Shoot and Root Responses of Eight Subtropical Species Grown in Cupric Hydroxide-treated Containers

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Abstract. The effect of $\text{Cu}(\text{OH})_2$ applied to interior container surfaces on shoot and root responses was evaluated on eight species cultivated in subtropical regions. Species studied were *Cedrela odorata* L.; *Eriobotrya japonica* (Thunb.) Lindl.; *Leea coccinea* Planch.; *Peperomia serpens* (Swartz.) Loud.; *Peperomia obtusifolia* (L.) A. Dietr.; *Radermachera sinica* (Hance) Hensl.; *Schefflera actinophylla* (Endl.) Harms; and *Swietenia mahagoni* (L.) Jacq. No foliar Cu toxicity symptoms developed on any species during the study. *Swietenia mahagoni* seedlings grew faster in height and had larger shoot : root ratios when grown in $\text{Cu}(\text{OH})_2$ -treated containers than in nontreated containers. *Leea coccinea* seedlings were taller and produced more shoot dry weight when grown in $\text{Cu}(\text{OH})_2$ -treated than in control containers. Applying $\text{Cu}(\text{OH})_2$ did not influence shoot growth of the other six species studied. Root coverage reduction on the exterior of the rootball in $\text{Cu}(\text{OH})_2$ -treated containers was excellent for all species studied, and coverage was completely eliminated in three species. Shoot and root responses to $\text{Cu}(\text{OH})_2$ -treated containers varied among subtropical species, which is consistent with shoot and root responses among temperate species.

Plants with vigorous root growth produce circling, malformed root systems when grown in containers. To correct root malformation of container-grown plants, root pruning often is required at transplanting (Harris, 1992). Copper-treated containers reduced or eliminated root malformation (Arnold, 1992; Arnold and Struve, 1993; Beeson and Newton, 1992; Ruter, 1994) and increased transplant survival and regrowth in various temperate species (Struve, 1993). The influence of Cu-treated pots on the growth of species cultivated in subtropical regions has received less study (Beeson and Newton, 1992; Svenson and Broschat, 1995; Svenson and Johnston, 1992). Our objective was to evaluate the effects of $\text{Cu}(\text{OH})_2$ -treated containers on shoot and root responses of eight species commonly cultivated in subtropical regions.

Materials and Methods

On 5 July 1991, *Swietenia mahagoni* (West Indian mahogany) seeds were sown two per pot, in 50 round pots (top = 90 mm in diameter)

filled with 0.4 liters of ProMix BX medium (Premier Brands, Stamford, Conn.). Seedlings were thinned to one per pot at emergence. On 9 Aug. 1992, 40 seedlings of similar height and stem diameter were selected. Ten seedlings were separated into shoots and roots and dried (3 days at 70°C), and 30 were potted into round containers (top = 150 mm in diameter) filled with 2.3 liters of a 5 pine bark : 4 peat-moss : 1 sand (by volume) medium. Before being filled with medium, interior surfaces of 15 containers were painted with a liquid latex- $\text{Cu}(\text{OH})_2$ compound [100 g $\text{Cu}(\text{OH})_2$ /liter; $\approx 4.6\%$ metallic Cu equivalent], formulated as Spin Out (Griffin Corp., Valdosta, Ga.), or were left nontreated. Seedlings received a dibble application of 24 g Osmocote 18N-3.1P-10K, (Grace-Sierra, Milpitas, Cal.; 8- to 9-month formula) at potting. Seedlings were grown under full sun [1950 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ maximum photosynthetic photon flux (PPF) as measured with a line quantum sensor (model LI-191SA; LI-COR, Lincoln, Neb.), with natural photoperiods (lat. 26.1N, long. 80.2W; Fort Lauderdale, Fla.), 65% to 85% average relative humidity, and an average 33°C maximum/25°C minimum. Seedlings received daily irrigation supplemented with natural rainfall. A completely randomized design was used ($n = 15$).

Shoot heights were measured 9 and 15 weeks after potting. Fifteen weeks after potting, shoots from treated and nontreated containers were removed from root systems and dried (3 days at 70°C). Root coverage on the exterior of the rootball was rated using the following scale: 1, <20% of the rootball cov-

ered with white root tips, no root circling; 3, $\approx 50\%$ of the rootball covered with white root tips, moderate root circling; and 5, > 80% of the rootball covered with white root tips, extensive root circling (Ruter, 1994). After rating the root system, roots were washed free of medium and dried. Using height measurements and dry weights, height growth rate (millimeters per day), plant growth rate (grams per day), and shoot : root ratios (grams per grams) were calculated. Data were analyzed using analysis of variance with mean separations by least squares means (SAS Institute, 1989).

On 20 Nov. 1991, seeds of *Cedrela odorata* (West Indian cedar) were sown as described for *S. mahagoni*. On 20 Feb. 1992, twenty-eight seedlings of similar height and stem diameter were potted into round containers (top = 220 mm in diameter) filled with 5.5 liters of medium as previously described. Before being filled with medium, interior surfaces of 14 containers were treated with $\text{Cu}(\text{OH})_2$, and 14 were left nontreated. After potting, containers were topdressed with 48 g of Osmocote 18N-3.1P-10K. Throughout the experiment, seedlings were grown in a single-layer polycarbonate greenhouse that was shaded (Kool Ray Liquid Shade; Continental Products, Euclid, Ohio) to provide 750 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ maximum PPF with natural photoperiods, 60% to 85% relative humidity, and an average 31°C maximum/22°C minimum. Seedlings were irrigated as needed. A completely randomized design was used ($n = 14$). Shoot heights were measured 8, 12, and 16 weeks after potting. Sixteen weeks after potting, shoots from treated and nontreated containers were removed from the root system and dried (3 days at 70°C). Root coverage at the container-medium interface was rated, and data were analyzed as previously described.

Rooted cuttings of *Schefflera actinophylla* 'Amate' (Amate umbrella tree) were potted on 10 Dec. 1991. Experimental procedures were the same as described for *C. odorata* with the following differences: plants were potted three per container, topdressed with 70 g of Osmocote 18N-3.1P-10K every 5 months, grown in a screenhouse covered with black shade cloth providing 780 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ maximum PPF with natural photoperiods, averaged 32°C maximum/23°C minimum, and were irrigated daily for 1 h using drip emitters (3.8 liters·h⁻¹) following days when natural rainfall was <25 mm. Shoot heights were measured 12, 16, and 22 weeks after potting. Twenty-two weeks after potting, shoots and root systems were evaluated as described for *C. odorata* ($n = 10$).

Uniformly graded seedling liners (20 seedlings per cell) of *Radermachera sinica* (China doll) were potted on 4 Feb. 1992. Experimental procedures were the same as described for *S. actinophylla* with the following differences: liners were potted in round pots (pots = 150 mm in diameter) filled with 1.2 liters of medium, pots were topdressed with 18 g Osmocote 18N-3.1P-10K, and plants were irrigated by rainfall supplemented with overhead irriga-

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tion (as needed). Shoot heights were measured 8 and 12 weeks after potting. Twelve weeks after potting, shoots and root systems were evaluated as described for *C. odorata* (n = 10).

Seeds of *Eriobotrya japonica* (loquat) were sown on 4 Feb. 1992 as described for mahogany. Experimental procedures were the same as described for *C. odorata* with the following differences: uniform seedlings were potted in round containers (top = 150 mm in diameter) filled with 2.25 liters of medium, as previously described, on 19 Apr. 1992 with 33C maximum/26C minimum, and shoots and root systems were evaluated 26 weeks after potting (n = 14).

Twenty-eight uniformly graded (300 mm stem length), bareroot *Leea coccinea* (West Indian holly) seedlings were potted on 5 Nov. 1993. Experimental procedures were the same as described for *C. odorata* with the following differences: containers were topdressed with 48 g SierraBlen 18N–3.1P–8.3K–1Fe (8- to 9-month formula; Grace-Sierra), and shoot heights were recorded 14 and 18 weeks after potting. Eighteen weeks after potting, shoots and root systems were evaluated as previously described (n = 14).

Rooted cuttings of *Peperomia serpens* (trailing peperomia), *P. serpens* 'Variegata' (variegated trailing peperomia), and *P. obtusifolia* (Baby rubber plant) were potted on 29 Dec. 1993. Experimental procedures were the same as described for *C. odorata* with the following differences: plants were potted in round pots (top = 11 cm in diameter) filled with 0.5 liters of medium as previously described, fertilized with 12 g of Osmocote 18N–3.1P–10K, grown with an average 29C maximum/21C minimum, and pinched on 21 Mar. 1994. Leaf and stem dry weights were determined 15 and 19 weeks after potting for *P. serpens* and *P. obtusifolia*, respectively. Root coverage on the exterior of the rootball was rated, and data were analyzed as previously described (n = 15).

Results and Discussion

Foliar Cu toxicity symptoms were absent on all species during the study. Root elongation on the exterior of the rootball ceased as root tips contacted the bottom or sidewall of Cu-treated containers. Growth-inhibited tips were swollen and appeared necrotic. These symptoms are consistent with the responses of temperate species (Arnold, 1992; Arnold and Struve, 1993; Beeson and Newton, 1992; Ruter, 1994).

Swietenia mahagoni had higher height growth rate, slower plant growth rate, less root dry weight, and higher shoot : root ratio when grown in Cu(OH)₂-treated containers rather than nontreated containers (Table 1). Seedlings grown in Cu(OH)₂-treated containers also had taller shoots 9 and 15 weeks after potting ($P \leq 0.05$; data not shown). Seedlings grown in Cu(OH)₂-treated containers had more total plant dry weight compared to nontreated containers ($P \leq 0.05$; data not shown). Tap roots account for most root system dry weight of mahoganies (Svenson and Broschat, 1995). Inhibiting tap root elongation in Cu(OH)₂-treated containers reduces total root system dry weight without reducing shoot dry weight, thereby increasing the shoot : root ratio. Beeson and Newton (1992) also reported faster height growth rates for *S. mahagoni* grown in Cu(OH)₂-treated containers. As indicated by the root coverage, control of root malformation and root circling on the exterior of the rootball was excellent in Cu(OH)₂-treated containers, a result consistent with an earlier study (Beeson and Newton, 1992).

Leea coccinea seedlings were taller and had more shoot dry weight and less root coverage on the exterior of the rootball when grown in Cu(OH)₂-treated rather than nontreated containers (Table 2). Arnold and Struve (1993) and Beeson and Newton (1992) reported increased shoot growth of temperate species grown in Cu-treated containers.

Table 3. Root coverage of seven subtropical plants as influenced by Cu(OH)₂ treatment of interior container surfaces.

Species	n	Root coverage ^a	
		Cu(OH) ₂	
		+	–
<i>Cedrela odorata</i>	14	1.2***	3.2
<i>Eriobotrya japonica</i>	14	1.1***	3.0
<i>Peperomia serpens</i>	15	1.0***	3.9
<i>P. serpens</i> 'Variegata'	15	1.0***	3.8
<i>P. obtusifolia</i>	15	1.0***	2.4
<i>Radermachera sinica</i>	10	1.0***	4.3
<i>Schefflera actinophylla</i>	10	1.1***	3.8

^aRoot coverage as described in Table 1.

***Significant at $P \leq 0.001$.

Applying Cu(OH)₂ had no influence on shoot heights or weights but did reduce root coverage on the exterior of the rootball for *C. odorata*, *E. japonica*, *P. serpens*, *P. serpens* 'Variegata', *P. obtusifolia*, *R. sinica*, and *S. actinophylla* (Table 3). Shoot heights averaged 469, 368, 455, and 592 mm for *C. odorata*, *E. japonica*, *R. sinica*, and *S. actinophylla*, respectively. Shoot dry weights averaged 7.6, 6.9, 7.7, 4.6, 8.1, 3.2, and 90.1 g for *C. odorata*, *E. japonica*, *P. serpens*, *P. serpens* 'Variegata', *P. obtusifolia*, *R. sinica*, and *S. actinophylla*, respectively. Our data for *S. actinophylla* are consistent with those of Case and Arnold (1992), who reported no influence of Cu(OH)₂-treated containers on shoot growth of *Schefflera arboricola* (Hayata) Hayata. In Svenson and Johnston's (1992) study, *R. sinica* was grown in Cu(OH)₂-treated square pots (top = 56 mm in diameter; 150 ml of medium) for 3 weeks, and shoots were shorter and had less dry weight than plants grown in nontreated pots. Shoot growth responses of *R. sinica* to Cu(OH)₂ treatment may vary according to container size.

The lack of shoot growth response to Cu(OH)₂ treatment for six of eight species in this study contrasts with reports of increased or decreased shoot growth for some temperate species (Arnold, 1992; Arnold and Struve, 1993; Beeson and Newton, 1992; Ruter, 1994). Root growth on the surface of the rootball was eliminated completely for *P. serpens*, *P. obtusifolia*, and *R. sinica* (Table 3), consistent with an earlier study on *R. sinica* (Svenson and Johnston, 1992) and with various temperate species (Beeson and Newton, 1992; Case and Arnold, 1992; Ruter, 1994). Shoot height growth rate of *S. mahagoni* and shoot height and weight of *L. coccinea* increased when grown in Cu(OH)₂-treated pots. Generally, shoot and root growth responses to Cu(OH)₂-treated containers varied among eight subtropical species. This result is consistent with the variable responses reported for temperate species.

Table 1. Height growth rate, plant growth rate, root dry weight, shoot : root ratio, and root coverage of *Swietenia mahagoni* as influenced by Cu(OH)₂ treatment of interior container surfaces.

Cu(OH) ₂	Ht growth rate (mm·day ⁻¹)	Plant growth rate (g·day ⁻¹)	Root dry wt (g)	Shoot : root ratio (g·g ⁻¹)	Root coverage ^a
+	4.5	0.21	0.71	2.7	1.1
–	3.5	0.26	0.92	2.0	3.8
	**	*	*	*	***

^aRoot coverage: 1, <20% of rootball covered with white root tips, no root circling; 2, ≈50% of rootball covered with white root tips, moderate root circling; 3, >80% of rootball covered with white root tips, extensive root circling.

*, **, ***Significant at $P \leq 0.05$, 0.01, or 0.001, respectively (n = 15).

Table 2. Shoot height, shoot dry weight, and root coverage of *Leea coccinea* as influenced by Cu(OH)₂ treatment of interior container surfaces.

Cu(OH) ₂	Shoot ht after 14 wks (m)	Shoot ht after 18 wks (m)	Shoot dry wt (g)	Root coverage ^a
+	1.2	1.4	134	1.2
–	1.1	1.2	108	3.1
	*	***	*	***

^aRoot coverage as described in Table 1.

*, ***Significant at $P \leq 0.05$ or 0.001, respectively (n = 14).

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