0	1.1	1.5	1.2	1.2	1.1
	Infested	1.8	2.6	2.3	2.1	3.7	2.6	2.8	2.9
Peat	Check	1.2	1.1	1.7	1.2	1.3	1.3	1.7	1.1
	Infested	3.9	4.0	3.5	3.8	3.9	3.9	3.6	3.8
LSD ($P = 0.05$)		0.8				0.3			

[a] Infested with 0.5 g of *Rhizoctonia solani* or *Pythium ultimum* soil inoculum per liter of container medium.

[b] Disease severity ratings: 1 = symptomless; 2 = diseased but not damped-off; 3 = postemergence damping-off; and 4 = preemergence damping-off, based on five pots each planted with 32 radish and eight cucumber seeds for the *Rhizoctonia* and *Pythium* bioassays, respectively.

significantly ($P = 0.05$) lower (1.1) in the sludge compost medium (Table 4). Easter lilies potted in the peat medium and in a batch of sludge compost medium stored 3 mo before utilization also developed significantly higher ($P = 0.05$) levels of root rot in the peat medium than in the sludge compost medium (3.8 vs. 2.8) (Table 4).

DISCUSSION

Sludge compost media prepared with compost removed from areas in curing piles with process temperatures < 60 C increased in suppressiveness to Pythium damping-off as temperatures declined (Fig. 1, Table 1). Furthermore, heating of the suppressive sludge compost medium destroyed the suppressive effect. Because the peat-perlite component of this sludge compost medium had been sterilized, the source of the suppression was the compost itself. This verifies previous findings for the activity of the microflora in various temperature zones of bark compost (3) and licorice root compost piles (15) against *P. ultimum* and *P. aphanidermatum*, respectively. Therefore, this suggests that compost curing pile temperatures can be used as an indicator of the potential suppressive effect to Pythium damping-off of a substrate amended with such compost.

Plant losses caused by *Pythium* spp. were not encountered at any of the commercial sites studied, although mild levels of root rot were found (Table 4). On the other hand, severe root rot was found on equivalent plants produced in conducive peat medium in a commercial greenhouse. These losses were caused by *P. aphanidermatum* naturally present in that environment. From nursery stock, *P. irregulare* was isolated. The greenhouse and nursery sludge compost media, therefore, suppressed not only diseases caused by *P. ultimum*, but those caused by other important *Pythium* spp. as well. Finally, this research demonstrates that data generated with this Pythium damping-off bioassay could predict plant losses with these container media under commercial conditions.

Mechanisms involved in suppression of diseases caused by *P. ultimum* and *R. solani* differ. *Rhizoctonia solani* propagules are eradicated from bark compost media colonized by hyperparasitic *Trichoderma* spp. (17), whereas propagules of *P. ultimum* and *P. aphanidermatum* survive but are suppressed through microbiostasis (3,4,15). It is not surprising, therefore, that several batches of the various types of sludge compost media were conducive to Rhizoctonia damping-off, even though they were suppressive to Pythium damping-off. All batches of sludge compost media that were suppressive to Rhizoctonia damping-off immediately after their formulation were media prepared with sludge compost cured 2 mo or more and stored directly adjacent to piles of composted hardwood bark. The outer low temperature layer of bark compost piles is known to harbor high population levels of antagonists against *R. solani* (4,12,13). Possibly, beneficial microorganisms from the bark compost piles colonized the outer low temperature layer of the sludge compost piles, thus rendering it suppressive. Interestingly, the center samples of these piles still were conducive, even though the mean temperature after 3 mo of curing had declined to 35 C.

Composted municipal sludge stored 4 mo or longer in 5–6 m high piles at the Columbus Southwesterly Composting Facility consistently did not suppress Rhizoctonia damping-off immediately after its formulation into various types of sludge compost container media. Sphagnum peat can be a source of antagonists of *R. solani* (21). Therefore, we sterilized sphagnum peat used in the preparation of sludge compost media with compost samples removed from the edge or center of piles. However, the Canadian sphagnum peat used in the preparation of sludge compost media at the commercial greenhouse and nurseries was not sterilized. Therefore, sphagnum peat was not a reliable source of antagonists for induction of suppression to Rhizoctonia damping-off, because some of the media remained conducive.

Losses caused by *R. solani* in a commercial greenhouse on cyclamen plants in a batch of *R. solani*-conducive sludge compost medium, as well as the conducive nature of the nursery sludge compost medium at the time of potting (Table 3), show that preventative control measures must be taken with sludge compost media. Apparently, the composting and curing process, as well as the environment at the Columbus Southwesterly Composting Facility, was not conducive for survival of beneficial microorganisms involved in suppression of Rhizoctonia damping-off. We have shown previously that this microflora in composts does not survive long-term exposure to 55 C (13,17). It is surprising, however, that adequate numbers or types of beneficial microorganisms apparently did not recolonize the screened sludge compost during curing in the isolated piles at the plant. These microorganisms are part of the natural microflora of hardwood tree bark (12,18), and bark is a component of wood chips used as a bulking agent in the compost process there.

Previously, we have shown that the environment surrounding the hardwood bark composting process affects the fungal species diversity and the relative population density of fungal antagonists of *R. solani* present in compost (12,18). Composted hardwood tree bark produced adjacent to a forest is colonized by a greater diversity of fungal species than that produced in a partially enclosed composting vessel (12). Apparently, such differences also existed in this work between batches of sludge compost cured in large piles at the composting plant and those cured in piles directly adjacent to the suppressive bark compost piles.

Two approaches can be used to render composts suppressive to Rhizoctonia and Pythium damping-off. The first is to manipulate the natural microflora present in the compost. The second is to introduce antagonists after the compost has been stabilized adequately for utilization purposes, but before peak temperatures have declined (3,13). We found that storage of sludge compost media for 3 wk or more after their formulation consistently solved the conduciveness dilemma. Whether stored in bags or in bulk piles at growers, adequate levels of suppressiveness to Rhizoctonia damping-off developed to prevent losses. The only losses caused by *R. solani* in a sludge compost medium in this work were those in the conducive batch that was utilized immediately after its formulation. These findings support those of Lumsden et al (14), who reported

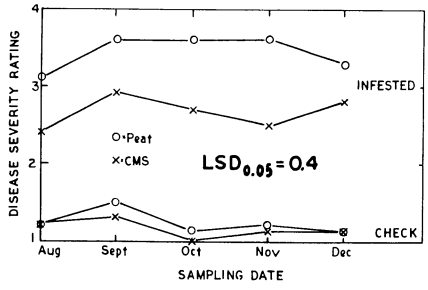

Fig. 3. Suppressiveness of peat and a sludge compost medium (CMS) to Rhizoctonia damping-off during production of poinsettia plants. Media were infested with 0.5 g of *Rhizoctonia* inoculum per liter of container medium. Disease severity rating: 1 = symptomless; 2 = diseased but not damped-off; 3 = postemergence damping-off; and 4 = preemergence damping-off. $LSD_{0.05}$ for all sampling times combined = 0.4.

Table 4. Root rot severity of poinsettias and Easter lilies produced in a commercial greenhouse in a peat and a sludge compost container medium

Medium	Mean root rot rating[a]	
	Poinsettia[b]	Easter lily[c]
Peat	2.8	3.8
Sludge compost	1.1	2.8
LSD ($P = 0.05$)	0.9	0.4

[a] Mean root rot rating: 1 = symptomless, 2 = mild, 3 = severe, 4 = severe root and crown rot, and 5 = dead plant.
[b] Based on four replications of 20 plants each.
[c] Based on four replications of 10 plants each.

that suppression of diseases caused by *Rhizoctonia* was enhanced by increasing the time between soil amendment and planting.

One critical property of container media providing biological control is that the effects last throughout production of the crop. Bioassays of poinsettia and nursery crop container media show that composted municipal sludge utilized at a volumetric ratio of 25 and 20% suppressed both Rhizoctonia and Pythium damping-off in 5-mo and 2-yr production cycles in floricultural and nursery crops, respectively. This is also supported by the low levels of *P. irregulare* root rot on *C. apiculata* and *T. media* observed in nurseries at the end of the second growing season and by the low levels of root rot observed on poinsettia and Easter lily plants in the sludge compost medium, as compared with that in the peat medium.

The foregoing discussion reveals that sludge compost media prepared with compost cured 4 mo or more should be stored for 3–4 wk before utilization to allow for the development of adequate levels of suppressiveness to diseases caused by *R. solani*. Furthermore, this procedure avoids phytotoxicity problems associated with utilization of inadequately cured composted municipal sludge.

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