Comparing Effects of Container Treatments on Nursery Production and Field Establishment of Trees with Different Root Systems[1]

Ursula K. Schuch[2], Dennis R. Pittenger and Philip A. Barker[3,4]
Botany and Plant Sciences Department and Cooperative Extension
Southern Region, University of California, Riverside, CA 92521

Abstract

The objectives of this study were to determine the effects of container volume, container shape, and copper-coating containers on root and shoot growth during nursery production and after establishment in the field. Liners of ficus (*Ficus retusa* L. 'Nitida'), a fibrous-rooted species, and Brazilian pepper (*Schinus terebinthifolius* Raddi.), a coarse-rooted species, were grown in regular or tall #1 containers in a glasshouse and were subsequently transplanted to the field or into #3 or #5 regular or tall containers. During the nursery phase, copper-coated containers improved rootball quality of ficus and pepper, but biomass production was not affected consistenly by copper coating. Tall, narrow versus regular containers restricted pepper growth throughout the nursery phase and field establishment, but had little effect on ficus. Biomass production of pepper trees was greatest in regular-shaped containers, and tall containers reduced growth consistently. Container shape did not affect shoot growth of ficus. The larger container volume of the #5 yielded greater total biomass of pepper and root dry weight of ficus during nursery production than did #3 pots. In the field, shoot dry weight of ficus was greatest when previously grown in #5 containers, and total biomass of pepper was greatest in both regular #3 or #5 containers.

Index words: container shape, container volume, cupric hydroxide, root quality, root circling, root matting.

Species used in this study: Ficus (*Ficus retusa* L. 'Nitida'); Brazilian pepper (*Schinus terebinthifolius* Raddi.).

Chemicals used in this study: Cupric hydroxide (SpinOut™, Griffin Corp., Valdosta, GA).

Significance to the Nursery Industry

Root systems of woody plants developed during nursery production affect future plant performance in the landscape. Factors such as container configuration, container volume, and copper-coating on the inside of containers are reported to influence plant growth during production and after transplanting. The coarse, laterally spreading root system of pepper trees did not adapt well to tall, narrow containers, and biomass production during the nursery phase and during field establishment was reduced in tall containers. The more fibrous root system of ficus trees was not affected consistently by container shape during production or field establishment. The benefits of copper-coated containers to rootball quality or plant growth were not ubiquitous during container production or field establishment of either species. None of the container treatments reduced surface root development of either species approximately one year after transplanting to

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[2]Current address: Department of Plant Sciences, University of Arizona, Tucson, AZ 85721.

[3]Western Center for Urban Forest Research and Education, Pacific Southwest Forest and Range Experiment Station, U.S. Department of Agriculture Forest Service, Davis, CA 95616.

[4]Associate Specialist, Area Environmental Horticulturist, Research Horticulturist Emeritus, respectively.

the field. In terms of establishment in the landscape, the benefits of tall, larger volume, or copper-coated containers did not consistenly result in larger plants approximately one year following transplanting for either coarse-rooted or fibrous-rooted species.

Introduction

Poor tree establishment and performance in the landscape along with shallow root growth after transplanting frequently can be attributed to poor-quality root systems in the original container-grown nursery stock (14, 25). Shallow growth of large roots after transplanting often brings about major, long-term costs from the damage they inflict upon sidewalks and other paved areas (19, 23). Trees that grow in conventional nursery containers often develop root system defects such as kinked or circling roots and extensive matting of fine roots at the rootball:container wall interface (14).

Typical nursery containers are constructed with a straight wall, and diameter about equal to the height. Containers of alternative dimensions have been developed to prevent root deformations such as matting, circling, kinking, and to improve root and shoot growth of container-grown trees (2, 24). Modification of the container side wall in square, stepped-pyramid, and polybag containers reduced root circling of four woody ornamentals compared with conventional straight-walled, round containers; however, the efficacy of alternative designs in enhancing new root generation and increased shoot and root dry weights in the landscape was species dependent (24). Stepped-pyramid containers reduced root circling but could not prevent kinking and matting of *Quercus rubra* L. roots at the container surface (2). Low-profile containers of 20 (7.9 in) to 30 (11.8 in) cm height and 84 cm (33.1 in) diameter led to successful production of trees that were able to withstand transplanting to difficult landscape sites (20). When diameter and height of containers were altered, species with fibrous and shallow roots benefited most from a shallow, broad container, whereas deep-rooted species had increased growth in deeper, narrower pots (11, 16). Similarly, northern red oak seedlings with strong taproots produced the greatest biomass in a narrow container with the height twice the diameter (13). Container configurations different from the standard straight-walled container with equal height and diameter did not affect plant growth, although they altered root morphology during production (18).

Container volume also affects plant growth. Increasing container volume generally results in greater plant growth (12, 15, 20). Eight species of tree seedlings growing in containers with a volume from 147 cm^3 to 683 cm^3 attained greatest height and caliper for two growing seasons when planted in the largest container size (1). However, greater container volume does not always result in greater seedling growth, but also depends on container depth and diameter and root morphology of individual plant species (13, 16, 22). Furthermore, species differences, fertilizer treatments, and timing of transplanting into larger containers differentially affect growth rates and final growth (9).

Application of Cu-based compounds to the interior surface of containers chemically prunes root tips when they contact the container wall. Roots pruned in this manner develop less circling, kinking and matting, and that improves root-system quality (6, 10, 17, 18, 21, 25). Cu-treated containers also increased root branching frequency in some species (3, 4, 7), which created a more fibrous root system and rapid root establishment upon transplanting into the landscape (3, 5).

Ficus (*Ficus retusa* L. 'Nitida') and Brazilian pepper (*Schinus terebinthifolius* Raddi.) were chosen for this study because they are planted widely in the Southwestern United States and their roots are notoriously vigorous and invasive to surrounding landscapes (23). Arborists and landscape professionals have observed differences in the morphology of ficus and pepper root systems; however, none of these characteristics have been documented from the nursery production phase throughout establishment in the landscape. The objectives of this study were to determine the effects of container volume, container shape (diam × ht), and coating containers with cupric hydroxide on root growth, shoot growth, and root morphology of two tree species with different root structure. We determined the effects of these treatments during container production and one year after transplanting trees to the field.

Materials and Methods

Nursery phase. Liners of ficus (*Ficus retusa* L. 'Nitida') and pepper (*Schinus terebinthifolius* Raddi.) were transplanted into #1 containers in January 1993 and were grown until July in a glasshouse at the University of California in Riverside. Plants were grown in UC #2 mix (8) and irrigated two or three times per week to maintain well-watered conditions. Fertilizer was provided in each irrigation with Foliage-Pro 3.1 N–1.3 P–5.0 K formulation at a rate of 100 mg L^{-1} (ppm) N (Dyna Gro Corp., San Pablo, CA). Temperature setpoints in the glasshouse were 28/18C (82/64F) day/night.

Two shapes of #1 container, each with a volume of 2.5 liter (2.6 qt) were used; the regular containers (injection molded poly) were 16.0 cm (6.3 in) tall with a top and bottom diameter of 15.0 cm (5.0 in), tall containers were 31.0 cm (12.2 in) tall with a top and bottom diameter of 10.5 cm (4.1 in). Tall containers were constructed from black PVC pipe with a bottom cap attached to one end. Four holes with a diameter of 2.3 cm (0.9 in) were drilled at the bottom of the vertical pipe to simulate drainage holes in the regular container. Cupric hydroxide ($Cu(OH)_2$) formulated at 100 g liter^{-1} in latex paint (Spinout™, Griffin Corp., Valdosta, GA) was applied to the inner surface of half of the containers of each shape before liners were transplanted.

In July 1993, trees were transplanted from #1 containers to #3 or #5 containers (blow molded poly). The growing substrate consisted of wood shavings:coarse bark:sand (9:8:3 by vol). Regular #3 containers had a top and bottom diameter of 25.5 cm (10.0 in) and 22.5 cm (8.8 in), respectively and a height of 24.0 cm (9.4 in). Tall #3 containers, also known as citrus pots in the nursery trade, had a top and bottom diameter of 21.0 cm (8.3 in) and 16.0 cm (6.3 in), respectively, and were 40 cm (15.7 in) tall. Regular #5 containers had a top and bottom diameter of 26.0 cm (10.2 in) and 22.0 cm (8.7 in), respectively, and a height of 30.5 cm (12.0 in). Tall #5 containers were manufactured by adding an extension of the same material to the tall #3 pots, resulting in 22.0 cm (8.7 in) top, 16.0 cm (6.3 in) bottom diameter and 50.0 cm (19.7 in) height. Regular and tall #3 and #5 containers were filled with 10.0 liter (10.6 qt) and 13.0 liter (13.7 qt) substrate, respectively. Trees from regular #1 containers with cupric hydroxide treatment were transplanted into either #3 or #5 regular containers treated with cupric hydroxide. Trees from all other treatments were also transplanted to containers, such that container shape (tall or regular) and copper treatment remained the same throughout the experiment.

At transplanting, trees were transported to a commercial nursery in Irvine, CA, where they were grown outdoors until they reached marketable size. Plants were watered with individual emitters in each pot and were continuously fertilized at each irrigation with 135 mg $liter^{-1}$ (ppm) N, 0 mg $liter^{-1}$ (ppm) P, 21 mg $liter^{-1}$ (ppm) K, and 0.03 mg $liter^{-1}$ (ppm) Mo.

Plant growth was monitored starting from the liner stage by measuring height and caliper 5 cm (2.0 in) above the medium surface. Ten trees of each species and treatment combination were randomly selected and harvested at the end of the #1 growing phase and the effects of container shape and cupric hydroxide were evaluated by determining root and shoot dry weight. Also, the surface area of the side and bottom of the rootball covered by circling and matted roots were rated visually according to the following criteria: 1 = none; 2 = slight, up to 25% of the surface covered; 3 = moderate, 25 to 50% of the surface covered; 4 = heavy, 50 to 75% of the surface area covered; and 5 = severe, > 75% of the surface covered.

Overall quality of the rootball was rated visually as follows: 1 = perfect, rootball stays intact, enough fibrous roots, no root circling at bottom or side; 2 = slight circling at bottom or side, or rootball not completely filled with roots and media crumbles, roots fill 75 to 90% of the container; 3 = moderate circling at bottom or side, rootball needs to be loosened before transplanting or rootball crumbles and roots fill 50 to 75% of the container; 4 = heavy circling or matting, rootball needs mechanical pruning before shifting or roots fill 25 to 50% of the container; 5 = unacceptable, severe circling or heavy matting, or roots fill < 25% of the container.

When plants reached marketable size in the outdoor nursery (November 1993 for pepper and April 1994 for ficus), ten trees per species and treatment combination were randomly selected and harvested. Pepper trees had reached this stage after four months and ficus after nine months. Data for all variables were collected and in addition, roots were separated based on diameter. Three diameter size classes were distinguished: < 2.0 mm (0.08 in), 2.0 to 5.0 mm (0.08 to 0.2 in), and > 5.0 mm (0.2 in), and dry weight of each size class was determined.

Trees were arranged in a completely randomized design and separated by species in the greenhouse and in the nursery. Analysis of variance was calculated for each variable, and mean comparisons were calculated with Tukey's Studentized Test (SAS Institute Inc., Cary, NC).

Field establishment. In July 1993, ten replicate plants of each species and treatment combination in #1 containers were planted in the field at the Experiment Station of the University of California in Riverside. The field soil is classified as a coarse-loamy, mixed, thermic Haplic Durixeralf (Hanford fine sandy loam with pH between 6.1 and 7.0). Trees were planted at a spacing of 3.0 m (118 in) within the row and 3.7 m (146 in) between rows. Treatments in this 2 × 2 factorial experiment were arranged in a randomized complete block design (+/– cupric hydroxide, tall or regular container shape).

In November 1993, ten replicate plants of marketable size from each treatment combination of the pepper trees grown in #3 or #5 containers were transplanted to the same field at a spacing of 3.7 m (146 in) within the row and 4.6 m (181 in) between rows. Marketable-sized ficus were transplanted to the field in April 1994. Data collected from ficus and pepper trees in the field, and previously grown in #3 and #5 containers, were analyzed as a split plot in a completely randomized design, with container volume as the main plot.

Trees were irrigated with minisprinklers that wetted an area 3.0 m (118 in) to 3.5 m (138 in) in diameter near the base of each tree. Weekly irrigations maintained adequate soil moisture in the top 75 cm (29.5 in) of soil. Urea at a rate of 200 g (7.06 oz) per tree [90 g (3.17 oz) N] was applied 60 days after transplanting within a 2.0 m (79 in) radius of the base of each tree.

Trees were harvested on the following dates: ficus and pepper previously grown in #1 containers in September and October 1994, pepper previously grown in #3 or #5 containers in November and December 1994, and ficus previously grown in #3 or #5 containers in May 1995. At harvest, tree height and caliper 5 cm (1.9 in) above the soil surface were measured. Shoot dry weight was determined after trees were cut, chipped, and dried in a forced air oven at 65C (149F) for one month. Root systems were excavated and roots were harvested (to a depth of 30 cm (11.8 in)) in three zones based on distance from the trunk: 0 to 33 cm (0 to 13 in), 33 to 66 cm (13 to 26 in), and 66 to 100 cm (26 to 39 in). Within each zone, roots were classified according to their diameter: < 2.0 mm (0.08 in), 2.0 to 5.0 mm (0.08 to 0.2 in), 5.0 to 10.0 mm (0.2 to 0.4 in), and > 10 mm (0.4 in). Dry weight was determined after roots were dried in an air-forced oven at 65C (149F).

Data collected from the #1 trees in the field were analyzed separately from the #3 and #5 trees, and each species was analyzed separately, both for nursery and field growth. Analysis of variance was calculated for each variable and mean comparisons were made using Tukey's Studentized Test.

Results and Discussion

Container shape did not affect ficus root or shoot development in the #1 containers. Pepper plants in regular-shaped #1 containers were taller, had greater caliper, and had greater above and below-ground biomass than plants produced in tall containers (Table 1).

Copper coating reduced matting and circling of roots on the side and bottom of rootballs or improved rootball quality by one rating unit during at least one stage of container production for both species (data not shown). However, in terms of plant growth, only pepper total dry weight was consistently affected throughout container production by an interaction ($P < 0.01$) between container shape and copper treatment (Table 2). Regular container shape without copper fa-

Table 1. Growth of pepper growing for 6 months in a greenhouse in #1 tall or regular containers. Means are averaged over cupric hydroxide treatments (n = 20).

Container shape	Height (cm)	Caliper (mm)	Dry wt (g) Shoot	Dry wt (g) Root	Dry wt (g) Total
Regular	166a[z]	91a	70.5a	15.8a	86.3a
Tall	149b	75b	41.7b	13.7b	55.4b

[z]Means within a column followed by different letters are significantly different at $P \leq 0.05$.

Table 2. **Dry weight of pepper after growing for six months in #1 containers in the greenhouse (n = 10) and four months in #3 or #5 containers of different shape and with or without cupric hydroxide coating (n = 20). Means are averaged over #3 and #5 container size treatments.**

Container shape	$Cu(OH)_2$	Dry wt (g) Total (#1)	Shoot (——— #3 or #5 ———)	Total (——— #3 or #5 ———)
Regular	+	70b[z]	210ab	251ab
	–	102a	249a	301a
Tall	+	52c	183b	226b
	–	59c	132c	168c

[z]Means within a column followed by different letters are significantly different at P ≤ 0.05.

vored the greatest total dry weight in #1 containers. After transplanting peppers to #3 or #5 containers, total dry weight continued to be greater in the regular non-treated containers, while the tall container shape without copper coating resulted in the lowest shoot and total dry weight production. (Table 2). The benefits of copper coating containers to rootball quality or plant growth were not ubiquitous during container production; however, copper coating had no detrimental effect on either variable in this study.

Size and biomass reduction of pepper trees grown in tall containers indicates that pepper root systems are not adapted to tall containers, and they prevent them from reaching their optimum growth potential. This may be because pepper trees have a coarse, lateral spreading root system that is inhibited by tall containers. Visual observations of a coarse lateral root system in pepper are corroborated by the fact that pepper plants grown in #3 or #5 containers had roots in the diameter classes < 2.0 mm, 2.0 to 5.0 mm, and > 5.0 mm accounting for 27%, 28%, and 45% of the total root dry weight, respectively. In contrast, ficus root or shoot growth in #1 containers was not affected by either container shape or copper treatment, suggesting that the root system of this species is adapted to different container shapes. This is probably because ficus root systems were found to be more densely branched and fibrous with almost equal distriubtion of root dry weights: 33%, 35%, and 32% were found for root diameter classes < 2.0, 2.0 to 5.0, and > 5.0 mm, respectively.

Greater container volume resulted in greater shoot dry weight of pepper and root dry weight of ficus. Pepper in #5 containers had 16% greater shoot dry weight and 19% greater total dry weight than plants grown in #3 containers. A significant interaction between container size and shape influenced root dry weight of ficus during the 9-month container production phase and 13 months after transplanting into the field. Ficus grown in regular #5 containers had the greatest total root dry weight, while by plants grown in regular #3 containers had the lowest root dry weight (Table 3). However, 13 months after they were transplanted to the field, root dry weight was less in ficus produced in tall #3 containers and equal among those produced in the other container sizes and shapes. Ficus shoot dry mass, total dry mass, and caliper were not influenced by any of the treatments after the 9-month nursery production phase. None of the treatments affected height, caliper or root dry mass of pepper, however.

Table 3. **Interaction means (P < 0.05) for root dry weight of ficus grown for 9 months outdoors in #3 or #5 containers and subsequently for 13 months in the field. Means are averaged over cupric hydroxide treatments (n = 20).**

Container (#)	Container shape	Root dry weight (g) Container	Field
3	Regular	31.8c	329a
3	Tall	34.9b	243b
5	Regular	45.3a	325a
5	Tall	35.2b	351a

[z]Means within a column followed by different letters are significantly different at P ≤ 0.05, Tukey's Studentized Test.

Increased plant growth in response to increasing container volume has been reported for a variety of woody species (9, 20, 22, 25). Generally, given enough time, plants in larger containers outperform their counterparts growing in smaller rooting volumes. Previous research reported that increased pot diameter was beneficial for shoot biomass of species with coarse lateral and deep as well as for species with medium fine roots (16). It is likely that greater diameter containers than used in this study may have increased both ficus and pepper growth (11, 16, 20), but were not tested. It is unclear why tall #3 containers resulted in lower root dry weight in ficus during field establishment. Possibly, these results reflect a transitory lag in growth.

Ficus transplanted from #1 containers and grown for 14 months in the field were not affected by container shape or copper coating. These trees had an average shoot dry weight of 3,522 g (124.2 oz), root dry weight of 221 g (7.8 oz), caliper of 35 mm (1.4 in), and height of 1.8 m (70.9 in). Dry weight of individual root classes of ficus was not affected by container shape or copper.

After growing 13 months in the field, ficus produced in #5 versus #3 containers had more above-ground biomass [3,150 g (111.1 oz) versus 2,485 g (87.6 oz), P < 0.05], but there were no effects on above-ground biomass from container shape or copper coating. In contrast, Biran and Eliassaf (1980) reported 35% less shoot dry weight of ficus that grew in 21 liter (22.2 qt) narrow and deep versus regular containers and were harvested after growing subsequently for 4 months in the field. Average caliper of trees was 37.3 mm (1.5 in) and average height was 2.0 m (78.7 in). It is interesting that biomass, height, and caliper of ficus from #1 and #5 containers were nearly the same 14 and 13 months, respectively, after transplanting.

Container shape and copper coating persisted to affect shoot and root dry mass of pepper trees transplanted from #1 containers into the field (Table 4). Trees grown in regular or copper-treated containers produced greater shoot biomass and developed more small-diameter roots, although root dry weight itself was not affected by container shape. Trees grown in regular #1 containers had larger caliper [66.7 mm (2.6 in) versus 61.6 mm (2.4 in)] than those grown in tall containers (P < 0.05), while copper coating had no effect on caliper. Height of pepper trees was 2.7 m (106.2 in) for all treatments.

Thirteen months after transplanting in the field, pepper trees grown in regular-shaped #3 or #5 containers produced 10,415 g (367.3 oz) above-ground biomass, whereas those in tall containers produced 9,067 g (319.8 oz) (P < 0.05). Pepper caliper and height, however, were not influenced by container volume, shape, or copper coating and measured

Table 4. Root and shoot dry mass of pepper growing for 14 months in the field after being grown for 6 months in the greenhouse in #1 tall or regular containers coated either with or without cupric hydroxide (n = 10).

	Dry wt (g)					
	Root class (diameter in mm)					
Container shape	< 2	2–5	5–10	> 10	Total root	Total shoot
Regular	40a	78a	137a	330a	586a	10,736a
Tall	25b	53b	109a	245a	431a	8,421b
$Cu(OH)_2$						
+	41a	80a	147a	399a	667a	11,189a
–	24b	52b	99b	179b	355b	7,991b

[z]Means within a column and treatment followed by different letters are significantly different at $P < 0.05$.

Table 5. Root dry mass (g) of ficus and pepper growing for 14 months in the field after being grown for 6 months in the greenhouse in #1 containers, or growing for 13 months in the field after being grown for 9 and 4 months, respectively in #3 or #5 containers outdoors. Means are averaged over container shape and container volume (n = 40).

#1	Ficus				Pepper			
	Root class (mm diameter)				Root class (mm diameter)			
Root zone (cm from trunk)	< 2	2–5	5–10	> 10	< 2	2–5	5–10	> 10
< 33	18.4a[z]	20.8a	36.3a	50.6a	16.0a	25.4a	55.8a	205.8a
33–66	12.4b	20.6a	26.2b	4.4b	9.6b	22.9a	42.0b	61.0b
> 66–100	7.1c	14.7b	9.8c	0.1b	6.8b	17.2b	24.8c	19.5c
Percentage	17	25	33	25	6	13	24	57
#3 + #5	**Ficus**				**Pepper**			
	Root class (mm diameter)				Root class (mm diameter)			
Root zone (cm from trunk)	< 2	2–5	5–10	> 10	< 2	2–5	5–10	> 10
< 33	43.1a	51.8a	59.0a	89.5a	38.2a	58.5a	110.1a	317.5a
33–66	14.9b	23.1b	13.5b	2.3b	10.6b	29.5b	39.8b	38.6b
> 66–100	4.8c	6.6c	3.1c	0.1b	5.7c	17.4c	15.3c	5.4b
Percentage	20	26	25	29	8	15	24	53

[z]Means within a column followed by different letters are significantly different at $P < 0.05$.

59.0 mm (2.3 in) and 2.6 m (102.3 in), respectively, when harvested from the field. Average total root dry weight of pepper trees in the field previously grown in #3 or #5 containers was 673 g (23.7 oz). Similar to ficus, trees transplanted to the field from regular or copper-treated #1 containers produced similar biomass to plants transplanted from regular #3 or #5 containers.

The different morphology of ficus and pepper root systems after growing for 13 or 14 months in the field are documented in Table 5. In plants transplanted from #1 containers directly into the field, the different root size classes contributed between 17% and 33% in ficus's fibrous root system, while the largest two size classes accounted for 80% of pepper's coarse root system. As expected, less root biomass was found with increasing distance from the trunk for all root size classes for both species.

Pepper and ficus trees growing 13 months in the field after being transplanted from #3 or #5 containers had roughly the same percentage of root mass: 77%, 17%, and 6% at <33 cm, 33–66 cm, and 66–100 cm from the trunk, respectively. Root mass of the different root size classes for these trees was more evenly distributed for ficus, with 20–29% root mass in each of the four size classes, while 77% of the root mass in pepper trees was comprised of larger roots with a diameter of 5–10 mm or > 10 mm (Table 5). Although the majority of root biomass for both species was located within 33 cm of the trunk, root system morphology differed greatly. We observed that pepper planted in the field developed a system of few large-diameter roots that extended horizontally to form a shallow, coarse root system regardless of the container treatment used to produce them. In contrast, ficus roots were more fibrous and less rigorous in their spatial orientation. Pepper in tall versus regular containers grew consistently less throughout the nursery phases and field establishment. Our results confirm previous reports that plants grown in containers benefit from a height/width ratio of the container that accommodate the growth characteristics of their root system (11, 13, 16). Ficus, to the contrary, has a more fibrous root system and was not affected by container configuration.

In summary, the effects of container volume, shape and cupric hydroxide coating were different for each species. Tall containers reduced biomass production in pepper, but not ficus. Our visual observation in the field along with data for the biomass of root size classes indicate that the coarse root system of pepper trees had a strong tendency for lateral spreading and was restricted by the narrow container diameter. Compared with a more fibrous root system of ficus, pepper roots do not seem to adapt easily to various container shapes. Pepper trees may grow even better in shallow and wide containers. During nursery production, both tall-narrow containers and copper coating inhibited pepper growth, but copper coating reduced the incidence of circling and matted roots in both species. None of the container treatments reduced the development of larger roots near the soil surface [within 30 cm (11.8 in)] for pepper and ficus, which suggests that the container production system has little influence in reducing root damage to infrastructure.

In this study during container production, root growth of the slower growing species, ficus, was affected by container shape and size, but shoot dry weight was not affected. During field establishment, however, the larger container size (#5 versus #3) was beneficial and resulted in greater shoot dry weight. For the more rapid growing pepper, however, total dry weight was greater in regular versus tall containers, while root dry weight was not affected.

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