J. AMER. SOC. HORT. SCI. 122(3):427–432. 1997.

Composts from Various Municipal Solid Waste Feedstocks Affect Vegetable Crops. I. Emergence and Seedling Growth

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ADDITIONAL INDEX WORDS. *Lycopersicon esculentum*, *Cucumis sativus*, *Capsicum annuum*, biosolids

ABSTRACT. **The composition of composts derived from municipal solid wastes can affect emergence and seedling growth. Composts consisting of biosolids and yard trimmings [standard compost (SC)] alone or with mixed waste paper (MWP), refuse-derived fuel (RDF), or refuse-derived fuel residuals (RDFR) were evaluated in seedling trays and pots for vegetable crop seedling emergence and growth. In trays, tomato (*Lycopersicon esculentum* Mill.), cucumber (*Cucumis sativus* L.), and pepper (*Capsicum annuum* L.) seedlings emerged faster from a commercial peat-lite mix and from sandy field soil than from the composts. Plants were tallest and shoots were generally heaviest in the peat-lite mix and aged SC and smallest in the field soil. MWP compost generally inhibited early seedling growth more than RDF or RDFR composts. Among the composts, seedlings were tallest and heaviest in SC. In pots, growth of each vegetable was generally greatest in SC, followed by other composts, and lowest in sandy soil. Tomato and pepper seedling emergence was more sensitive to the inhibitory effects of the RDF, RDFR, and MWP composts than cucumber seedling emergence. Fertilizer increased plant growth in each medium except SC, in which cucumber stem diameter was not increased. Adding MWP, RDF, or RDFR to SC generally decreased seedling emergence and growth. The composts prolonged days to emergence and decreased percent emerged seedlings. However, subsequent seedling growth in composts was equal to or greater than seedlings in the peat-lite mix and much greater than those in the sandy field soil.**

Recently, production of large quantities of composts has made possible using compost commercially in vegetable crop production systems. In some localities, municipalities and private companies are now producing commercial quantities of composts from various municipal feedstocks. Compost effects on crop production can vary according to the feedstock, compost production methods, storage, and use rates and methods (Diaz-Ravina et al., 1989; Roe and Kostewicz, 1992; Vega-Sanchez et al., 1987; Wong and Chu, 1985). Phytotoxic compounds produced during the composting process (Chen and Inbar, 1993) may not break down before compost use. However, bioassays using living plants and seeds can indicate the presence or absence of these compounds (Chen and Inbar, 1993).

To ensure beneficial integration of composts in crop production systems, investigations are needed to determine the effects of additional compost feedstocks, optimum application rates, and combinations of composts and interactions with inorganic fertilizers.

The objectives of this investigation were to evaluate composts containing various municipal feedstocks for indications of presence of phytotoxic compounds or other inhibitors of tomato (*Lycopersicon esculentum*), cucumber (*Cucumis sativus*), and pepper (*Capsicum annuum*) seedling emergence and growth. Also, early plant growth of tomatoes, cucumbers, and peppers in varying rates of the composts, amended or not amended with inorganic fertilizers, was evaluated.

Materials and Methods

A standard compost (SC) containing biosolids (wastewater sludge) and yard trimmings (wood chips, grass clippings, and leaves from homeowners and landscaping firms) and three composts containing those feedstocks with mixed waste paper (MWP), refuse-derived fuel (RDF), or refuse-derived fuel residuals (RDFR) were used in these experiments (Table 1). Due to production constraints, composts were not all available for experimental purposes at the same time or in the same quantities. Therefore, not all four composts were used in each experiment.

When composts were delivered to the experimental site, six to nine random grab samples were taken and combined, and a composite sample was analyzed for nutrients and heavy metals (Table 2).

Nitrate and NH_4 N were analyzed colorimetrically on an autoanalyzer (Alpkem; OI Analytical, Wilsonville, Ore.). Water-soluble nutrients and metals were extracted by adding distilled water to 25 g (dry mass equivalent) of compost while mixing until the sample was just saturated. At saturation, the samples flowed slightly when the container was tipped and were easy to work with a spatula. After mixing, the samples were equilibrated for 1 h and rechecked for saturation. The saturated sample had no appreciable free water on the surface but had not stiffened. Water content was

Received for publication 28 May 1996. Accepted for publication 13 Dec. 1996. Univ. of Florida Agricultural Experiment Station journal series R-04950. We thank Ted Winsberg for his support of this project through the use of his farm and other resources. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
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Table 1. Composition, water-holding capacity, and carbon-to-nitrogen ratios of composts used in the experiments.

Compost[z]	Compost feedstocks (% by vol) Biosolids	Yard trimmings	Mixed waste paper	RDF	RDF residual	Water-holding capacity ($g \cdot g^{-1}$)	C:N ratio
MWP	20.4	43.6	36.0			1.91	16.9
RDF	18.5	17.8		63.7		NA[y]	12.7
RDFR	10.3	16.2			73.5	0.73	17.3
SC	16.1	83.9				1.66	18.3

[z]RDF = refuse derived fuel, MWP = mixed waste paper, RDFR = refuse derived fuel residuals, SC = standard compost of yard trimmings and biosolids.
[y]NA = data not available.

adjusted as necessary by adding compost or water, and the sample was allowed to equilibrate for another 30 min. After equilibration, the saturated sample was centrifuged at 5856× g_n for 15 min, and the supernatant solution was decanted and filtered through no. 42 filter paper for subsequent analysis for nutrients and metals. EPA method 3050 was used for total nutrient and metal determination. This is an acid digestion procedure to prepare sediments, sludges, and soil samples for analysis by inductively coupled argon plasma spectroscopy (ICP). The compost samples were air dried for 4 d and ground to a powder with a ball mill grinder. A 1.0- to 2.0-g sample was digested in nitric acid and then treated with dilute hydrogen peroxide. When the peroxide reaction was completed, the sample was refluxed with hydrochloric acid and diluted to 100 mL for analysis.

Water-holding capacity of the compost was determined by a procedure used to control moisture content in soil samples during aerobic incubation for determination of mineralizable N (MacKay and Carefoot, 1981). Samples were placed in 150-mL filter units fitted with a 0.45-µm filter, compacted to achieve uniform density, saturated with water, and allowed to equilibrate for 90 min. After equilibration, the samples were placed on a vacuum manifold at 0.01 MPa tension, regulated with a mercury manometer, for 5 h. A subsample was oven dried at 105 °C for 24 h and the moisture content at 0.01 MPa was determined.

Particle size distribution was also determined. Percentages of medium (10 to 20 mesh) and fine (<20) sizes were similar. In the >10 mesh size, RDFR compost contained 14% inerts (plastics, glass, rocks, and other inorganic materials) and 30% fiber (pieces of organic matter, primarily woody material, in these composts) and the other composts contained 1% to 3% inerts and 46% to 50% fiber.

Total C and N concentrations were determined by combustion at 1010 °C in a CNS analyzer (Carlo-Erba NA-1500; BICO, Burbank, Calif.). Compost samples were air dried for 4 d and ground to a powder with a ball grinder before combustion.

Cucumber bioassay

Equal amounts (by volume) of no. 5 vermiculite and SC (screened through a 0.63 cm sieve) (Table 1) were mixed. A vermiculite-only treatment was also used. Due to limited availability of trays, each replication was placed into a different size polystyrene seedling tray with inverted pyramid cells (Speedling, Inc.). Trays for replication 1 contained 595 inverted pyramid cells (1.4 × 1.4 × 3.75 cm deep), replication 2 contained 392 cells (1.6 × 1.6 × 6.25 cm deep), and replication 3 contained 200 cells (3.1 × 3.1 × 7.5 cm deep). Each tray was seeded with 50 'Dasher II' cucumber seeds (1 seed/cell) with each tray as a replication. Trays were placed on a concrete pad in full sun and watered manually daily. A completely randomized block experimental design was used with each medium replicated three times. Emerged seedlings were counted 3, 4, 5, and 9 d after seeding (DAS) and mean days to emergence (MDE) were calculated by adding together each day's emergence calculated by the formula (days to emergence) (number emerged each day)/total number emerged (Gerson and Honma, 1978).

Greenhouse experiments

Composts were screened through a 0.63-cm sieve. An Oldsmar fine sand (sandy, siliceous, hyperthermic Alfic Arenic Haplaquad) served as the control. Polystyrene inverted pyramid cell Speedling trays (cell size 5 × 5 × 1.25 cm deep) were filled with each medium. 'Solar Set' tomato, 'Jupiter' pepper, and 'Thunder' cucumber seeds were sown at 1 seed/cell and 72 seeds/tray (Table 3). Temperatures during the growth period varied between experiments (Table 3). Each tray was a replication and there were four replications of each medium. A completely randomized block experimental design was used for each greenhouse experiment. Emerged seedlings were recorded when the seedling was visible through the soil and counted every 24 h. After the final count (Table 3), 20 plants per treatment were removed from media and plant heights (from the medium surface to highest node) were measured. Seedlings were severed into shoots and roots at the medium surface, washed, dried for 4 d at 68 °C, and weighed.

GREENHOUSE EXPT. 1. Media used were RDFR and SC, sandy field soil, a batch of SC that had been aged in an open pile for about 8 months, and a peat-lite mix (Metro Mix 220; Grace-Sierra, Milpitas, Pa.).

GREENHOUSE EXPT. 2. Media used were MWP and SC, sandy field soil, and peat-lite mix.

GREENHOUSE EXPT. 3. Media used were MWP and RDF, a 1:1 (v:v)

Table 2. Nutrient and heavy metals concentrations of composts.

Compost[y]	NH_4 N[z] (ppm)	NO_3 N[z] (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Cd (ppm)	Pb (ppm)	Ni (ppm)	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (%)	pH	EC ($dS \cdot m^{-1}$)
MWP	260	35	88	247	348	3.6	46	13	27.2	1.61	0.88	0.35	4.01	0.21	1.00	5.9	3.55
RDF	163	397	104	318	219	5.0	93	20	23.5	1.85	0.98	0.34	4.57	0.23	1.16	6.4	6.37
RDFR	512	1	273	587	2112	7.8	169	43	22.5	1.31	0.55	0.34	3.97	0.27	1.43	7.7	8.21
SC	147	161	59	208	131	3.2	38	11	33.8	1.85	0.80	0.43	3.83	0.24	0.75	7.2	4.44

[z]NH_4 N, NO_3 N values are in ppm in saturated water extracts of the composts.
[y]MWP = mixed waste paper, RDF = refuse-derived fuel, RDFR = refuse-derived fuel residuals, SC = standard compost of yard trimmings and biosolids. Mean of three (MWP and RDF), two (RDFR), and five (SC) samples.

Table 3. Chronology of greenhouse experiments and mean minimum and maximum temperatures during the growing period.

	Tomato	Pepper	Cucumber
	Expt. 1		
Sowing date (1994)	28 June	31 May	9 May
Days to harvest	10	14	7
Mean min temp	20.5	NA[z]	NA
Mean max temp	32.9	NA	NA
	Expt. 2		
Sowing date (1994)	24 June	8 July	6 June
Days to harvest	10	17	7
Mean min temp	20.3	20.6	21.1
Mean max temp	32.9	33.9	32.6
	Expt. 3		
Sowing date (1994)	28 Sept.	8 Sept.	6 Sept.
Days to harvest	11	14	7
Mean min temp	25.2	25.3	25.5
Mean max temp	32.6	33.6	34.3

[z]NA = not available.

mixture of MWP and vermiculite, a 1:1 (v:v) mixture of RDF and vermiculite, sandy field soil, vermiculite only, and peat-lite mix.

Shadehouse experiment

Thirty nursery pots (15.1 cm in diameter × 15.1 cm deep) were filled with each of MWP, RDFR, SC, or Myakka sand field soil (sandy, siliceous, hyperthermic Aeric Haplaquad) on 2 June 1994. Ten pots of each medium were planted with a 'Solar Set' tomato transplant (about 4 weeks old), ten with a 'Jupiter' bell pepper transplant (about 5 weeks old), and ten with two 'Thunder' cucumber seeds, all sown about 2 cm deep. Pots were placed on black fabric on the floor of a shadehouse covered with a 47% shadecloth. Each pot was an experimental unit and there were 10 replications of each treatment for each crop. In addition to rainfall and daily overhead irrigation, five replications of each crop were watered daily with 237 mL of a solution of 400N–176P–332K (ppm) and five with 237 mL of water only. A completely randomized experimental block design was used, and pots were rearranged weekly. Tomatoes were grown from 2–17 June, peppers from 2–20 June, and cucumbers from 2–21 June 1994. On the ending dates, stem diameter was measured about 1 cm above the soil surface. Plants were removed with root systems intact and severed at the soil line, and roots were washed. Shoot height (soil surface to upper node) was measured, and shoots and roots were dried for 4 d at 70 °C and weighed.

Data from all experiments were subjected to analyses of variance and treatment means separated by Duncan's multiple range test (5% level) by SAS software (SAS Institute, Cary, N.C.).

Table 4. Seedling emergence and growth characteristics of cucumber seedlings grown in composts,[z] compost–vermiculite mixtures, peat-lite mix, or sandy soil (greenhouse Expts. 1, 2, and 3).

Medium	MDE[y]	Emergence (%)	Plant ht (mm)	Shoot mass (mg)	Shoot:root ratio
		Expt. 1			
RDFR	6.5 b[x]	94.8 a	116 b	47.6 a	3.4 b
SC	9.7 a	89.2 ab	114 b	46.6 a	3.0 b
Aged SC	8.7 a	82.5 b	127 a	50.6 a	5.3 a
Sand	4.6 c	95.5 a	88 c	33.6 b	1.1 c
Peat-lite	6.5 b	94.0 a	133 a	51.0 a	3.4 b
		Expt. 2			
MWP	9.3 a	80.2 c	89 c	27.2 c	3.4 a
SC	7.0 b	94.5 b	128 b	41.0 b	2.3 b
Sand	4.9 c	95.2 a	95 c	29.2 c	0.7 c
Peat-lite mix	7.0 b	89.0 b	145 a	46.2 a	3.4 a
		Expt. 3			
MWP	8.3 a	82.5 b	124 c	30.3 a	2.3 b
RDF	8.3 a	85.8 ab	124 c	30.2 a	2.6 b
MWP–vermiculite	6.6 b	91.5 a	133 ab	31.8 a	2.2 b
RDF–vermiculite	6.9 b	92.2 a	127 bc	30.8 a	2.4 b
Sand	5.3 c	94.0 a	101 d	25.0 b	0.8 c
Vermiculite	8.4 a	94.0 a	87 e	22.9 b	1.3 c
Peat-lite mix	7.6 ab	94.2 a	137 a	32.6 a	3.3 a

[z]RDFR = refuse derived fuel residuals, SC = standard compost of yard trimmings and biosolids, MWP = mixed waste paper, RDF = refuse derived fuel.
[y]MDE = mean days to emergence.
[x]Mean separation in columns within crops by Duncan's multiple range test, $P \leq 0.05$.

Results and Discussion

Cucumber bioassay

This simple bioassay was included because it is being used by some commercial composters to test for compost maturity and phytotoxicity (W. Smith, personal communication). Percent emergence from the SC/vermiculite mix differed from emergence from vermiculite only at 4 DAS, when it was 81% in the mixture and 67% in the vermiculite. Final MDEs of 7.2 and 7.8 for the SC–vermiculite mixture and vermiculite, respectively, were similar. There was no evidence of phytotoxic effects on cucumber seed emergence from this compost.

Greenhouse experiments

Cucumbers. Cucumbers always emerged most rapidly when sown in sand compared with other media (Table 4). Cucumber emergence was delayed in 100% MWP or RDF relative to peat-lite medium, but was hastened by combining vermiculite with either MWP or RDF. Percentage emergence was highest in sand, peat-lite mix, RDFR, and SC (Expt. 1); sand (Expt. 2); and RDF compost, sand, peat-lite mix, vermiculite, and mixes of MWP and RDF composts with vermiculite (Expt. 3). Plants were taller when grown in peat-lite mix or aged SC (Expt. 1), in peat-lite mix (Expt. 2), or in peatlite mix and the mixtures of MWP and RDF composts with vermiculite (Expt. 3). Shoot weight was lowest in sand and vermiculite compared with all other media except MWP compost in Expt. 2. Shoot-to-root ratios were highest in aged SC in Expt. 1, MWP and peatlite mix in Expt. 2, and peat-lite mix in Expt. 3 compared with other media.

Peppers. Pepper emergence was fastest in peat-lite mix, aged SC, and RDF with vermiculite, and slowest in RDFR, MWP, sand, or RDF compared with other media (Table 5). Percentages of emergence were generally similar, with only RDFR and MWP composts (with and without vermiculite) decreasing percent emergence. Plant height and shoot weight were greatest in aged SC and peat-lite mix compared with other media. Shoot-to-root ratios were highest in SC (Expt. 1); MWP, SC, and peat-lite mix (Expt. 2); or RDF (Expt. 3).

Tomatoes. Tomatoes emerged faster from sand, compost–vermiculite mixes, vermiculite, or peat-lite mix than from compost media (Table 6). Percent emergence was higher in sand and peat-lite mix (Expts. 1 and 2) or mixtures of MWP or RDF composts with vermiculite, vermiculite, and peat-lite mix than in composts (Expt. 3). Plants were taller in peat-lite mix. Shoots were heaviest in SC or aged SC (Expt. 1) and peat-lite mix (Expts. 1 and 2), except in the last experiment where shoot weight was higher in peat-lite mix and MWP or RDF composts with vermiculite than vermiculite (Expt. 3). Shoot-to-root ratios were highest in SC, aged SC, and peat-lite mix and lowest in sand.

Physical factors such as soil particle size and water-holding capacity can affect emergence and seedling growth. Seedlings emerged faster from sandy soils, vermiculite, and peat-lite mix. A loose, porous medium is preferred for seed germination (Ball, 1985), and these media may have allowed the most favorable air and water infiltration. Percent emergence differed by species, but was rarely highest in the composts.

Wong and Chu (1985) reported that chemical constituents and properties of compost extracts, such as NH_3, salts, ethylene oxide, heavy metals, and pH, affected seed germination and root elongation. The higher NH_4 N and/or NO_3 N, especially in RDF and RDFR composts (Table 2), may have been an influencing factor in seedling emergence in our experiments. Roe and Kostewicz (1992) reported lower levels of watermelon but not tomato seedling emergence in yard-trimming composts with N from additional organic or inorganic sources. Adding RDF or RDFR to SC increased levels of most of the heavy metals (Table 2). Waste paper may also have added other phytotoxic compounds. Campbell et al. (1995) reported that tomato plant height was decreased by media

Table 5. Seedling emergence and growth characteristics of pepper seedlings grown in composts,[z] compost–vermiculite mixtures, peat-lite mix, or sandy soil (greenhouse Expts. 1, 2, and 3).

Treatments	MDE[y]	Emergence (%)	Ht (mm)	Shoot dry mass (mg)	Shoot:root ratio
		Expt. 1			
RDFR	32.7 a[x]	53.2 b	53 c	8.7 c	1.7 b
SC	23.8 b	58.5 ab	60 b	10.5 b	2.3 a
Aged SC	19.4 c	67.2 a	66 a	13.4	1.8 b
Sand	23.2 b	68.5 a	35 d	6.7 d	0.7 c
Peat-lite mix	16.0 c	62.2 ab	65 a	14.1 a	1.7 b
		Expt. 2			
MWP	23.1 a	65.0	71 b	14.7 b	2.5 a
SC	22.0 a	66.5	75 b	16.0 b	2.3 a
Sand	25.5 a	69.2	38 c	7.5 c	0.7 b
Peat-lite mix	15.6 b	78.2	82 a	21.9 a	3.0 a
		Expt. 3			
MWP	21.2 b	52.2 c	72 c	13.8 c	1.9 c
RDF	25.0 a	68.8 b	67 d	13.8 c	3.2 a
MWP–vermiculite	21.9 b	50.0 c	77 b	15.7 bc	1.6 cd
RDF–vermiculite	17.4 c	78.8 ab	79 b	17.2 b	1.8 c
Sand	20.8 b	73.0 ab	38 e	6.6 d	0.3 e
Vermiculite	22.0 b	70.8 ab	39.9 e	5.5 d	1.3 d
Peat-lite mix	15.0 c	80.5 a	88.5 a	21.3 a	2.6 b

[z]RDFR = refuse-derived fuel residuals, SC = standard compost of yard trimmings and biosolids, MWP = mixed waste paper, RDF = refuse-derived fuel.

[y]MDE = mean days to emergence.

[x]Mean separation in columns within crops by Duncan's multiple range test, $P \leq 0.05$.

amended with paper sludge <14 weeks old. Even curing the paper sludge for 21 weeks did not increase tomato growth to the level of that in peatmoss-amended media. Sterrett et al. (1983) reported that cabbage (*Brassica oleracea* L.) and tomato transplants grown in a wastewater sludge compost medium with a high level of heavy metals were generally smaller than those in a peat–vermiculite or low-metal biosolids compost medium.

Compost maturity and its measurement continues to be a controversial subject within the industry and science of composting. With peppers and cucumbers, there were more increases in growth characteristics in the aged SC than in the other composts compared with sand and peat-lite mix (Tables 4 and 5). Phytotoxic materials produced during the composting process can affect plant growth (Wong and Chu, 1985). Many compost production systems include a curing period, which may allow for the breakdown of some of these phytoxins. The aged SC used in Expt. 1 may have been through changes similar to these cured composts.

Wong and Chu (1985) reported that tomatoes were more sensitive to compounds in immature compost than Chinese white cabbage (*Brassica chinensis* L.) and carrots (*Daucus carota* L. var. *sativa*). However, we compared tomatoes to peppers and cucumbers, which may be more sensitive than the species used for comparison by these other researchers. In Expt. 1, tomatoes were the species least affected by changes in compost maturity (Tables 4–6).

Nitrogen immobilization from high C-to-N ratios has been reported to be a problem with some composts (Inbar et al., 1990). Carbon-to-nitrogen ratios of the composts used in these experiments were all <20, which is generally low enough to prevent this effect. Incubating these composts with soil resulted in rates of N mineralization that did not indicate that lack of N would be a problem (data not shown).

Plants that have adequate nutrition and water generally tend to have a higher shoot-to-root ratio than plants that are deficient in either. The shoot-to-root ratio of the seedlings in sand was always the lowest, and vermiculite was similar or slightly higher (Tables 4–6), indicating that conditions for growth of seedlings in those media were not as favorable as in the composts or peat-lite mix. Only with cucumbers in the greenhouse Expt. 3 was the shoot-to-ratio higher in peat-lite mix than in composts (Table 4).

Adding vermiculite appeared to improve speed of emergence of tomatoes and cucumbers from MWP compost and percent emergence of tomatoes from RDF compost (Tables 4 and 6). This may be due to physical changes in the medium or dilution of toxic compounds contained in the MWP and RDF composts.

Formulations of this peat-lite mix and other brands of commercial growing media have been developed to encourage maximum rates of seedling emergence and growth. When comparing growth in these mixes with that in the composts, further investigations are needed to identify the specific factors affecting seedling emergence and plant growth.

Shadehouse experiment

Adding fertilizer increased cucumber plant height; pepper stem diameter, plant height, shoot weight, and shoot-to-root ratio; and tomato plant height, root weight, and shoot-to-root ratio and decreased cucumber and tomato root weight (Table 7).

Fertilizer × media interaction was only significant for cucumber stem diameter (Table 7). In MWP compost, RDFR compost, and sand, adding fertilizer significantly increased stem diameter. In SC, the increase was not significant (data not shown).

Except for plant height in MWP compost, composts increased plant height and root weight of cucumbers compared with sandy soil. Pepper and tomato shoot weight was heaviest in RDFR, and lightest in sandy soil. Shoot-to-root ratios of cucumbers and tomatoes were similar among treatments, but pepper shoot-to-root ratios were generally higher in plants grown in composts than in sand.

Table 6. Seedling emergence and growth characteristics of tomato seedlings grown in composts,[z] compost–vermiculite mixtures, peat-lite mix, or sandy soil (greenhouse Expts. 1, 2, and 3).

Medium	MDE[y]	Emergence (%)	Plant ht (mm)	Shoot mass (mg)	Shoot:root ratio
		Expt. 1			
RDFR	15.8 a[x]	71.5 b	64 b	4.7 b	2.0 b
SC	12.6 b	50.5 c	61 bc	4.6 b	3.3 a
Aged SC	10.4 b	64.5	61 bc	5.7 a	3.4 a
Sand	7.0 c	84.5 a	57 c	4.8 b	1.1 b
Peat-lite mix	6.0 c	83.2 a	78 a	6.4 a	2.2 ab
		Expt. 2			
MWP	8.3 b	74.5 b	72 b	4.8 c	1.5
SC	10.5 a	62.5 b	72 b	5.7 b	2.2
Sand	8.5 b	88.2 a	58 c	4.5 c	0.9
Peat-lite mix	5.9 c	90.0 a	87 a	6.7 a	2.2
		Expt. 3			
MWP	15.2 a	53.0 b	69 d	5.4 ab	2.6 ab
RDF	13.9 a	55.8 b	73 cd	5.2 ab	3.4 a
MWP–vermiculite	9.0 b	77.2 a	88 b	6.2 a	2.0 bc
RDF–vermiculite	10.8 b	83.5 a	77 c	5.8 a	2.8 ab
Sand	7.9 bc	84.5 a	73 cd	5.3 ab	0.7 d
Vermiculite	8.5 bc	79.8 a	71 cd	4.1 b	1.7 c
Peat-lite mix	5.8 c	86.8 a	95 a	6.2 a	2.9 a

[z]RDFR = refuse-derived fuel residuals, SC = standard compost of yard trimmings and biosolids, MWP = mixed waste paper, RDF = refuse-derived fuel.
[y]MDE = mean days to emergence.
[x]Mean separation in columns within crops by Duncan's multiple range test, $P \leq 0.05$.

Table 7. Stem diameter, plant height, shoot and root mass, and shoot-to-root ratios of plants grown in pots with sand or various composts[z], with or without fertilizer (shadehouse experiment).

Treatment	Stem diam (mm)		Plant ht (cm)	Shoot mass (mg)	Root mass (mg)	Shoot:root ratio
			Cucumbers			
	Fertilizer (F)					
Medium (M)	+	–				
MWP	6.7	5.1	10.5 b[y]	595	390 a	2.6
RDFR	6.6	5.8	14.9 a	596	354 a	3.3
SC	6.3	5.9	15.0 a	495	385 a	2.0
Sand	5.5	3.4	10.5 b	285	125 b	2.3
F						
+			16.8	600	220	3.8
–			11.4	386	407	1.3
F effects			*	NS	*	NS
F × M	**		NS	NS	NS	NS
			Peppers			
Medium						
MWP	5.2 b		19.8 b	1105 b	1945 bc	0.7 a
RDFR	5.2 b		20.9 a	1355 b	2675 ab	0.5 ab
SC	5.7 a		22.0 a	1790 a	3040 a	0.8 a
Sand	4.0 c		15.7 c	360 c	1400 c	0.3 b
F						
+	5.1		20.4	1375	2025	0.8
–	4.9		18.9	930	2505	0.4
F effects	*		**	**	NS	*
F × M	NS		NS	NS	NS	NS
			Tomatoes			
Medium						
MWP	4.3 b		26.2 c	1010 bc	775 b	2.8
RDFR	4.7 b		30.1 ab	1450 b	930 b	2.2
SC	5.2 a		32.2 a	2895 a	1815 a	2.0
Sand	4.2 b		27.6 bc	705 c	775 b	1.5
F						
+	4.6		30.3	1577	782	2.8
–	4.6		28.0	1452	1222	1.4
F effects	NS		*	NS	*	*
F × M	NS		NS	NS	NS	NS

[z]MWP = mixed waste paper, RDFR = refuse derived fuel residuals, SC = standard compost of yard trimmings and biosolids.
[y]Mean separation in columns within crops by Duncan's multiple range test, $P \leq 0.05$.
[NS,*,**]Nonsignificant or significant at $P \leq 0.05$, respectively.

Although these composts often slightly prolonged and decreased emergence, subsequent growth in the composts was equal to or higher than growth in the commercial peat-lite mix and highly improved compared with a sandy field soil.

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