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Composted Turkey Litter: I. Effect on Chemical and Physical Properties of a Pine Bark Substrate[1]

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Abstract

Cotoneaster dammeri C.K. Schneid. 'Skogholm' and *Hemerocallis* sp. 'Red Magic' plants were potted into a pine bark substrate amended with 0, 4, 8, 12, or 16% (by vol.) composted turkey litter and were grown under 1-, 2-, or 3-day irrigation frequencies. Compost increased container capacity and available water 12-16% and 17-30%, respectively, compared to pine bark alone (0% compost). Unavailable water and bulk density increased with increasing compost rate, while air space decreased. Total porosity was unaffected by compost addition. Substrate solutions were extracted from the 'Skogholm' cotoneaster containers via the pour-through nutrient extraction method at 0, 18, 36, 54, 78, and 102 days after initiation. Ammonium, NO_3, P, K, Ca, Mg, and micronutrient substrate solution concentrations increased with decreased irrigation frequency due to decreased leaching. Substrate nutrient concentrations and pH increased with increasing rate of compost addition. Compost provided adequate nutrient supplies throughout the growing season except for K and micronutrients which were depleted after day 78.

Index words: substrate amendment, water usage, nutrient efficacy.

Species used in this study: 'Skogholm' cotoneaster (*Cotoneaster dammeri* C.K. Schneid.'Skogholm') and 'Red Magic' daylily (*Hemerocallis* sp. 'Red Magic').

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Significance to the Nursery Industry

Amending the pine bark with composted turkey litter (compost) has the potential to increase substrate water retention and thereby potentially increasing nutrient efficacy within the container solution. Reduced frequencies of irrigation and increased water holding capacity of the substrate resulted in less N, P, K, Ca, Mg, and micronutrients lost from the container due to leaching. Compost increased the concentrations of all nutrients and pH in the substrate solution. Compost adequately supplied all macronutrients needed for plant growth for 102 days except K, which was insufficient in the container after 78 days.

Introduction

Water quality and quantity are two major environmental concerns of nursery owners (23). Due to the porous nature and limited water reserves of most container substrates, container production requires large amounts of water to produce rapid plant growth. Unfortunately, a significant proportion of the applied water passes through the container carrying nutrients with it (28). This has led to interest in modifying the container substrate to improve water and nutrient efficacy. Although several alternative cultural practices may improve water and nutrient efficiency, engineering container substrates to hold more water and nutrients seems to be one of the more practical approaches. Research has shown that composted organic material has the potential to improve the physical and chemical properties of container substrates (10).

Many organic materials (sewage sludge, grape marc, animal waste, yard waste, food processing waste) have been examined as container amendments (19). In most cases, these organic materials cannot be used directly because of phytotoxity, N immobilization, high salt content or structural incompatibility (11). However, composting eliminates many of these disadvantages. Depending upon the type of compost and the substrate (pine bark, peat, soil), water availability can be decreased (3), increased (25), or unchanged (10). In general, compost acts as a slow release fertilizer regardless of the composted material or the substrate, partially or completely substituting for the traditional fertilizer program (3, 8). Amending common substrates with compost will require changes (irrigation and fertility) in the traditional container production program (8).

The poultry industry is currently seeking alternative disposal methods for litter produced during poultry production (20). For every one to five flocks raised, the litter (bedding and manure) is removed from confinement houses and replaced with fresh bedding. Litter is rich in nutrients and is primarily used as an organic fertilizer on cropland. However, because poultry production is concentrated near processing facilities, the quantity of litter produced may exceed the agricultural crop demand in these areas. Composting may be an alternative method of disposal. There are few reports that have examined composted poultry litter as a horticultural substrate amendment (2, 18). Therefore, the objective of this study was to characterize the chemical and physical proper-

[1]Received for publication January 20, 1993 and in revised form May 28, 1993. Technical assistance of William Reece, Mary Lorscheider, Beth Harden, the Horticultural Substrates Laboratory, NCSU, Dept. of Horticultural Science, and the Analytical Service Laboratory, NCSU, Department of Soil Science, is gratefully acknowledged. This research was supported, in part, by grants from the nursery industry through contributions of the Horticultural Reasearch Institute, 1250 I Street, N.W., Suite 500, Washington, DC, 20005, Grace/Sierra Horticultural Products and the North Carolina Nurserymen Association. The composted turkey litter used in this study is a commercial material distributed under the trade name "Sustane" by Sustane Corporation, Cannon Falls, Minn. This paper is from a thesis submitted by the senior author in partial fulfillment of the requirements for the MS degree.

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ties of a pine bark based substrate amended with composted turkey litter.

Materials and Methods

The experiment, a 3 × 5 factorial in a split-plot design with eight single plant replications, was conducted on a gravel pad at North Carolina State University, Horticultural Research Unit 4, Raleigh. The two factors were three irrigation frequencies (main plots) of 1, 2, or 3 days and five compost rates (subplots) of 0, 4, 8, 12, or 16% (by vol.) (compost weighed 552 kg/m³ (933 lbs/yd³)). Uniform rooted cuttings of *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' and bare root divisions of *Hemerocallis* sp. 'Red Magic' were potted into 3.8 liter (#1) containers on May 13, 1991. Each container received 1400 ml (47 oz) of water daily via pressure compensated drip emitters per specified irrigation frequency. Compost ranged in particle size from 1.0–2.5mm. Particle size distributions of pine bark × compost substrates are listed in Table 1.

Milled pine bark [(<13 mm)(0.5 in)] was amended on a m³ (yd³) basis with compost. For comparison to a common commercial substrate, 48 containers of milled pine bark were amended on a m³ (yd³) basis with 0.91 kg (2.0 lbs) dolomitic limestone and 0.9 kg(1.5 lbs) Micromax micronutrient fertilizer and incorporated into the irrigation × compost rate split plot design. These "commercial substrate" plants were top dressed with 18 g (0.63 oz) Osmocote 17-3-10 (17-7-12) per plant on May 24, 1991 (Day 0). An additional 13 containers of each of the pine bark × compost substrate combinations were filled at initaition of the study. These fallow containers were irrigated daily and received similar cultural practices as those with plants.

Physical properties. All physical property analyses were conducted at the Horticultural Substrates Laboratory, Department of Horticultural Science, N.C. State Univ., Raleigh. After 13 weeks, three 150 g (0.33 lbs) samples of each substrate were dried at 105°C (221°F) for 24 h and placed in a Rotap Shaker for 10 min. Each sample was weighed and particle size was then expressed as a percentage of the total weight of the sample.

After 13 weeks, 7 intact, naturally compacted samples were extracted from each of the fallow compost × pine bark substrates with cylindrical aluminum rings, 347.5 cm³ (21.2 in³) in volume (7.6 cm dia, 7.6 cm ht) (3 in dia, 3 in ht). Aluminum rings were fitted with a base plate attached to the bottom of the ring. The base plate consisted of an inner and an outer ring both containing 8 holes. The plate can be rotated so that the holes align to an open or a closed position. Aluminum rings with base plates attached were inserted into a Buchner funnel so that the base plate fits snugly into the bottom of the funnel. Rubber stoppers were inserted into the bottom of the funnels to prevent drainage.

Base plates were rotated into the open position and distilled water was added in between the aluminum cylinder and the Buchner funnel walls to allow water to be absorbed through the base plate. Water was added slowly in a stepwise fashion as outlined in Karlovich and Fonteno (12) to prevent air entrapment. Water level was eventually brought to the top of the substrate where it was allowed to equilibrate for an additional 15 min before drainage.

The base plate was then closed carefully so not to disturb the contents of the cylinder. Rubber stoppers were removed

Table 1. Particle size distribution of pine bark x compost substrates after 13 weeks.

Particle size range (mm)	Pine bark	Compost (by vol)			
		Percent			
	0	4	8	12	16
	(percent by wt)				
>6.3	13.5	9.8	6.7	9.0	8.3
6.3-4.0	15.0	13.8	11.9	13.6	14.1
4.0-2.8	12.4	13.8	13.6	16.8	15.5
2.8-2.0	11.8	15.2	16.5	17.2	16.3
2.0-1.4	9.9	13.5	14.7	12.7	13.0
1.4.1.0	9.1	10.5	11.0	8.6	9.2
1.0-0.7	8.4	8.1	8.9	6.4	6.9
0.7-0.5	6.9	5.5	5.3	4.6	4.9
0.5-0.4	3.9	3.1	3.1	2.9	3.1
0.4-0.3	3.2	2.5	2.8	3.0	3.2
0.3-0.2	1.8	1.4	1.8	1.9	2.1
0.2-0.1	1.8	1.3	2.0	1.6	1.5
<0.1	2.4	2.0	1.8	1.9	1.6

and water from around the aluminum cylinder and the base plate was allowed to drain. A graduated cylinder was placed under each funnel, the base plate opened and the sample allowed to drain for 60 min.

After drainage the aluminum cylinder and the base plate were removed from the funnels and base plates were detached. Wet weights of samples were recorded. Samples were placed in a forced-air drying oven at 105°C (221°F) for 24 h and dry weight recorded. Total porosity was defined as [(wet weight − dry weight) + drainage water] ÷ volume of sample. Bulk densities were determined for each substrate by calculating its volume, drying 24 h at 105°C (221°F) and weighing (13).

Five cylindrical aluminum rings, 115.8 cm³ (7.1 in³) in volume (7.6 cm dia, 2.5 cm ht) (3 in dia, 1 in ht), were packed to a known bulk density from each of the fallow pine bark × compost substrates after 13 weeks. Data for moisture retained on a measured volume basis were collected at a moisture tension of 1500 kPa, according to Klute (13) and Milks *et al.* (15).

Total porosity (TP) and unavailable water (UW) were equal to volume wetness at saturation and 1500 kPa, respectively. Container capacity (CC) was calculated using the equilibrium capacity variables model developed by Bilderback and Fonteno (1) and refined by Milks *et al.* (15). Air space (AS) was calculated as the difference between TP and CC. Available water (AW) was calculated as the difference between CC and UW (15).

Chemical properties. The substrate solution was extracted from the 'Skogholm' cotoneaster containers via the pour-through nutrient extraction method (26) at 0, 18, 36, 54, 78, and 102 days after initiation. The pour-through sample was obtained by pouring 150 ml (5 oz) of distilled water on the substrate surface 2 h after irrigation and collecting the leachate. After samples were filtered through Whatman #1 paper, pH was determined. Leachates were then frozen for future NO^3 (4) and NH^4 (5) analyses using a spectrophotometer (Spectronic 1001 Plus, Milton Roy Co., Rochester, NY). Phosphorus, K, Ca, Mg, Mn, Cu, Zn, Fe, and B were determined by inductively coupled plasma emission spectroscopy. Nitrate and ammonium solution analyses were

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conducted at the Horticultural Substrates Laboratory. All other solution analyses were conducted at the Analytical Services Laboratory. Irrigation water, which was sampled at each collection time, averaged (mg/liter): 0.05 NO_3, 0.34 NH_4, 0.2 P, 0 K, 16.3 Ca, 2.5 Mg, 0 Mn, 0 Cu, 0 Zn, 0 Fe, and 0 B. Average pH was 7.8.

All variables were tested for differences using analysis of variance and regression analysis (21). All reported means separations were performed via least significant difference (LSD) procedures at $p \leq 0.05$.

Results and Discussion

Physical properties. Percentage of particle sizes in the particle range of the compost (1.0–2.5 mm) for all rates of compost addition were greater than for pinebark (0% compost) (Table 1). This suggests that the compost did not break down substantially after 13 weeks.

Compost rate yielded a quadratic response in AS, with the maximum AS value occurring at 12% compost (excluding 0%)(Table 2). However, compost decreased air space compared to pine bark alone (0% compost). Total porosity was unaffected by compost addition and was within the acceptable range (a minimum of 85%) of substrate characteristics proposed by de Boodt and Verdonck (7), while AS in the compost amended substrates was below the proposed acceptable range (20-30%).

Compost increased CC 12 to 16% above pine bark (0% compost); however, there were minimal differences between the compost amended substrates (Table 2). The addition of compost to the substrate appears to have shifted the pore space distribution within the container, resulting in increased water retention and decreased AS. Hemphill *et al.* (10) reported similar results with a substrate composed of composted sewage sludge, conifer bark, and perlite.

Available water increased quadratically in response to increasing compost rate, with the maximum AW value occurring at 8% compost (Table 2). Compost increased AW by 17-30% compared to pine bark (0% compost). However, UW increased linearly with increasing compost rate. Similar results were noted by Warren and Fonteno (25) with a sandy loam soil amended with composted poultry litter and by Bilderback and Fonteno (2) with a pine bark-based substrate amended with composted poultry litter. The response in AW and UW reflects the relationship found with AS and CC.

There was a linear increase in BD with increasing rate of compost addition (Table 2). Similar results were reported by Bilderback and Fonteno (2)

Chemical properties. Only data for the samples taken 18, 54, and 102 days after initiation are shown, as they adequately describe the response seen in the data for all sample times. Irrigation frequency affected the substrate concentration of NO_3, NH_4, K, P, except for K substrate concentrations at 102 days (Table 3). Compost addition affected the nutrient concentrations of all measured nutrients except K at 102 days.

Substrate pH was significantly affected by compost (Table 3). In general, substrate pH increased with increasing compost (data not shown). Irrigation frequency did not affect substrate pH at 18 and 54 days but did at 102 days (Table 3). At 102 days, substrate pH tended to decrease with decreasing irrigation frequency (data not shown). The commercial substrate, which was amended with dolomitic limestone, and the 12% and 16% compost rates had similar pH levels throughout the study (data not shown).

Except for 0% compost substrate, NH_4 concentration increased with decreasing irrigation frequency (Table 4) due to decreased leaching. Gilman *et al.* (9) reported that rate of N leached from cypress wood chips increased when increasing amounts of water were applied daily. At 18 days, substrate NH_4 concentration increased with increasing compost regardless of irrigation frequency (Table 4). At 54 and 102 days substrate NH_4 concentration was significantly affected by compost only with the 3-day irrigation frequency (date not shown). By day 54 under daily irrigation and 102 days under 2-day irrigation, compost substrate NH_4 concentrations were not significantly different from pine bark (0% compost), suggesting that NH_4 release had ceased (data not shown). By day 102, with 3-day irrigation, the commercial substrate and 8%, 12%, and 16% compost substrates had higher substrate NH_4 concentrations than pine bark (0% compost), while all rates of compost had lower substrate NH_4 concentrations than the commercial substrate.

Similar to NH_4, substrate NO_3 concentration increased with decreasing irrigation frequency due to decreased leaching (Table 5). Warren and Bilderback (24) and Stewart *et al.*

Table 2. Physical properties of pine bark x compost amended pine bark substrates.

Compost rate	Total porosity[z] (TP)	Air space[y] (AS)	Container capacity[x] (CC)	Available water[w] (AW)	Unavailable water[v] (UW)	Bulk density (BD)
(v/v)	Percent volume					(g/cm^3)
0	84.7	24.0	60.7	29.6	31.4	0.20
4	83.8	13.4	70.4	37.4	33.0	0.23
8	84.1	13.4	70.7	38.4	32.4	0.23
12	85.1	17.0	68.1	34.7	33.2	0.23
16	85.1	16.1	69.0	35.6	33.7	0.24
Significance[u]						
L[t]	NS	*	**	NS	**	**
Q	NS	**	**	**	NS	**

[z]Based upon percent volume of 7.6 x 7.6 cm core at 0 kPa.
[y]TP-CC.
[x]Measured as percent volume of a 7.6 x 7.6 cm core at drainage.
[w]CC-UW.
[v]Based upon percent volume of a 7.6 x 2.54 cm core at 1500 kPa.
[u]NS, *, ** Nonsignificant or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

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Table 3. Response of container substrate solution nutrient concentrations, NO_3:NH_4 ratio, and pH to irrigation frequency and compost rate: 18, 54, and 102 days after initiation.

Source of variation	NO3 18	NO3 54	NO3 102	NH4 18	NH4 54	NH4 102	K 18	K 54	K 102	P 18	P 54	P 102
	Container substrate concentration (mg/liter) — Days after initiation											
Irrigation (I)	**z	**	**	**	**	*	**	**	NS	**	**	**
Compost (C)	**	**	**	**	**	**	**	**	NS	**	**	**
IXC	**	*	NS	*	**	*	**	**	NS	NS	**	**

	Ca 18	Ca 54	Ca 102	Mg 18	Mg 54	Mg 102	NH4:NO3 ratio 18	NH4:NO3 ratio 54	NH4:NO3 ratio 102	pH 18	pH 54	pH 102
Irrigation	**	NS	**	NS	NS	*	NS	NS	—y	NS	NS	**
Compost	**	**	**	**	**	**	**	**	—	**	**	**
IXC	NS	**	NS	NS	**	NS	NS	NS	—	NS	*	*

zNS,*,** Nonsignificant or significant at $p \leq 0.05$ or $p \leq 0.01$, respectively.

yData not available. NH_4 approaching zero.

Table 4. Effect of irrigation frequency and compost rate on substrate solution NH_4 concentration 18 days after initiation.

Compost (v/v)	18 days after initiation — NH_4 (mg/liter) — Irrigation frequency (days): 1	2	3	L^z (irr)
0	0.5	0.3	0.3	—y
4	8.7	10.2	15.3	*
8	27.2	41.8	54.5	**
12	39.9	77.5	105.7	**
16	66.2	115.7	127.5	*
comm.x	0.3	0.7	0.5	
Significancew (compost)				
L^z	**	**	**	
Q	NS	NS	NS	

zNS, **, * Nonsignificant or significant at $p \leq 0.01$ or $p \leq 0.05$, respectively.

yZero compost rate excluded from regression analysis.

xCommercial substrate data not included in the regression analysis. Comparisons of commercial substrate to compost substrates based on LSD = 24 mg/l.

wL = linear, Q = quadratic, irr = irrigation frequency.

(22) reported similar results. At 18 and 54 days, substrate NO^3 concentration increased with increasing compost rate regardless of irrigation frequency (Table 5). However, by 102 days, substrate NO_3 concentration increased with increasing compost rate only for the 2-day irrigation frequency.

By 102 days, both the compost and the commercial substrate NO_3 concentrations were not significantly different from pine bark (0% compost) with 1- and 2-day irrigation (Table 5). With 3-day irrigation, the commercial substrate and 8%, 12%, and 16% compost rates had higher substrate NO_3 concentrations than pine bark (0% compost), illustrating the effects of reduced leaching by reduced frequency of irrigation.

The composted turkey litter product had an analysis of 5.0-0.88-3.3 (5-2-4). Of the 5% total nitrogen, 1.5% of it was in the ammoniacal form and the remaining 3.5% was in a water insoluble form. The high initial concentrations of ammonium with increasing rate of compost compared to the low levels of nitrate (Tables 4, 5) and the high NH_4:NO_3 ratio (5.2, 4% compost; 16.3, 16% compost) at the 18-day sample time was a result of the readily available form of ammoniacal nitrogen. By 54 days, a large portion of the ammoniacal nitrogen had been leached or converted to nitrate through nitrification, as seen by the reduction in substrate NH_4 concentration with a subsequent increase in substrate NO_3 concentration and lower NH_4:NO_3 ratio (1.6, 4% compost; 0.3, 16% compost). The ammonium ion can be adsorbed to the negative charges of the substrate, leached, taken up by the plant, or converted to NO_3 via nitrification (27). Nitrification of NH_4 available in the substrate solution to NO_3 is a relatively rapid process (28). Niemiera (16) calculated that 100 mg/liter NH_4 could be nitrified to NO_3 in 50 h in a 3.8 liter bark-filled container at 100% gravimetric moisture. Niemiera and Wright (17) and Chrustic and Wright (6) reported increased nitrification and lower NH_4:NO_3 ratios with increased rates of limestone additions and higher substrate pH levels. Compost raised the pH of the pine bark based substrate and provided sufficient NH_4 so that nitrification occurred, thereby providing a slow release of $N0_3$.

At 18 days, substrate K concentration increased quadratically with increasing compost under the 1-day irrigation with the maximum at the 12% rate (Table 6). At 54 days, increasing rate of compost resulted in a linear increase in substrate K concentration under all irrigation treatments. Substrate K concentration increased with decreasing irrigation frequency due to decreased leaching. Potassium ions appeared to be readily leached from the substrate solution and did not differ from the 0% compost rate at 54 days with daily irrigation , at 78 days with 2-day irrigation, and at 102 days with 3-day irrigation. Mengel and Kirkby (14) reported that K in poultry manure is predominately found in a water-soluble form and can be easily leached. Data herein supports this conclusion.

At 18 days, substrate P concentration increased quadratically with increasing compost rate for 1- and 2-day irrigations with a maximum attained at 12% compost (Table 7). At 54 and 102 days, substrate P concentration increased linearly with increasing compost rate regardless of irrigation frequency. Similar to the other nutrients, substrate P concentration increased with decreasing irrigation frequency for all compost rates. The 12% and 16% compost rates maintained higher substrate P concentrations than the commercial substrate regardless of irrigation frequency and sample time (Table 7).

Substrate Ca concentration increased with increasing compost rate for all irrigation frequencies and sample times (Table 8). In contrast to the other nutrients, substrate Ca concentration decreased with decreasing irrigation frequency (data not shown). The irrigation water most likely provided a source of Ca above that provided by the compost, as the 0% compost substrates had relatively high substrate Ca concentrations.

At 54 days, 12% and 16% compost substrates yielded higher Ca concentrations than the commercial substrate containing dolomitic limestone (Table 8). Increased Ca retention of the compost amended substrates over the commercial substrate could be due to increased availability from the compost, increased water-holding capacities, or increased cation exchange capacity (CEC) (data not shown) of these substrates. Substrate Mg concentration responded similarly

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Table 5. Effect of irrigation frequency and compost rate on substrate solution NO_3 concentration: 18, 54, and 102 days after initiation.

	Days after initiation											
	18				54				102			
	NO_3 (mg/liter)											
	Irrigation frequency (days)											
Compost (v/v)	1	2	3	L[z] (irr)	1	2	3	L[z] (irr)	1	2	3	L[z] (irr)
0	0.5	0.5	1.1	—[y]	0.0	0.0	0.0	—	0.5	0.3	0.4	—
4	1.4	2.8	3.1	**	2.9	3.2	7.3	*	0.8	0.8	1.3	NS
8	3.1	4.0	4.6	NS	6.7	9.3	17.4	*	0.8	1.3	1.9	**
12	3.0	6.9	7.9	**	11.0	15.7	22.8	**	0.7	1.2	2.2	**
16	4.3	6.7	8.2	**	7. 4	19.9	23.9	**	1.3	1.8	1.9	NS
comm.[x]	5.5	4.5	4.1		0.9	2.3	4.8		1.2	1.4	4.5	
Significance[w] (compost)												
L[z]	**	**	**		*	**	**		NS	*	NS	
Q	NS	NS	NS		**	NS	NS		NS	NS	NS	

[z]NS, **, * Nonsignificant or significant at $p \leq 0.01$ or $p \leq 0.05$, respectively.

[y]Zero compost rate excluded from regression analysis.

[x]Commercial substrate data not included in the regression analysis. Comparisons of commercial substrate to compost substrates based on LSD=2.6 mg/l, 18 days; LSD=6.0 mg/l, 54 days; LSD=1.2 mg/l, 102 days.

[w]L = linear, Q = quadratic, irr = irrigation frequency.

Table 6. Effect of irrigation frequency and compost rate on substrate solution K concentration: 18 and 54 days after initiation.

	Days after initiation							
	18				54			
	K (mg/liter)							
	Irrigation frequency (days)							
Compost rate (v/v)	1	2	3	Lz (irr)	1	2	3	Lz (irr)
0	6.3	8.0	10.5	—[y]	6.3	7.3	7.5	—
4	11.0	17.0	21.8	**	7.3	7.3	10.8	NS
8	17.8	21.3	33.0	*	6.8	18.5	25.3	**
12	19.3	30.0	35.3	NS	10.0	20.3	33.0	**
16	16.5	22.3	29.0	**	10.0	21.0	29.5	**
comm.[x]	10.8	8.3	13.0		6.8	7.3	12.3	
Significance[w] (compost)								
L[z]	NS	NS	NS		*	**	**	
Q	*	NS	NS		NS	NS	*	

[z]NS, **, * Nonsignificant or significant at $p \leq 0.01$ or $p \leq 0.05$,r espectively.

[y]Zero compost rate exlcuded from regression analysis.

[x]Commercial substrate data not included in the regression analysis. Comparisions of commercial substrate to compost substrates based on LSD=9.4 mg/l, 18 days; and LSD=6.8 mg/l, 54 days.

[w]L = linear, Q = quadratic, irr = irrigation frequency.

to Ca to irrigation frequency and compost rate (data not shown).

Irrigation frequency did not significantly affect substrate Fe concentration at any sample time (data not shown). Compost rate significantly affected substrate Fe concentration at 18 days but not at 54 days (data not shown). In addition, the irrigation × compost interaction was not significant. At 18 days, there was a quadratic response to increasing compost in substrate Fe concentration with a maximum at 12% compost (data not shown). By 78 days, substrate Fe concentrations of compost and commercial substrates were below the detection level of the analytical laboratory instrumentation. The 12% and 16% compost substrates produced significantly higher substrate Fe concentrations than the commercial substrate. Substrate Mn, Cu, Zn and B concentrations responded similarly to substrate Fe (data not shown).

The sustained nutrient release across sample times of the substrates amended with 8%, 12%, and 16% compost rates was possibly due to the increased nutrient content of the higher amendment rates as well as the increased CEC of these substrates (data not shown). A substrate with a higher CEC is potentially able to replenish nutrients lost due to plant uptake or leaching as the nutrient cation is released from the exchange site into the substrate solution. Compost provided adequate nutrients throughout the growing season except for K and the micronutrients which were depleted after day 78.

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Table 7. Effect of irrigation frequency and compost rate on substrate solution P concentration: 18, 54, and 102 days after initiation.

	Days after initiation											
	18				54				102			
	P (mg/liter)											
	Irrigation frequency (days)											
Compost (v/v)	1	2	3	L^z (irr)	1	2	3	L^z (irr)	1	2	3	L^z (irr)
0	1.3	1.4	1.8	—[y]	0.6	0.7	0.9	—	0.5	0.5	0.5	—
4	5.4	9.9	13.8	**	1.4	2.2	3.6	**	0.5	0.6	0.8	**
8	13.3	20.0	26.3	**	3.6	10.3	12.2	**	0.9	1.5	2.3	**
12	17.0	26.3	39.0	*	6.4	13.0	19.0	**	1.3	2.8	3.2	**
16	14.5	19.5	26.0	*	7.9	15.0	15.3	**	1.5	3.2	3.8	**
comm.[x]	2.4	2.1	3.1		1.0	1.5	2.6		0.5	0.6	1.4	
Significance[w] (compost)												
L^z	**	*	NS		**	**	**		**	**	**	
Q	**	**	NS		NS	*	**		NS	NS	*	

[z]NS, **, * Nonsignificant or significant at $p \leq 0.01$ or $p \leq 0.05$, respectively.

[y]Zero compost rate excluded from regression analysis.

[x]Commercial substrate data not included in the regression analysis. Comparisons of commercial substrate to compost substrates based on LSD=9.1 mg/l, 18 days; LSD=3.0 mg/l, 54 days; and LSD=0.5 mg/l, 102 days.

[w]L = linear, Q = quadratic, irr = irrigation frequency.

Table 8. Effect of compost rate on substrate solution Ca concentration.

Compost rate (by vol)	Ca (mg/l) Days after initiation 18	54	102
0	6.2	7.2	6.1
4	4.9	7.9	7.8
8	5.9	12.3	11.6
12	8.2	18.0	18.5
16	8.2	17.5	28.0
comm.[y]	7.6	8.0	7.4
Significance[x]			
L^z (compost)	**	**	**
Q	NS	NS	NS

[z]NS, **, * Nonsignificant or significant at $p \leq 0.01$ or $p \leq 0.05$, respectively.

[y]Commercial substrate data not included in the regression analysis. Comparisons of commercial substrate to compost substrates based on LSD=2.9 mg/l, 18 days; LSD=4.0 mg/l, 54 days; and LSD=1.9 mg/l, 102 days.

[x]L = linear, Q = quadratic. Zero compost rate excluded from regression analysis.

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