Differential Suppression of Damping-off Caused by *Pythium aphanidermatum*, *P. irregulare*, and *P. myriotylum* in Composts at Different Temperatures

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ABSTRACT

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The suppressiveness of compost amendments to pre-emergence damping-off of cucumber incited by isolates of *Pythium aphanidermatum*, *P. myriotylum*, and *P. irregulare* was studied. Growth chamber experiments were designed to examine the effects of temperature (20, 24, 28, and 32°C), compost type (municipal biosolids [MC] and leaves [LC]), and compost dose (40, 80, 160, and 320 mg/cm³) on suppression of damping-off (i.e., increase in seedling stands) caused by different *Pythium* isolates obtained from different hosts. In dose-response experiments, LC was suppressive at dosage rates ≥ 80 mg compost/cm³ of sand, whereas MC was suppressive at rates ≥ 40 mg/cm³. Damping-off severity induced by each of the three *Pythium* spp. was temperature-dependent. For example, *P. aphanidermatum* and *P. myriotylum* caused damping-off at each of the four temperatures tested, whereas *P. irregulare* caused disease only at 20 and 24°C. MC was suppressive to *P. aphanidermatum* at 20 and 24°C, whereas LC was suppressive at 28 and 32°C. Both composts significantly suppressed damping-off caused by *P. irregulare* at 20°C (85% suppression in MC and 60% suppression in LC) and at 24°C (approximately 60% suppression in both composts), and by *P. myriotylum* at all temperatures tested. In experiments with a variable temperature cycle (32°C for 14 h, day and 22°C for 10 h, night), only *P. aphanidermatum* and *P. myriotylum* caused damping-off of cucumber seedlings. Under these conditions, LC significantly suppressed damping-off caused by *P. aphanidermatum* (20% suppression) or *P. myriotylum* (37% suppression) but MC was not suppressive. In experiments where the two composts were mixed, a significant negative interaction between the two composts was observed for the suppression of *P. myriotylum* and *P. irregulare* at 20°C and of *P. irregulare* at 24°C, but not for *P. aphanidermatum* at any of the tested temperatures. There was no difference in aggressiveness among isolates within each of the three *Pythium* spp., regardless of their host origin. However, a significant variation in suppressiveness of LC was observed among isolates of *P. aphanidermatum* (11 isolates) derived from the same host, but not for *P. irregulare* (9 isolates) or *P. myriotylum* (7 isolates).

Additional keywords: biological control, disease suppression, microbial activity

Pythium seed and seedling rots, as well as root rots and foliar blights of cuttings, are among the more devastating diseases of greenhouse-grown crops; they affect nearly every crop grown in every part of the world. These diseases are destructive, particularly in artificial sand-based or peat-based growth media, because of high plant densities and favorable environmental conditions for disease development. A wide variety of *Pythium* spp. have been described from greenhouse production systems (32). Among the most common species are *P. ultimum*, *P. aphanidermatum*, *P. irregulare*, *P. myriotylum*, *P. spinosum*, and

P. splendens (11). In a survey of *Pythium* spp. in Israeli greenhouses, *P. aphanidermatum* and *P. myriotylum* were two of the most frequently isolated species from different plant hosts (2). In a recent evaluation of 34 isolates of *Pythium* collected from diseased *Gypsophila paniculata* (baby's breath) cuttings, 60% of the isolates were identified as *P. aphanidermatum* and 19, 17, and 3% were *P. irregulare*, *P. myriotylum*, and *P. ultimum*, respectively (3). *P. aphanidermatum* and *P. myriotylum* are considered to be broad host-range species favored by very warm conditions, whereas others, such as *P. ultimum* and *P. irregulare*, are considered to be broad host-range species favored by cool conditions (32).

Growers have traditionally relied on preventive fungicide drenches for the management of diseases in greenhouse environments caused by *Pythium* spp. However, in the past 15 years, there has been a noticeable move away from peat- and

sand-based growth media toward compost-amended media suppressive to *Pythium* spp. and other soilborne pathogens (15,17). Despite reported successes, variability in suppression and a poor understanding of factors affecting this variability continue to hamper the widespread adoption of compost-amended growth media.

A number of factors may affect suppression of diseases in compost-amended growth media caused by *Pythium* spp. These factors include compost type (10,27), organic matter quality (4–6) and quantity (12), and associated levels of microbial activity (7–10,18,22,30). It is likely that other factors, such as temperature, moisture, compost dosage, and target pathogen, can also contribute to variations in suppressiveness.

The purpose of this study was to better understand conditions that affect variability in suppressiveness of *Pythium* spp.-induced disease by (i) evaluating suppressiveness of two different composts to damping-off incited by isolates of *P. aphanidermatum*, *P. irregulare*, and *P. myriotylum* obtained from different hosts and (ii) determining the influence of compost type, dosage, and growth temperature on the suppression of damping-off caused by each of the three *Pythium* spp.

MATERIALS AND METHODS

Isolates of *Pythium* spp. Isolates of *Pythium* spp. used in this study were recovered from hosts showing typical disease symptoms on roots (*Lycopersicon esculentum*, *Anigozanthos* spp., *Lisianthus ressellianus*, and *Gerbera jamesonii*) or from symptomatic foliage of *Gypsophila paniculata* or *Pelargonium domesticum* (Table 1). To study possible variations in disease suppression between sand and sand amended with composts as well as among isolates of *Pythium* spp., we selected 11 isolates of *P. aphanidermatum* (7 from *G. paniculata*, 3 from *Lycopersicon esculentum*, and 1 from *P. domesticum*), 9 isolates of *P. irregulare* (7 from *G. paniculata* and 1 each from *Gerbera jamesonii* and *Lisianthus ressellianus*), and 6 isolates of *P. myriotylum* (4 from *Gypsophila paniculata* and 2 from *Anigozanthos* spp.). In experiments designed to examine the effects of either constant or cyclic temperatures on damping-off suppression, we selected three isolates of each *Pythium* spp.

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Composts. Based on previous laboratory and field experiments (10), composts that differed in suppressiveness to diseases caused by *Pythium* spp. were chosen for comparative purposes. A municipal biosolids compost (MC) and a leaf compost (LC) were used throughout the study. MC was collected from a municipal wastewater treatment facility in Schenectady, New York. LC consisted of leaves and twigs from mixed deciduous trees collected in Endicott, New York. Both composts were approximately 1.5 years old at the time of these experiments. These composts have been described in more detail elsewhere (10).

Experiments consisted of four treatments: (i) sand (used as an inert material with no suppressive properties toward diseases caused by *Pythium* spp.), (ii) sand amended with MC, (iii) sand amended with LC, and (iv) sand amended with a 1:1 mixture (vol:vol) of the two composts. The pH of sand and compost-sand mixtures ranged from 5.9 to 6.2. Mixtures of LC and MC were studied to determine whether there were any positive or negative synergistic responses in disease suppressiveness between the two composts. Before use in laboratory experiments, composts were sieved through a 2-mm screen to remove the coarsest particles and were mixed with oven-dried sand (48 h at 95°C, sieved to a particle size range of 0.5 to 1.0 mm) at a rate of 80 mg dry weight of compost per 1 cm³ of compost-sand mix unless stated otherwise. This rate was shown in previous studies to be suppressive to *Pythium* spp.-incited diseases (10) and corresponded to a compost amendment rate of approximately 20% (vol/vol).

Effects of composts on *Pythium* damping-off of cucumber. A cucumber damping-off bioassay was used throughout

this study to assess the suppressiveness of compost-sand mixes (23). Inoculum of *P. aphanidermatum*, *P. myriotylum*, and *P. irregulare* consisted of a 1-day-old culture grown on potato dextrose agar (Difco Laboratories, Detroit) at 27°C. Cucumber seeds (*Cucumis sativus* L. 'Marketmore' 76) with 100% germinability were used in a method modified from that described by Craft and Nelson (10). Briefly, 40 glass cylinders (2.0 cm in height by 2.5 cm in diameter) were arranged in a grid (4-cm centers) on a sheet of moistened blotting paper (20 by 28 cm) supported on a Plexiglas sheet. Next, a 5-mm-diameter mycelial disk taken from a 24-h culture of each *Pythium* isolate was placed on the filter paper in the center of each cylinder. Cylinders were filled either with 3 cm³ of sand or compost-amended sand. A single cucumber seed was sown in each cylinder and the seed was covered with 0.4 cm³ of sand. With the aid of an alcohol-disinfested plant mister, sterile deionized water was applied to the cylinders until the sand surface was moist. The blotter paper served to draw water through the cylinders, equilibrating at a constant water content. There were four replicate cylinders in each experiment. These replicate cylinders were used to calculate stand values. A set of noninoculated cylinders served as controls. This entire assembly was placed in a clear plastic box to reduce moisture loss and maintain a high relative humidity during the experiment. As a measure of damping-off severity, seedling stands were determined 5 days after sowing when plants were incubated at 28 and 32°C, and 7 days after sowing when plants were incubated at 20 and 24°C. Low percent-seedling stands indicated high damping-off severity, whereas high percent-seedling stands indicated high disease suppressiveness. Ex-

periments were repeated at least three times and at least four experimental runs were then used as replicates in subsequent statistical analyses.

Compost dosage and temperature experiments. In experiments designed to study the effects of compost dose on seedling stands, 40, 80, 160, and 320 mg dry weight of compost per 1 cm³ of mix were used. Dose effects on *P. aphanidermatum* were studied in growth chambers at 28°C for LC and at 20°C for MC because results from initial experiments indicated that these were the temperatures at which the respective composts showed suppressiveness.

Plastic boxes containing bioassays were incubated in a series of growth chambers, each with a 14-h photoperiod and a constant temperature of 20, 24, 28, or 32°C. Some experiments were conducted in a growth chamber with a temperature cycle consisting of 32°C for 14 h (days) and 22°C for 10 h (nights). In each box, there were 10 treatment combinations (three *Pythium* spp. × three isolates, plus one control), each with four replicate cylinders. These four replicate cylinders were used to establish a seedling stand value. Cylinders were watered with the plant mister as necessary to keep the sand surface moist. Seedling stands were determined 5 days after sowing when plants were incubated at 28 and 32°C, and 7 days after sowing when plants were incubated at 20 and 24°C. Temperature experiments were repeated four times with each experimental run considered a replicate.

Positive or negative interactions between LC and MC in mixtures were evaluated by determining seedling stands in the mixture and comparing stand values with the expected combined values from each of the two composts. No interaction occurred when seedling stands in the compost mixture (LC + MC) did not differ from those calculated from (LC – Sand) + (MC – Sand). Positive interactions occurred when seedling stands in LC + MC were significantly greater than those calculated from (LC – Sand) + (MC – Sand). Negative interactions occurred when seedling stands in LC + MC were less than those calculated from (LC – Sand) + (MC – Sand).

Variation in aggressiveness and disease suppression among isolates of *Pythium* spp. Variation in aggressiveness and

Table 1. Origin of isolates of *Pythium aphanidermatum*, *P. irregulare*, and *P. myriotylum* used in this study

Species	Isolate numbers	Host origin
<i>P. aphanidermatum</i>	12, 50, 58, 60, 80, 82, 84	<i>Gypsophila paniculata</i>
	64, 65, 67	<i>Lycopersicum esculentum</i>
	79	<i>Pelargonium domesticum</i>
<i>P. irregulare</i>	70	<i>Lisianthus resselianus</i>
	72	<i>Gerbera jamesonii</i>
	137, 139-144	<i>Gypsophila paniculata</i>
<i>P. myriotylum</i>	95	<i>Anigozanthos</i> sp.
	96, 149, 152, 160, 161	<i>Gypsophila paniculata</i>

Table 2. *P* values obtained from factorial analyses of arcsin-transformed percentage seedling stands in leaf compost (LC), municipal biosolids compost (MC), and LC + MC for each *Pythium* sp. at different temperatures

Source	<i>P. aphanidermatum</i>				<i>P. myriotylum</i>				<i>P. irregulare</i>	
	20 ^a	24	28	32	20	24	28	32	20	24
Replicate	0.070	0.670	0.820	0.080	0.640	0.130	0.350	0.570	0.070	0.070
Isolate	0.990	0.040	0.730	0.360	0.001	0.001	0.001	0.090	0.010	0.006
MC	0.001	0.003	0.040	0.910	0.001	0.008	0.001	0.049	0.001	0.001
LC	0.350	0.070	0.001	0.001	0.001	0.016	0.004	0.001	0.007	0.003
MC + LC	0.130	0.270	0.770	0.060	0.001	0.004	0.910	0.110	0.001	0.001

^a Temperature in °C.

disease suppression among isolates of each *Pythium* sp. were studied in sand and in LC-amended sand. Experiments with *P. aphanidermatum* and *P. myriotylum* were incubated at 28°C and those with *P. irregulare* were incubated at 20°C. In all, 11, 7, and 9 isolates were used for *P. aphanidermatum*, *P. myriotylum*, and *P. irregulare*, respectively. As with the temperature experiments, seedling stands were determined 5 days after sowing when plants were

incubated at 28°C and 7 days after sowing when plants were incubated at 20°C.

Statistical analysis. All analyses were performed with the Statistical Analysis System (SAS Institute, Inc., Cary, NC). Prior to analyses, percentage data were transformed by calculating the arcsin of the square root. In experiments designed to study the suppressive effects of composts (LC, MC, and LC + MC) at different growth temperatures (constant temperatures of 20, 24, 28, and 32°C or a cyclic day-night temperature regime of 32 and 22°C, respectively), data were analyzed as factorial experiments. Experiments at each temperature were repeated four times and each experimental run was considered a replicate. To determine significant positive or negative interactions of LC and MC in mixtures, *t* tests were used to compare seedling stands from the compost mixture (LC + MC) with the combined stands from each compost individually [(LC – Sand) + (MC – Sand)].

We found significant interactions between temperature and compost type for *P. aphanidermatum* and *P. myriotylum*. Therefore, for simplicity of presentation, separate analyses (*P* values) for individual temperatures are presented in Table 2. Comparisons of seedling stands between sand and compost treatments were made using Dunnett's test. In experiments designed to examine the effect of composts on the suppression of damping-off caused by different isolates from three *Pythium* spp. or experiments investigating compost dosage rates, means were separated using the Student-Neuman-Keuls test.

RESULTS

Compost dosage and temperature experiments. In nonamended sand, *P. aphanidermatum* caused 100% pre-emergence damping-off (i.e., 0% seedling stands) of cucumber at each of the four temperatures tested. *P. irregulare* caused damping-off only at 20 and 24°C. Inoculation with *P.*

myriotylum resulted in 4, 29, 12, and 2% seedling stands at 20, 24, 28, and 32°C, respectively (Fig. 1). MC was suppressive to damping-off caused by *P. aphanidermatum* at 20, 24, and 28°C but not at 32°C, whereas LC was suppressive to *P. aphanidermatum* only at 28 and 32°C (Fig. 1A). Both LC and MC were suppressive to *P. myriotylum* at all temperatures tested (Fig. 1C). Damping-off caused by *P. irregulare* was suppressed at both 20 and 24°C (Fig. 1B). Mixtures of the two composts (LC + MC) were significantly suppressive to damping-off caused by *P. irregulare* and *P. myriotylum* at 20 and 24°C (Fig. 1, Table 2), but resulted in significant negative interactions leading to lower-than-expected seedling stands (Table 3). For example, expected seedling stands in LC + MC were 100% for *P. myriotylum* at 20°C and for *P. irregulare* at 20 and 24°C. However, actual seedling stands were 62.5, 75.0, and 77.1%, respectively.

When experiments were performed under a daily temperature cycle of 14-h days at 32°C and 10-h nights at 22°C, *P. aphanidermatum* and *P. myriotylum* incited significant levels of damping-off but *P. irregulare* did not. Under this temperature and light regime, LC and LC + MC significantly suppressed damping-off caused by *P. aphanidermatum* and *P. myriotylum* (Fig. 2). MC was not suppressive to damping-off incited by either of the two species under these conditions.

MC was suppressive at concentrations ≥ 40 mg/cm³, whereas LC was suppressive only at dosages ≥ 80 mg/cm³. Suppression did not increase significantly with compost dosage rates > 80 mg/cm³ (Fig. 3).

Variation in aggressiveness and disease suppression among isolates of *Pythium* spp. When tested in sand alone, no significant variation in aggressiveness was observed among isolates of *P. aphanidermatum* or *P. irregulare* (Table 4). Isolates 96 and 149 of *P. myriotylum* were significantly less aggressive than other isolates of

Fig. 1. Percent cucumber seedling stands at 20, 24, 28, and 32°C in sand and in sand amended with either a municipal biosolids compost (MC), a leaf compost (LC), or a mixture of both composts (LC + MC). Each histogram represents mean seedling stands from four experiments. Three isolates each of (A) *Pythium aphanidermatum*, (B) *P. irregulare*, and (C) *P. myriotylum* were used in each experiment. Sand was amended with each compost at a rate of 80 mg/cm³. Experiments were conducted in controlled-temperature growth chambers with a 14-h photoperiod. Percent seedling stands were determined 5 days after sowing at 28 and 32°C and 7 days after sowing at 20 and 24°C. Seedling stands in noninoculated cylinders with sand or in sand amended with composts was 100%. Bars with an asterisk (*) represent means that are significantly (*P* < 0.05) different from sand at the same temperature according to Dunnett's test.

Table 3. Negative interactions between leaf compost (LC) and municipal biosolids compost (MC) in mixtures

<i>Pythium</i> spp.	Temperature (°C)	Mean seedling stand (%)	
		LC + MC ^y	(LC – sand) + (MC – sand) ^z
<i>P. aphanidermatum</i>	20	50.0	79.2 (<i>P</i> = 0.17)
	24	39.6	54.2 (<i>P</i> = 0.38)
	28	56.2	50.0 (<i>P</i> = 0.59)
	32	31.2	54.2 (<i>P</i> = 0.09)
<i>P. myriotylum</i>	20	62.5	100.0 (<i>P</i> = 0.001)
	24	52.1	52.1 (<i>P</i> = 1.0)
	28	72.9	58.3 (<i>P</i> = 0.49)
	32	56.2	79.2 (<i>P</i> = 0.19)
<i>P. irregulare</i>	20	75.0	100.0 (<i>P</i> = 0.001)
	24	77.1	100.0 (<i>P</i> = 0.04)

^y Actual stand.

^z Expected stand. Interactions between the two composts are interpreted as follows: No interaction occurs when seedling stands in the compost mixture (LC + MC) do not differ from those calculated from (LC – sand) + (MC – sand). Positive interactions occur when seedling stands in LC + MC are greater than those calculated from (LC – sand) + (MC – sand). Negative interactions occur when seedling stands in LC + MC are less than those calculated from (LC – sand) + (MC – sand). *P* values derived from *t* test comparisons of expected and actual seedling stands.

P. myriotylum (with the exception of isolate 152). When evaluated in sand amended with LC, only two isolates of *P. aphanidermatum* differed in their response to composts; isolate 58 was suppressed to a greater degree than isolate 60. Damping-off severity among different isolates of *P. irregulare* or *P. myriotylum* did not differ. Seedling stands in LC did not differ significantly among isolates from different plant hosts (*P* values > 0.10).

DISCUSSION

In previous studies, damping-off of cucumber caused by *P. aphanidermatum* was suppressed with composts prepared from separated cattle manure (22–24), grape marc (24), licorice roots (14), municipal biosolids (21), and sugarcane residues (30). Even though *P. aphanidermatum*-incited damping-off of cucumber was suppressed by composted municipal biosolids, damping-off of bean was not (21). Although there are no reports on the suppression of *P. myriotylum*- or *P. irregulare*-incited diseases, empirical evidence suggests that damping-off caused by either *P. myriotylum* or *P. irregulare* can potentially be suppressed in other compost-amended substrates (13,16,19). Our results corroborate these findings on the suppression of cucumber damping-off caused by *P. aphanidermatum* and further demonstrate that composts prepared from MC or LC also suppress damping-off of cucumber incited by *P. myriotylum* and *P. irregulare*.

Most importantly, our results have shown that not all *Pythium* spp. are equally suppressed; the level of suppression of each species was dependent on the incubation temperature. For example, MC was

Fig. 2. Suppressiveness of a leaf compost (LC) and a municipal biosolids compost (MC) to *Pythium aphanidermatum* and *P. myriotylum* under a fluctuating temperature and light regime (32°C for 14 h, day, and 22°C for 10 h, night). Each value represents a mean seedling stand from four experiments. In each experiment, three isolates each of *P. aphanidermatum*, *P. irregulare*, and *P. myriotylum* were used. Sand was amended with each compost at 80 mg/cm³. Seedling stands in noninoculated cylinders with sand or with compost-sand mixtures was 100%. *P. irregulare* did not cause disease at these temperatures; therefore, data are not presented. Mean seedling stand values followed by an asterisk (*) are significantly different from sand according to Dunnett's test.

suppressive to damping-off caused by *P. aphanidermatum* at 20, 24, and 28°C but not at 32°C, whereas LC was suppressive only at 28 and 32°C. *P. myriotylum*, on the other hand, was suppressed at all temperatures in both composts. *P. irregulare* caused disease on cucumber only at 20 and 24°C; therefore, evaluations of suppressiveness could only be made at these temperatures, at which both MC and LC were suppressive to damping-off caused by *P. irregulare*. To our knowledge, this is the first report of differential effects of temperature on suppressiveness of composts to soilborne plant pathogens.

The mechanisms supporting these differential temperature responses are not clear but may be due in part to different levels of microbial activity in the different composts at different incubation temperatures. Results from numerous studies have indicated that suppressiveness of different composts to diseases caused by *P. ultimum*, *P. aphanidermatum*, or *P. graminicola* can be linked to increased levels of microbial activity in the composts themselves or in soils receiving compost amendments (5,7–10,14,22). It is also likely that, in contrast to general microbial activity, more specific activities arising from different microbial consortia active under different temperature regimes in different composts could explain the differential responses among the three *Pythium* spp. tested. However, it is unlikely, given our present knowledge, that these microbial properties could be predicted based on our knowledge of the substrate alone, because different batches of the same feedstock may vary greatly in microbial activity and suppressiveness of *Pythium* spp. (10).

Due to the profound effects of temperature on microbiological processes, one

Fig. 3. Effect of leaf compost (LC) and municipal biosolids compost (MC) dosage rates on cucumber damping-off caused by *Pythium aphanidermatum*. Each value represents mean seedling stands in three experiments. In each experiment, four replicates from each of three isolates of *P. aphanidermatum* were tested. The effect of LC was tested at 28°C and MC was tested at 20°C. Seedling stands in noninoculated cylinders with sand was 100%. Mean seedling stand values for each compost treatment followed by the same letter are not significantly different (*P* = 0.05) according to the Student-Neuman-Keuls test.

could reason that increases in both temperature and compost dosage rate should lead to increases in microbial activity in compost-amended sand, and that these increases in microbial activity should increase the level of suppression of *Pythium* spp. Our results with the suppression of *P. aphanidermatum* in LC support this hypothesis. LC was more suppressive at higher temperatures (28 and 32°C) and at higher dosage rates (>40 g/cm³). However, this is in direct contrast with our results on the suppression of *P. aphanidermatum* and *P. myriotylum* in MC. First, the suppression of *P. aphanidermatum* in MC decreased as temperatures increased. Second, the level of suppression was not affected by compost dosage rate. Finally, although there was an apparent trend of decreasing suppressiveness with increasing temperatures, *P. myriotylum* was suppressed significantly in MC at both low and high temperatures.

Table 4. Differential aggressiveness to cucumber seedlings among isolates of *Pythium aphanidermatum*, *P. myriotylum*, and *P. irregulare* in sand and in sand amended with leaf compost (LC)^y

Species, temperature, (°C), isolate number	Sand ^z	LC
<i>P. aphanidermatum</i> , 28°C		
50	0.0 a	18.8 ab
58	0.0 a	62.5 a
60	0.0 a	6.3 b
64	0.0 a	31.3 ab
65	0.0 a	25.0 ab
67	0.0 a	50.0 ab
79	6.3 a	31.3 ab
80	0.0 a	12.5 ab
82	0.0 a	25.0 ab
84	0.0 a	31.3 ab
127	12.5 a	50.0 ab
<i>P. irregulare</i> , 20°C		
70	0.0 a	41.7 a
72	0.0 a	58.3 a
137	0.0 a	50.0 a
139	0.0 a	33.3 a
140	0.0 a	25.0 a
141	0.0 a	33.3 a
143	0.0 a	25.0 a
144	0.0 a	50.0 a
<i>P. myriotylum</i> , 28°C		
95	0.0 b	31.3 a
96	18.8 a	56.3 a
149	18.8 a	56.3 a
150	0.0 b	50.0 a
152	6.3 ab	68.8 a
160	0.0 b	12.5 a
161	0.0 b	25.0 a

^y Mean seedling stands (%) were determined 5 days after planting for *P. aphanidermatum* and *P. myriotylum* (28°C incubation) and 7 days for *P. irregulare* (20°C incubation).

^z Each number represents the mean percent seedling stands from three separate experiments, each with four replicates. Sand was amended with leaf compost at the rate of 80 mg/cm³. Seedling stands in noninoculated cylinders with sand or with compost-amended sand was 100%. Percentages in each column followed by the same letter are not significantly different (*P* = 0.05) according to the Student-Neuman-Keuls test.

There are a number of possible explanations for these results. First, both *P. aphanidermatum* and *P. myriotylum* are known to be more aggressive at elevated temperatures (1,20,25,26,28,29,31). It is possible that, when levels of microbial activity are relatively low and providing only a moderate level of disease suppression, the increased aggressiveness at these higher temperatures masks suppressive effects seen in the municipal biosolids compost. This type of temperature response has been observed in the biological control of *P. aphanidermatum* by sugar beet rhizosphere bacteria (29). In that study, suppression of *P. aphanidermatum* was expressed at 20°C and correlated directly with bacterial activity in the rhizosphere. However, this suppression was not expressed at 27°C. Second, it is possible that microbial activity in MC is greater at 20 to 24°C than at 28 to 32°C. Third, it is likely that temperature effects on composts differ because of qualitative differences in compost microbial communities. For example, with composts such as LC that are inherently low in microbial biomass and activity (10), increases in temperature may serve to sufficiently increase the total amount of microbial activity to more suppressive levels. For composts such as MC, which is higher in microbial biomass and activity relative to LC (10), it is possible that increases in temperature will actually result in species compositional changes that result in a reduction of suppressive microbial populations.

Results with compost mixtures further support the notion that microbial communities in the two composts are quite distinct and respond differently to temperature. The observation that, at some temperatures, lower-than-expected levels of disease suppression were observed in the mixtures indicates that organisms responsible for the suppression of specific *Pythium* spp. may also be suppressed in the mixtures and not act additively or synergistically. Clearly, more work is needed on the relationships of temperatures and microbial activity in composts to resolve some of these questions.

Our work has demonstrated that suppression of *Pythium* spp.-incited damping-off is dependent not only on compost type and incubation temperature, but suppressiveness is also *Pythium* sp.-specific. These findings, along with the observation that disease suppressiveness may vary among isolates of the same species (e.g., *P. aphanidermatum*), complicate the use of composts for control of disease caused by *Pythium* spp. However, at the same time, these observations help to identify conditions for which MC or LC composts would potentially be most effective in suppressing *Pythium* spp.-induced diseases.

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