Rooting Foliage Plant Cuttings in Compost-formulated Substrates

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SUMMARY. Three composts, derived from municipal solid waste with biosolids, yard trimmings, and yard trimmings with biosolids, were mixed by volume with sphagnum peat and pine bark to formulate 12 substrates. After characterizing physical and chemical properties, the substrates, along with a control, were used for rooting single eye cuttings of pothos (*Epipremnum aureum*) and terminal cuttings of maranta (*Maranta leuconeura*) and schefflera (*Schefflera arboricola*) in enclosed polyethylene tents. All cuttings initiated roots with no significant difference in root numbers per cutting 14 days after sticking, but root lengths 21 days and root-ball coverage ratings 45 days after sticking were significantly affected by substrates. Five of 12 compost-formulated substrates resulted in root lengths of cuttings equal to or longer than the control. In addition to desirable physical properties such as bulk density, total porosity, and air space, common chemical characteristics of the five substrates included low concentration of mineral elements, initial electrical conductivity ≤3.0 dS·m^{-1} based on the pour through extraction method, and pH between 3.8 to 5.0. The five substrates were formulated by combining composted municipal solid waste with biosolids or yard trimmings with biosolids volumetrically at 20% or less or composted yard trimmings at 50% or less with equal volumes of sphagnum peat and pine bark.

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Composts derived from biosolids (BS), municipal solid waste (MSW), and yard trimmings (YT) have been used as soil amendments for improving vegetable, fruit, and field crop production (Ozores-Hampton et al., 1998; Shiralipour et al., 1992). Composts also are used as components of container substrates for producing bedding (Klock, 1997; Logan and Lindsay, 1996), landscape (Beeson, 1996; Jarvis et al., 1996), and tropical foliage plants (Conover and Poole, 1990; Fitzpatrick et al., 1998; McConnell and Shiralipour, 1991). However, little information is available on the use of compost-formulated substrates for rooting foliage plant cuttings.

Currently, plants from at least 100 genera are grown as ornamental foliage plants. Although many plants are now propagated through tissue culture, a large number of genera are still propagated using cuttings. Vegetative propagation generally requires high quality substrates (Hartmann et al., 1990). Consequently, composts have not been considered proper substrates for rooting. However, if composts could be used to formulate suitable substrates for vegetative propagation, another potential market for compost use in foliage plant production would exist.

The objectives of this study were to 1) measure physical and chemical properties of compost-formulated substrates along with a control, 2) evaluate root development of foliage plant cuttings in compost-formulated substrates in comparison to that of the control, and 3) determine if compost-formulated substrates were equal or superior to the control substrate for rooting foliage plant cuttings.

Materials and methods

COMPOSTS AND COMPOST-FORMULATED SUBSTRATES. Three representative Florida composts, derived from MSW+BS (Sumter County Solid Waste Facility, Fla.), YT (Consolidated Resource Recovery, Sarasota, Fla.), and YT+BS (AllGro, Inc., West Palm Beach, Fla.), were mixed in volumetric combinations with sphagnum peat (SP) and pine bark (PB) (Fafard, Inc., Apopka, Fla.) to obtain 12 substrates (Table 1). The MSW+BS was composed of two parts of MSW, mainly household garbage from Sumter County, and one part of 16% polymer-dewatered BS, primarily sewage sludge from cities of Wildwood, Clemont, and the Villages, based on weight. After 3 d of aerobic digestion, the MSW+BS was windrow-cured for 21 d and then screened as finished compost. The feedstock of YT from Sarasota consisted of grasses, leaves, and tree debris, which were screened and then composted 90 d using the windrow method. The YT+BS comprised three parts of YT, coming from the West Palm Beach landscape companies including grass, limbs, and leaves, and two parts of 16% lime-dewatered BS that was mainly the city sewage sludge, based on weight. The final YT+BS product was derived from 90 d of in-vessel composting. The three composts were used two weeks after delivery. There were no hazards in handling these composts. A common industry substrate, UF-2 [University of Florida container mix 2 (Poole et al., 1981)] composed of 50% SP and 50% PB, was used as a control.

PHYSICAL AND CHEMICAL PROPERTY DETERMINATION. Physical properties of substrates were measured using the Australian Standard Method (Standards Australia, 1989). Each substrate was homogenized and used to fill five 76-mm-diameter by 150 mm tall (3 × 6 inches) polyvinyl chloride cylinders capped on one end with five holes. Substrate-filled cylinders were allowed to soak vertically in water for 24 h then drained and resoaked for 30

Table 1. Components in volumetric percentage of control substrate and municipal solid waste (MSW) with biosolids (BS), yard trimmings (YT), YT with BS, sphagnum peat (SP), and pine bark (PB) formulated compost substrates.[z]

Substrate	Proportion of components by volume (%)				
	MSW+BS	YT	YT+BS	SP	PB
1	20			40	40
2	50			25	25
3	80			10	10
4		20		40	40
5		50		25	25
6		80		10	10
7			20	40	40
8			50	25	25
9			80	10	10
10	12	12	12	32	32
11	20	20	20	20	20
12	28	28	28	8	8
13 (control)				50	50

[z]MSW+BS was two parts MSW with one-part BS, and YT+BS was three parts YT with two parts BS, based on weight.

min three more times. Cylinders were carefully removed to saucers and, after 15 min elapsed, the volume of water drained from cylinders was recorded. Substrate weights after draining and after drying at 80 °C (176 °F) for 48 h, were recorded. Bulk density (g·cm^{-3}) was measured by weighing a known volume of the homogenized oven-dried substrate. Data from the above determinations were used to calculate physical properties of total porosity, container capacity, moisture content, and air space of the 13 substrates. Electrical conductivity (EC) and pH of the substrates were determined using the pour-through method (Yeager et al., 1983). Total carbon and nitrogen, cation exchange capacity (CEC), and concentrations of extractable elements—aluminum (Al), boron (B), barium (Ba), calcium (Ca), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), potassium (K), lithium (Li), magnesium (Mg), molybdenum (Mo), sodium (Na), nickel (Ni), phosphorus (P), lead (Pb), sulfur (S), and zinc (Zn)—of the substrates were measured by Fafard Analytical Service (Athens, Ga.) using the methods described by Jones et al. (1991).

Plant materials and rooting conditions. Cupric hydroxide-treated 10-cm (4-inch) containers were filled with substrates and placed on shaded glasshouse benches enclosed by polyethylene tents (Hartmann et al., 1990) with a mist frequency of 10 s every 10 min from 7:00 AM to 8:00 PM. All substrates attained their container capacities within 2 d. Then single eye cuttings of pothos 'Golden Pothos', terminal cuttings [10 to 12 cm (3.9 to 4.7 inches)] of maranta 'Kerchoveana' and schefflera 'Goldenfinger' obtained from local nurseries were stuck using three cuttings per container without rooting hormones. Rooting substrate temperatures in the enclosed tents ranged from 24 to 32 °C (75 to 90 °F) and maximum photosynthetically active radiation (PAR) was at 152 mmol·m^{-2}·s^{-1} (800 fc).

Experimental design, data collection and analysis. The experiment was arranged as completely randomized design with 15 replications per treatment. Fourteen days after sticking, cuttings from five of the 15 replications were removed and all roots longer than 1 mm were counted. Twenty-one days after sticking, cuttings from five of the remaining 10 replications were removed by gently washing the substrate from the roots. Individual root length per cutting was measured, and total root length per cutting was calculated by summing up the length of individual roots. Forty-five days after sticking, root-ball coverage of the remaining five replicates was graded based on the following scales: 1 = 0% to 20%, 2 = 21% to 40%, 3 = 41% to 60%, 4 = 61% to 80%, and 5 = 81% to 100% root ball coverage with white, healthy roots (Poole and Conover, 1984).

Analysis of variance was conducted using the general linear model procedure of the Statistical Analysis System (SAS Institute Inc., Cary, N.C.). Where significant differences ($P < 0.05$) occurred in chemical or physical properties, root numbers, root lengths, or root ball coverage ratings, means were separated using Fisher's protected least significant differences (LSD) at the 5% level.

Results and discussion

Substrate physical and chemical properties. Substrates were either a light or dark brown and had no detectable odor. As the percentage of compost increased in the substrates, bulk density significantly increased, but total porosity, moisture content, and air space decreased (Table 2). There was no difference in container capacity among the substrates. Substrates with bulk density ranging from 0.15 to 0.8 g·cm^{-3} (dry weight), total porosity of 50% to 75%, container capacity between 20% to 60% by volume, moisture content of 50% to 75%, and air space 10% to 20% are generally considered acceptable for rooting or producing containerized plants (Bunt, 1988; De Boodt and Verdonck, 1972; Poole et al., 1981; Maronek et al., 1985). When the measured physical property parameters of the formulated substrates were compared to these listed ranges, all were within the suggested ranges except air space in substrates 3, 6, and 9 that was below 10%. Air space less than 10% may affect root respiration and is considered unacceptable for greenhouse substrates (Bunt, 1976).

As the compost proportion in substrates increased, EC, pH, and CEC increased (Table 2). An EC reading of bulk solution extracted using the pour-through method above 3.0 dS·m^{-1} is generally considered to be the upper limit for the production of foliage plants

Table 2. Physical and chemical characteristics of control and compost-formulated substrates.

	Physical					Chemical			
Substrate[z]	Bulk density ($g\cdot cm^{-3}$)[y]	Total porosity (%)	Container capacity (%)	Moisture content (%)	Air space (%)	EC ($dS\cdot m^{-1}$)[x]	pH[x]	C:N ratio[w]	CEC[w] (meq/100 g)[w]
1	0.15[v]	65.1	50.5	75.7	14.7	1.5	4.6	15.4	14.0
2	0.20	57.6	48.3	70.8	10.0	6.0	6.0	20.7	19.5
3	0.31	53.8	44.5	62.5	4.5	10.5	6.9	26.9	26.8
4	0.17	72.7	59.8	74.0	12.9	1.4	4.7	22.5	20.4
5	0.28	67.9	57.7	65.7	10.2	2.9	5.1	24.2	23.1
6	0.52	62.1	54.4	53.5	5.5	6.2	6.2	25.4	25.5
7	0.16	68.6	54.2	74.1	11.5	2.1	5.0	18.5	16.0
8	0.28	63.4	53.4	66.2	10.4	5.7	6.0	20.4	19.4
9	0.39	58.1	51.1	65.9	8.4	9.6	6.6	21.8	22.8
10	0.20	74.2	60.8	75.6	13.8	2.3	4.6	22.6	19.5
11	0.30	68.2	57.2	65.5	11.2	6.5	5.8	23.7	23.4
12	0.38	63.5	53.8	58.7	10.8	12.4	6.4	21.9	26.9
13	0.15	66.7	48.4	75.9	18.2	0.3	3.8	15.2	14.8
$LSD_{(0.05)}$	0.10	10.1	NS	7.7	3.9	2.4	2.2	5.6	6.0

[z]See Table 1 for detailed information on substrate components.
[y]27.7 $g\cdot cm^{-3}$ = 1 $lb/inch^3$.
[x]EC = electrical conductivity; substrate solution extracted using pour through method (Yeager et al., 1983).
[w]Carbon to nitrogen ratio (C:N) and cation exchange capacity (CEC) were analyzed by Fafard Analytical Service, Athens, Ga.
[v]Mean separation in column by Fisher's protected least significant differences at $P \le 0.05$; [NS]Nonsignificant.

(Conover et al., 1992). Among the 13 substrates, EC readings >3.0 $dS\cdot m^{-1}$ were bulk solutions extracted from substrates of 2, 3, 6, 8, 9, 11, and 12, which all had compost percentage of 50% or higher. Substrate CEC varied from 14 to 27 meq/100 g but was well within the suggested ranges of 2 to 40 meq/100 g (Poole et al., 1981). Recommended pH for foliage plant production ranged from 5.5 to 6.5 (Poole et al., 1981). Substrates with pH > 6.5 were 3 and 9 but <5.5 were 1, 4, 5, 7, 10, and 13, the control. The carbon to nitrogen ratio (C:N) of substrates ranged from 15.2 to 26.9, suggesting that most substrates were within maturity range since composts with C:N ratio 25 or less are considered to be mature (Ozores-Hampton et al., 1998). Concentrations of Na, P, K, Ca, Mg, Cu, Mn, Fe, and Zn increased as compost proportions in substrates increased (Table 3). Concentrations of S in substrates 2, 3, 8, 9, 11, and 12 were >100 $mg\cdot kg^{-1}$ (ppm) and B in substrates 9 was 10.5 $mg\cdot kg^{-1}$. These levels are considered too high for foliage plant growth (Joiner et al., 1983). Other tested elements: Al, Ba, Cd, Co, Cr, Li, Mo, Ni, and Pb were either well below the U.S. Environmental Protection Agency's (USEPA's) permissible heavy metal loading ranges (USEPA, 1993) or negligible (data not shown).

ROOT INITIATION AND GROWTH. Fourteen days after sticking, all cuttings had initiated roots, and root number per cutting by species did not significantly vary among substrates (Table 4). Initial substrate differences in physical and chemical properties appeared to have little effect on root initiation. However, 21 d after stick-

Table 3. Elemental concentrations of control and compost-formulated substrates[z].

	Concn [$mg\cdot kg^{-1}$ (ppm)]								
Substrate[y]	Sodium	Phosphorus	Potassium	Calcium	Magnesium	Copper	Manganese	Iron	Zinc
1	75.8[x]	53.7	172.0	1223.1	218.7	3.2	2.5	38.5	21.2
2	578.2	100.7	664.7	2165.4	255.2	7.8	6.7	93.9	34.0
3	688.9	129.9	1016.6	2105.3	315.9	11.7	10.9	110.9	30.3
4	27.5	43.0	211.1	761.9	110.6	1.3	3.4	43.1	8.3
5	80.6	145.3	739.0	1844.6	297.7	3.0	5.9	69.2	19.2
6	91.3	185.0	1004.9	1984.9	356.0	3.8	6.8	71.5	22.2
7	56.7	159.7	269.8	1724.3	237.0	2.0	3.4	150.5	9.0
8	210.9	239.0	1055.7	3448.6	498.2	3.5	6.2	326.8	12.7
9	364.8	289.0	1446.7	4731.8	620.8	4.2	8.8	359.7	14.5
10	76.8	140.0	340.2	1844.6	260.1	3.2	3.6	101.7	18.8
11	302.5	203.0	938.4	2666.7	425.3	4.9	7.5	212.2	26.5
12	435.8	204.0	1290.3	2887.2	498.2	5.5	9.3	257.8	26.8
13	8.9	8.7	66.5	447.1	87.5	0.6	2.0	25.7	2.0
$LSD_{(0.05)}$	152.2	86.6	445.5	537.8	125.4	1.8	3.5	85.7	7.9

[z]Analyzed by Fafard Analytical Services, Athens, Ga., based on methods described by Jones et al., (1991).
[y]See Table 1 for substrate components.
[x]Mean separation in column by Fisher's protected least significant differences at $P \le 0.05$; [NS]Nonsignificant.

Table 4. Root numbers (RN) per cutting initiated 14 d after sticking from and total root lengths (RL) per cutting 21 d after sticking of pothos 'Golden Pothos', maranta 'Kerchoveana', and schefflera 'Goldenfinger' cuttings in control and compost-formulated substrates.

	Pothos		Maranta		Schefflera	
Substrate[z]	RN (no.)[y]	RL (cm)[x]	RN (no.)	RL (cm)	RN (no.)	RL (cm)
1	6.0[w]	8.8	4.8	8.1	7.8	6.2
2	5.8	6.7	4.2	5.0	8.1	4.5
3	5.5	4.5	4.6	3.6	7.4	3.0
4	6.6	8.5	5.0	7.8	7.2	6.3
5	6.1	7.8	5.1	7.2	7.5	5.9
6	5.9	5.1	4.5	4.7	6.8	4.5
7	5.7	8.7	5.9	7.4	6.1	6.1
8	6.2	6.6	5.2	5.3	7.4	4.9
9	6.0	4.3	6.0	4.2	6.8	3.2
10	5.6	7.9	5.5	7.2	7.2	6.4
11	5.8	5.0	4.9	4.0	6.9	4.0
12	6.2	4.4	4.6	3.2	7.0	3.0
13	5.4	8.0	5.1	7.3	6.7	6.0
$LSD_{(0.05)}$	NS	1.4	NS	1.5	NS	1.1

[z]For detailed information on substrate components see Table 1.
[y]Root numbers determined 14 d after sticking.
[x]Root lengths determined 21 d after sticking.
[w]Mean separation in column by Fisher's protected least significant differences at $P \leq 0.05$; [NS]Nonsignificant.

ing, root lengths per cutting by species were affected by substrates (Table 4). Total root lengths of pothos comparable to or longer than those of the control were produced in substrates 1, 2, 4, 5, 7, 8, and 10, while root lengths of maranta and schefflera that were comparable to or longer than the control were generated in substrates 1, 4, 5, 7, and 10. Root ball coverage 45 d after sticking also was significantly affected by substrates, but the effects were less pronounced than those on root lengths. More substrates exhibited root ball coverage ratings equal or superior to the control (Table 5).

Root initiation and growth in relation to substrate initial EC and pH levels. Results from this study suggest that root initiation was independent of substrate physical and chemical properties, whereas root lengths and root ball coverage ratings were affected by substrate properties. Root length measurements and root ball coverage ratings revealed that substrates with at least 10% air space, low concentrations of mineral elements, low initial EC readings (3.0 $dS \cdot m^{-1}$ or less based on the pour through method), and low pH (3.8 to 5.0 initially) had better root growth.

Judd and Cox (1992) investigated the relationship between EC levels and initial root growth of new guinea impatiens and reported that an EC of 1.5 $dS \cdot m^{-1}$ or higher (based on the 1:2 extraction method) was associated with suppressed root growth during an initial 42-d growth cycle. Other studies using nutrient mist or controlled-release fertilizers showed that nutrient supplements did not promote root initiation but did improve root development after root primordia initiation had occurred (Johnson, 1977; Wott and Tukey, 1967). Our results show that root initiation was not affected by substrate nutrient level.

It is interesting to note that significantly longer total root lengths were produced in substrates with pH lower than the recommended (5.5 to 6.5) for foliage plant production. Low pH has also been shown to enhance rooting of woody plant cuttings. Holt et al. (1998) found that stem cuttings of azalea (*Rhododendron* spp.) had higher rooting percentages and produced larger root balls at pH 4.5 than at pH 7.5. Williams et al. (1985) reported that several Australian woody species rooted in vitro in a medium with a pH of 4.0, but not when the medium pH was 5.5. Harbage and Stimart (1996) demonstrated that as pH decreased

Table 5. Root-ball coverage ratings[z] of pothos 'Golden Pothos', maranta 'Kerchoveana', and schefflera 'Goldenfinger' 45 d after sticking in control and compost-formulated substrates.

Substrate[y]	Pothos	Maranta	Schefflera
1	3.9[x]	3.5	3.9
2	3.2	2.6	2.5
3	1.9	1.5	1.4
4	4.0	3.7	4.2
5	3.7	3.5	4.0
6	3.0	2.8	2.9
7	4.1	4.1	3.8
8	3.0	2.0	2.2
9	2.3	2.4	1.5
10	4.4	3.8	4.1
11	3.0	2.4	3.0
12	2.0	1.8	1.0
13	3.6	3.4	3.5
$LSD_{(0.05)}$	1.1	0.8	1.7

[z]Root-ball coverage ratings: 1 = 0% to 20%, 2 = 21% to 40%, 3 = 41% to 60%, 4 = 61% to 80%, and 5 = 81% to 100% root ball coverage with white, healthy roots (Poole and Conover, 1984).
[y]See Table 1 for substrate components.
[x]Mean separation in column by Fisher's protected least significant differences at $P \leq 0.05$; [NS]Nonsignificant.

from 7 to 5.5, lower concentrations of auxin [1 H-indole-3-butyric acid (IBA)] were required to increase root count of apple (*Malus domestica*) microcuttings.

Conclusions

Root initiation was not significantly influenced by physical and chemical properties of compost-formulated substrates, but root elongation and subsequent growth (root ball coverage) were affected. Substrates with a minimum air space of 10%, EC reading ≤3.0 $dS \cdot m^{-1}$ (based on the pour through extraction method), and pH between 3.8 to 5.0 supported root growth comparable or superior to the control substrate. Five of twelve compost-formulated substrates (1, 4, 5, 7, and 10) possessed these characteristics. This study showed that composts, after being appropriately mixed with sphagnum peat and pine bark, could be used as container substrates for rooting foliage plant cuttings. The development of compost-formulated rooting substrates would further expand compost use in the foliage plant industry.

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