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Effects of Nursery Container Type on Root Growth and Landscape Establishment of *Acer rubrum* L.[1]

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Abstract

Trees of red maple (*Acer rubrum* L.) were planted into seven container types evaluated for their ability to reduce number of roots deflected by the container wall. Seedlings were grown 70 weeks (production phase) in seven container types to a mean trunk diameter of 3.9 cm (1.5 in) and were transplanted into a sandy soil and grown with frequent or periodic irrigation for 24 weeks (landscape phase). There was no effect of container type on total root mass, trunk diameter or height during the production phase. Total deflected root length was less in low-profile plastic containers, chemical root pruning containers, air root pruning containers (ARPC), and wood boxes than in standard black plastic containers (SBPC). Trees produced in the SBPC had the most horizontally-oriented deflected root length while the ARPC and SBPC had the most vertically-oriented deflected root length. Trees grown in the ARPC had less roots on the inside of the root ball than all other container types. Container type did not influence root and shoot growth, but impacted stem water potential in the first five months after transplanting to the landscape. Trees frequently irrigated during the landscape phase had greater trunk diameter, height, and generated more new root mass than those which were infrequently irrigated.

Index words: container production, container design, root modification, deformed roots, circling roots, air root pruning, chemical root pruning, root morphology, transplanting, root growth, *Acer rubrum*.

Significance to the Nursery Industry

Red maple trees produced in a variety of container production methods grew shoots at the same rate in the nursery. Roots also grew at a similar rate but the amount of circling roots was reduced by growing in low-profile containers, chemical root-pruning containers, air root-pruning containers, or in wooden boxes. Trees irrigated more frequently after planting in the landscape grew larger trunks, were taller, and produced more new roots into the soil than infrequently irrigated trees regardless of container type. Low profile air root pruning containers and containers with copper compounds were more stressed than other container types at various stages after planting into the landscape. Growing trees in alternative containers designed to reduce circling roots produces a better quality root system than the standard plastic container without sacrificing post-transplant growth.

Introduction

Plants grown in standard plastic containers often have deflected roots, which are kinked or grow along the sides of the root ball. These roots can contribute to long-term tree growth problems in the landscape such as instability (14) and restricted growth (11).

The type of nursery container used during production can have a dramatic impact on root morphology of container-grown plants (23). Copper compounds applied to the interior surface of plastic containers reduce root deflection on many woody species (19), and caused an increase (5, 16), decrease (3, 5), or no effect (5, 13) on root to shoot ratios. Shoot growth was increased for some species and decreased for other species when grown in copper-treated containers

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(5, 13). Plants grown in copper-treated containers were less stressed during production than similar plants grown in standard plastic containers (7).

Roots in porous-walled plastic containers stopped growing when they reached the container wall-substrate interface (15), and generated more new roots following transplanting from porous-walled containers (12) compared to SBPC. Mahogany (*Swietenia mahagoni* L. (Jacq.)) grown in air root-pruning containers had lower root mass and higher shoot to root ratios than trees grown in standard black plastic containers (8). Other container designs such as low-profile or square containers have also been shown to reduce root deformities. Plants grown in a square container had less circling roots compared to those in a standard black plastic container, (20) and roots were matted on the bottom of the square container (1).

This experiment was designed to compare root morphology and root growth in seven different container types, and subsequent establishment in the landscape under two different irrigation regimes.

Materials and Methods

Production in the nursery. Sexually propagated trees of red maple (*Acer rubrum* L.) were obtained from a nursery in central Florida (Herrmann's Nursery, San Antonio, FL) in 3.0 liter (#1) containers. In February 1995, trees were planted into seven different container types in Gainesville, FL (USDA hardiness zone 8b). The seven container types were: (a) 66 liter (#15) standard black plastic container (SBPC) (Lerio Corp., Mobile, AL), (b) 66 liter (#15) SBPC treated on interior surfaces with $Cu(OH)_2$ at a rate of 100 g/liter (13.3 oz/gal) latex carrier (Spin Out™, Griffin Corp., Valdosta, GA) before planting, (c) low-profile black plastic container (58 cm (23 in) diameter × 33 cm (13 in) deep; Lerio Corp.), (d) corrugated aluminum air root pruning container (ARPC) (43 cm (17 in) diameter × 41 cm (16 in) deep; Accelerator, Hold-Em, Inc., West Palm Beach, FL), (e) low-profile corrugated aluminum ARPC (56 cm (22 in) diameter × 30 cm (12 in) deep), (f) wooden square container (constructed of untreated pine, 42 × 42 × 42 cm (16.5 × 16.5 × 16.5 in); Ridge Pallets, Bartow, FL), and (g) wooden square container treated on interior surfaces with Spin Out™ before planting. Each corrugated aluminum ARPC was perforated with holes of two types: round, 3.2 mm (0.13 in) diameter, and rectangular, 6.3 mm (0.25 in) × 25.4 mm (1 in), with rounded ends. ARPCs were bottomless and were placed on a non-woven fabric cloth (style S700, 110 mil thickness, Hold-Em, Inc. West Palm Beach, FL).

Trees were planted into each container in 0.056 m^3 (2.0 ft^3) of substrate consisting of aged pine bark, domestic peat, sand (4:5:1 by vol) supplemented with 1.78 kg/m^3 (3 lb/yd^3) Step micronutrients (The Scotts Company, Marysville, OH) and dolomite to a pH of 6.0–6.5. Trees were 8.5 mm (0.33 in) in trunk diameter six inches above soil line, 88 cm (2.9 ft) in height at planting, and were spaced on 1.2 m (4 ft) by 1.2 m (4 ft) centers. All trees were placed on a woven ground cloth and once tall enough were tied to a wire trellis 1.2 m (4 ft) from ground level to prevent them from blowing over. Trees were planted in a randomized complete block design with one replicate per container type per block (28 blocks, 7 trees per block).

All container types were irrigated similarly during the 70 weeks of the production phase. Trees received 10 liters (2.6 gal) of water once a week during the first 13 weeks after planting, 4 liters (1.1 gal) once daily during weeks 14 through 23, 4 liters twice daily during weeks 24 through 29, 4 liters three times daily during weeks 30 through 38, 8 liters (2.1 gal) once daily during weeks 39 through 42, 8 liters once every three days during weeks 43 through 56, 8 liters once daily during weeks 57 through 65, and 10.6 liters (2.8 gal) twice daily during weeks 66 through 70.

At the beginning of week 16, all black plastic containers were placed inside a 110-liter (# 25) black plastic container to buffer soil temperatures. After placement into the 110-liter containers, substrate temperature measurements, measured 5 cm inside the container edge, were within 2C (3.6F) for all container types. Branches originating on the bottom 15 cm (6 in) of the trunk were removed while branches originating between 15 cm and 46 cm (18 in) were pruned back to 15cm in length during week 26. No pruning was done above 46 cm. All trees received 85 g (3 oz) Osmocote 18N–2.6P–9.9K (18–6–12, The Scotts Company, Marysville, OH) 13 and 29 weeks after planting.

At the end of the production phase (May 1996) all seven trees from five blocks were destructively harvested. Deflected roots greater than 2 mm in diameter were collected and sorted based on location in the top or bottom half of the root ball and on angle of growth. Deflected roots were defined as any root located within 1 cm of the outside vertical surface of the root ball. Deflected root growth was classified as: H = an angle < 45° from the soil surface (horizontal orientation), or V = an angle > 45° from the soil surface (vertical orientation). For example, a deflected root growing parallel to the top of the root ball was classified as H; one growing straight down the side was classified as V. Deflected root length was measured on roots in each category. Root mass was measured after roots were washed and dried at 70C (158F) for one week. Deflected root data were analyzed using a three-way analysis of variance with three main effects: production method, location of roots in the top versus bottom half of the root ball, and angle of growth.

Roots in the interior of the root ball were cleaned and sorted into 0–2 mm, 2–5 mm, 5–10 mm, and >10 mm diameter classes. Roots were dried at 70C (158F) for one week and weighed. Dry mass of the shoots (trunk, stems, and leaves combined) were also measured. Trunk diameter at 15.3 cm (6 in) above the soil line and tree height to the tallest bud were measured 11 and 70 weeks after planting. Interior root data were analyzed using a two-way analysis of variance with production method and root diameter class as main effects. Shoot mass, trunk diameter, and tree height data were analyzed using a one-way analysis of variance with production method as the main effect.

Planting in the landscape. In May 1996, twenty blocks from the production phase were transported to a site 1.6 km (1 mile) away and transplanted into a well-drained Millhopper sand (loamy, siliceous, hyperthermic Grossarenic *Paleudults*) on 2.4 m (8 ft) centers in rows oriented north to south. Root balls of wooden square containers were planted so that two sides of the root ball were parallel to the row. Planting holes were as deep as the container and 30 cm (12 in) wider. Treatments for the landscape phase were seven container types either frequently or infrequently irrigated (7 × 2 factorial). Trees were planted in a randomized complete block design with one replicate per treatment per block (10 blocks, 14 trees per block). All trees were staked at planting to stabilize them in the soil. Trees were grown in the landscape environment for 24 weeks.

All treatments were irrigated to saturation each day the first week after planting. On the frequent irrigation schedule, 10 trees from each container type (70 trees total) received 38 liters (10 gal) of water daily during weeks 2 through 9, then every other day during weeks 9 through 24. On the infrequent irrigation schedule, 10 trees from each container type (70 trees total) received 38 liters (10 gal) of water weekly during weeks 2–3, every third day during weeks 4–9, every 10 days during weeks 10–19, and no irrigation during weeks 20–24. Rainfall totals at the site were 4.6 cm (1.8 in) for weeks 1 and 2 (May), 6.6 cm (2.6 in) for weeks 3–6 (June), 20.6 cm (8.1 in) for weeks 7–10 (July), 13.7 cm (5.4 in) for weeks 11–15 (August), 2.8 cm (1.1 in) for weeks 16–19 (September), and 14.7 cm (5.8 in) for weeks 20–24 (October). A scheduled irrigation was not applied if 6.3 cm (2.5 in) or more of rain fell since the previous irrigation. All trees received 85 g (3 oz) of Osmocote 18N–2.6P–9.9K (18–6–12) over the root ball 1 and 15 weeks after transplanting.

After 24 weeks (October), root systems of 5 blocks (70 trees) were harvested. All roots outside of the 66-liter (#15) root ball and within two wedge-shaped sections [defined by 45° angles from the trunk on the northeast and southwest sides of the tree (a total of ¼ of the new root growth)] were excavated and removed. Each wedge-shaped section was extended as far from the trunk and as deep as necessary to include all roots growing outside the root ball in this area, including new roots under the original root ball. Root mass was measured after roots were washed and dried at 70C (158F) for one week. Data were analyzed using a three-way analysis of variance with production method, irrigation frequency, and compass direction as main effects.

Trunk diameter at 15.3 cm (6 in) above the soil line and tree height to the tallest bud were measured weeks 1 and 24 after planting in the landscape. These data were analyzed using a two-way analysis of variance with production method and irrigation frequency as main effects.

Midday (1230–1430 HR) stem water potential (Ψ_{Stem}) was measured on infrequently irrigated trees during weeks 2, 3, and 9. Ψ_{Stem} was measured at 2 ½ hour intervals (diurnally) starting before dawn (pre-dawn) until sunset on 4 trees of each treatment during weeks 3 and 9. Irrigation was withheld from both frequently and infrequently irrigated trees for six days during week 9 so that Ψ_{Stem} readings under water stressed conditions could be measured. Diurnal measurements during week 9 were stopped after the 1330 HR reading due to rainfall. Ψ_{Stem} was measured with a pressure chamber (Soil Moisture Equipment Co., Santa Barbara, CA) using compressed nitrogen increased at a rate of 2.5 kPa/sec. Ψ_{Stem} was measured on 8 cm (3 in) long shoots with foliage taken from the sunny side of the tree. Infrequently irrigated trees were rated during week 12 as exhibiting signs of stress or no signs of stress. Signs of stress were defined as wilt, leaf browning, or leaf drop. Differences in stress ratings among production methods were analyzed using the SAS nonparametric one-way procedure with the Wilcoxon option (17).

Data were analyzed using the SAS general linear models procedure (17). Means were compared using least square means and Duncan's multiple range test from the general linear models procedure.

Results and Discussion

Production in the nursery. Tree height 2.8 m (9.2 ft) and trunk diameter 3.9 cm (1.54 in) were similar among container types at the end of the production phase of the experiment.

The main effects container type and angle of growth (H or V) were significant ($p < 0.05$) for deflected root length; however, container type and angle of growth interacted (Table 1). The SBPC and low-profile black plastic container had more H-oriented than V-oriented deflected root length. The ARPC had significantly more V-oriented than H-oriented deflected root length. This distinction between root orientation has not been previously reported. SBPC had more H-oriented deflected root length than all other production methods. This was consistent with previous research which used visual ratings to determine that SBPC had more deflected roots compared to various root control methods (4, 20). SBPC and ARPC had equal amounts of V-oriented deflected root length and both had more V-oriented deflected root length than the other five container types (Table 1).

The interaction of container type and angle was also significant ($p < 0.05$) for deflected root mass (Table 1). The SBPC, the wooden square container, and the wooden square container with $Cu(OH)_2$ had similar H-oriented deflected root mass. The SBPC had significantly more H-oriented deflected root mass than the remaining four container types. The ARPC

Table 1. Deflected root length, deflected root mass, and root mass inside the root ball for seven container types (66-liter) after 70 weeks.

Container type	Deflected root length (cm) H angle[z]	Deflected root length (cm) V angle	Deflected root mass (g) H angle	Deflected root mass (g) V angle	Root mass inside root ball (g)
Standard black plastic container (SBPC)	503.7aA[y]	270.5bA	11.9aA	9.5aAB	237.3A
Standard black plastic container with $Cu(OH)_2$	115.4aB	44.8aB	5.3aB	2.8aC	213.8A
Low-profile black plastic container	200.5aB	63.5bB	5.5aB	1.6aC	193.9AB
Air root pruning container (ARPC)	92.5bB	240.7aA	4.7bB	14.1aA	149.4B
Low-profile air root pruning container	136.8aB	120.5aB	3.9aB	6.1aBC	235.2A
Wooden square container	143.6aB	74.0aB	7.4aAB	4.4aBC	232.38A
Wooden square container with $Cu(OH)_2$	146.3aB	89.1aB	6.4aAB	5.2aBC	236.23A

[z]Angle of root growth along the side of the root ball (deflected root) was classified into one of two categories: (H) an angle < 45° from the soil surface (horizontal orientation), or (V) an angle > 45° from the soil surface (vertical orientation).

[y]Values for H and V angles within a container type for deflected root length or mass with the same lower-case letter are not significantly different according to Duncan's multiple range test at P < 0.05. Values in a column with the same upper-case letter are not significantly different according to Duncan's multiple range test at P < 0.05. Values are a mean of 5 observations.

was the only container type to have significantly more V- than H-oriented deflected root length and mass. Copper hydroxide proved effective at reducing deflected root growth on plastic containers, whereas, it appeared to have no affect on wooden containers. This difference in effectiveness could be due to the binding of copper cations to the wood making them unavailable to the root tip.

This distinction in root orientations among container types could lead to differences in stability or establishment of landscape size trees. Unless new lateral root tips develop to replace down turned root tips on V-oriented roots, newly planted trees could have reduced stability and altered growth, perhaps leading to poor performance, windthrow, stunting, and even death (22).

There was a significant effect of location in the root ball (top vs. bottom half) on deflected root length and mass. Independent of container type, deflected root length and mass were greater in the top half of the root ball, 189.1 cm (6.2 ft.) and 8.6 g (0.30 oz.), respectively, compared to 131.2 cm (4.3 ft.) and 4.0 g (0.14 oz.) in the bottom half. Deflected roots are often associated with matting or spiraling of roots toward the bottom of the container (4). Perhaps the shallow-rooted nature of *Acer rubrum* (9) or the frequent irrigation during production led to the increase of roots in the top half of the root ball.

The effects of container type and root diameter class were significant for root mass inside the root ball. These measurements excluded deflected roots. The ARPC had less root mass inside the root ball than all production methods except the low-profile black plastic container (Table 1). This was consistent with results by Fitzpatrick et al. (8) in which ARPC grown *Swietenia mahagoni* had less root mass than similar plants grown in SBPC. For all container types there was greater root mass in the 0–2 mm diameter class [867.3 g (30.6 oz.)] than in the other diameter classes {2–5 mm [276.2 g (9.8 oz.)], 5–10 mm [198.1 g (7.0 oz.)], and >10 mm [156.6 g (5.5 oz.)]}. There was no interaction between root diameter class and container type. There were no significant differences ($P < 0.05$) in total root mass (mass of deflected roots combined with root mass inside the root ball) among container types (data not shown).

Planting in the landscape. Tree height and trunk diameter were similar among container types at planting and after five months of growth in the landscape. However, irrigation frequency after transplanting had a significant ($P < 0.01$) effect on tree height and trunk diameter. After five months in the landscape, average trunk diameter on frequently irrigated trees was greater [5.8 cm (2.3 in.)] and trees were taller [3.4 m (11.0 ft.)] than infrequently irrigated trees at 4.7 cm (1.9 in.) in average trunk diameter and 2.7 m (8.8 ft.) in height.

New root growth five months after transplanting was analyzed by container type, irrigation frequency, and compass direction from which new roots were harvested. Irrigation frequency and compass direction both significantly ($P < 0.05$) influenced new root growth; however, there was no effect of container type and there were no interactions. In contrast, Brass et al. (6) showed that one cultivar of red maple had increased new root growth one year after transplanting when grown in 23.3-liter (# 5) copper-treated containers, whereas another cultivar showed no difference in new root growth compared to those in untreated containers. Arnold (2) found more new root growth from oak seedlings (*Quercus shumardii* Buckl.) grown in copper-treated 2.3-liter (0.5 gal) containers than from those in standard plastic containers 21 days after transplanting. Perhaps the larger, landscape-sized plant material used in our study, grown in copper-treated containers, responds differently after transplanting than smaller liner-sized material grown in copper-treated containers. In our study there may have been differences in new root growth among treatments in the first few weeks after transplanting; however, this was not measured.

Frequently irrigated trees had more ($P < 0.01$) new root mass [102.9 g (3.6 oz)] than infrequently irrigated trees [52.5 g (1.9 oz.)]. Most new root growth occurred from the sides of the root ball with few new roots being recovered from under the root ball. New root mass from the NE side of the tree was 85.5 g (3.0 oz.), which was greater ($P < 0.05$) than the 69.1 g (2.4 oz.) of new root mass harvested from the SW side of the tree. This could be due to greater exposure to the sun on the SW side of the root system, whereas the canopy shades the NE side. Watson and Himelick (21) found similar results in red maple (USDA hardiness zone 5) with greater root quantity and a more developed root system in the north quadrant.

Averaged across irrigation frequencies there were no differences among container types in diurnal Ψ_{Stem} measurements during weeks 3 and 9. However, Ψ_{Stem} measurements taken diurnally during week 3 showed that frequently irrigated trees were less stressed ($P < 0.01$) than infrequently irrigated trees

Table 2. Midday Ψ_{Stem} and tree stress rating for infrequently irrigated trees transplanted from seven different container types.

Container type	Midday Ψ_{Stem} Week 2 (–MPa)	Midday Ψ_{Stem} Week 9 (–MPa)	Number of trees stressed or not stressed Week 12	
			No stress (no.)	Stressed[z] (no.)
Standard black plastic container (SBPC)	1.41Ab[y]	1.63B[x]	4	6AB[w]
Standard black plastic container with $Cu(OH)_2$	1.69A	1.69B	2	8AB
Low-profile plastic container	1.52AB	1.61B	4	6AB
Air root pruning container (ARPC)	1.50AB	1.68B	6	4A
Low-profile air root pruning container	1.68A	1.84A	3	7AB
Wooden square container	1.24B	1.60B	7	3A
Wooden square container with $Cu(OH)_2$	1.63A	1.63B	1	9B

[z]Stressed trees exhibited one or more of the following symptoms: wilting, leaf drop or leaf necrosis.

[y]Values in a column with the same letter are not significantly different according to Duncan's multiple range test at $P < 0.1$. Values are a mean of 6 observations.

[x]Values in a column with the same letter are not significantly different according to Duncan's multiple range test at $P < 0.1$. Values are a mean of 6 observations.

[w]Values in a column with the same letter are not significantly different by Wilcoxon sign rank test at $P < 0.1$. Values are a mean of 10 observations.

(data not shown). Ψ_{Stem} measurements taken diurnally during week 9, after both frequently and infrequently irrigated trees had not been irrigated for 6 days, still showed that frequently irrigated trees were less stressed ($P < 0.05$) than infrequently irrigated trees.

Midday Ψ_{Stem} is a useful indicator of plant stress in many tree species (18). For our research on red maple, midday Ψ_{Stem} on infrequently irrigated trees showed significant differences among container types for two of the three midday readings taken during weeks 2, 3, and 9. Trees from wooden square containers had less negative Ψ_{Stem} (least stressed), than trees from SBPC with Spinout™, low-profile ARPC, and wooden square container with Spinout™ (Table 2). The only difference in midday Ψ_{Stem} among container types during week 9 was for the low-profile ARPC, which was significantly more negative (more stressed) than the others. This indicates that trees of red maple grown in low-profile ARPCs were probably more stressed in the first nine weeks after transplanting than trees from other container types. Similar results were found in tree stress ratings from week 12 in which the low-profile ARPC was one of the container types exhibiting the most stress (Table 2). Trees from wooden square containers with $Cu(OH)_2$ were significantly more stressed than wooden square containers without $Cu(OH)_2$ and those from ARPCs.

Our midday Ψ_{Stem} measurements and stress rating contrasted with Arnold (2) who showed that seedlings grown in copper-treated containers were less stressed after planting than those grown in SBPCs. Trees generating less root growth after planting are often more water stressed after planting (2, 10). Perhaps the increased stress on trees grown in the wooden square container with $Cu(OH)_2$ and low profile ARPC was due to limited root growth in the weeks following transplanting. In contrast, since trees from wooden boxes were the least stressed after planting, they may have established quicker than those from other container types.

There was no effect of container type on above-ground tree growth at the end of the production or landscape phases of this experiment. Cupric hydroxide applied to the inside of a black plastic container was more effective at reducing the amount of horizontally-oriented deflected roots than the SBPC without cupric hydroxide. The black plastic container with cupric hydroxide also was effective at reducing vertically-oriented deflected roots, compared to both the plastic container without cupric hydroxide and the air root-pruning container. Reduction in interior root mass in trees produced in the air root-pruning container had also been found previously in mahogany (8). These changes in root morphology during production did not affect root growth in the landscape phase measured five months after planting; however, there may have been root growth differences among container types in the first few weeks after planting that went undetected. Previous transplant studies in this hardiness zone suggest the maples in this study were likely established by five months after planting (10). Differences in root growth before plants were established could explain the variation in stress among container types. Future research excavating roots at periodic intervals after transplanting would help clarify this. A reduction in tree stress and an increase in trunk diameter, height, and new root growth on trees frequently irrigated after transplanting points to the need for regular irrigation following planting.

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