Root Pruning and Planting Depth Impact Root Morphology in Containers[1]

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Abstract

Increasingly, producers and consumers are realizing that roots play a major role in nursery tree quality. To remain competitive, producers need to find economically viable methods of increasing quality standards. Two studies were designed to test methods of improving root systems in a container root ball. In the first, three different root pruning methods and two planting depths were imposed as 3.7 liter (1 gal) container-grown Royal poinciana [*Delonix regia* (Bojer) Raf.] and trumpet-tree [*Tabebuia heterophylla* (DC.) Britton] were shifted to 25 liter (6.6 gal) containers. Root pruning and planting depth had no impact on trunk caliper or tree height. Vertical root ball slicing or shaving off the periphery of the root ball increased the number of straight roots inside root balls and reduced the presence of deflected roots, but shaving had a greater effect and was associated with consistently high-quality root systems. Trees planted with the top-most root 10 cm (4 in) below the 25 liter (6.6 gal) container substrate surface had more deflected roots and fewer straight roots than trees planted with roots close to the surface. In the second study, teasing or shaving live oak (*Quercus virginiana* Mill. 'SNDL') in 3.7 liter (1 gal) container root balls resulted in identical root systems in 57 liter (15 gal) containers one year later, and both treatments resulted in higher quality root systems than trees not root pruned.

Index words: circling roots, deflected roots, descending roots, root culls, shaving, slicing, straight roots.

Species used in this study: royal poinciana (*Delonix regia*), live oak (*Quercus virginiana* 'SNDL', Cathedral Oak®), trumpet-tree (*Tabebuia heterophylla*).

Significance to the Nursery Industry

The architecture of the root system in nursery root balls impacts establishment and subsequent anchorage in the landscape. Number of straight roots in the root ball has been associated with improved anchorage; whereas roots deflecting downward or around the trunk appear to reduce stability. Root pruning when shifting to a large container size by shaving off the periphery of the root ball, deep vertical slicing into the root ball sides, or teasing and pulling on small-diameter roots at the root ball periphery reduced attributes associated with weak root systems. Related studies also show that this improves anchorage when planting into the landscape.

Introduction

Focus on tree nursery stock root systems has intensified in recent years because of poor anchorage and health resulting from growing conditions in some nurseries (6, 9, 19). Poor

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root growth into substrate of the larger container can result in unstable trees (31) caused by downward deflected and circling roots in smaller propagation containers (11, 34). Many studies on conifer seedlings show that root deflection can contribute to long-term growth problems after planting in the forest (29). Roots on shade trees in larger containers also deflect deeper into the substrate and proliferate at the bottom of containers (32), presumably due to the abundance of moisture, oxygen and nutrients in that location. Twenty-eight percent of tree failures in California urban and suburban landscapes were related to root defects (12) suggesting that a portion of failures may be traceable to root morphology in the nursery root ball.

Several states have recently included root system attributes as part of grades and standards and specifications for nursery stock including Florida (1), California (28) and Illinois (2) in an effort to improve quality. The most recent edition of the American Standard for Nursery Stock (3) also addresses root flare depth for the first time since its publication in 1927. A myriad of container designs and innovations were introduced 25 years ago to the market in an effort to improve root systems (4). Although root systems in some containers have been the subject of intense evaluation (5, 7, 22, 25, 32) and improvements in root systems are evident in selected markets, the problem of deformed root systems on nursery trees is far from solved.

Even if innovations in container design were shown to generate the ideal root system, nurseries have millions of existing containers in their inventory. Because replacing current inventory with a new design might be considered economically impractical, recent investigations have focused on various root ball manipulation strategies for improving quality of the root system using current container technology. Slicing (18, 34) or shaving off the periphery (21) of 10 liter (2.6 gal) container root balls on temperate- and tropical-zone trees when shifting from one container size to another can reduce the number of roots that deflect down, around, and up the sides of the container. This pruning shifted the large-diameter woody roots from the root-pruned container periphery to the substrate of the larger container and increased the number of straight lateral roots in the finished root ball. Cutting roots on the root ball periphery has also been associated with more straight roots following planting into the landscape (23) and forest (30).

Gilman et al. (16) showed that shallow [2.5 cm (1 in) deep] slicing 11 liter (2.9 gal) container root balls top-to-bottom on shrubs (*Ilex cornuta* Lindl. & Paxt. 'Burfordii') at planting into field soil resulted in a redistribution of roots in the landscape, not an increase in roots compared with non-pruned controls. Lightly scoring or teasing the root ball periphery from slightly larger trees (*Tilia cordata* Mill. and *Salix alba* L.) in 25 liter (6.6 gal) or 40 liter (10.6 gal) containers also had no impact on number of roots growing into landscape soil (35).

Deep planting in a container can also result in deformed root systems (11). After one year in above-ground containers, height and caliper of *Cornus florida* L. was significantly less on trees that were planted deeply compared to those that were planted shallow (8, 14). Liners of Cathedral Oak® live oak planted deeply into 10 liter (2.6 gal) Accelerator® (Nursery Supplies Inc., Chambersburg, PA) containers generated circling roots over the root flare which reduced root system quality (16). Fare (14) and Gilman et al. (20) showed that red maple (*Acer rubrum* L.) planted deeply into 10 and 170 liter (2.6 and 45 gal) containers, respectively, had many roots growing over the root flare compared to trees planted more shallow. There is less known about the impact of planting depth in containers on root systems of tropical trees.

Objectives of the current study were to compare impacts on growth and root system morphology from various planting depths and root ball manipulation techniques in containers on two commonly grown tropical trees and one temperate tree.

Materials and Methods

Study 1: In June 2008, thirty-six seed propagated, 16-month-old, Royal poinciana and 36 pink trumpet-trees averaging 1.5 and 1.0 cm (0.6 and 0.4 in) caliper and 35 cm (13.8 in) in height (for both) respectively, were shifted from 2.5 liter (0.7 gal) smooth-sided black plastic containers (#1, Classic 300S, 16.5 cm (6.5 in) wide by 16.5 cm deep, Nursery Supplies Inc., Chambersburg, PA) into 23 liter (6.1 gal) smooth-sided black plastic containers [#7, Classic 2800, 35.6 cm (14 in) wide by 29.2 cm (11.5 in) deep, Nursery Supplies Inc.] and arranged in a randomized complete block design. Prior to planting, trees were subjected to one of three root pruning treatments: 1) cut 5 cm (2 in) deep radially from the top surface through to the bottom surface of the root ball in four equidistant sides of the root ball, and remove the bottom 2 cm (0.8 in) of the root ball with a Corona (RC 4060, Corona Clipper, 22440 Temescal Canyon Rd., Corona, CA 92883) 17 cm (6.7 in) root pruning saw (sliced); 2) remove the entire outer 2 cm (0.8 in) of the root ball with the same hand pruning saw, and remove the bottom 2 cm (0.8 in) of the root ball (shaved); 3) no root pruning (not pruned). Trees were planted into a standard nursery mix which consisted of approximately 30% pine bark, 30% sand, 30% topsoil and 10% vermiculite with the top-most root either 2 cm (0.8 in) below substrate surface [to prevent growth reductions from shallower planting (17)] or 10 cm (4 in) below the surface. Trees were placed approximately 0.6 m (2.0 ft) apart on woven black plastic nursery ground cloth and irrigated with enough volume to encourage active growth through an overhead system once daily. Trees were fertilized one month after planting with 3–4 month Osmocote 19-6-12 [N-P_2O_5-K_2O, 84 g (0.19 lb) per 23 liter (6.1 gal) container] and subsequently pruned to a dominant leader and hand weeded.

Trees were arranged in a randomized complete block design with one tree of each of the 6 treatment combinations (3 root prunings × 2 planting depths) in each of 6 blocks for each species separately. The study was conducted at the Ft. Lauderdale Research and Education Center, FL, USDA hardiness zone 10b (2000). In December 2008, tree height and trunk diameter at 15 cm (5.9 in) above substrate (caliper) were measured, and root balls were washed so various root attributes could be measured (Table 1).

Study 2: In December 2008, cutting-propagated *Quercus virginiana* Mill. Cathedral Oak® with a 15 mm (0.6 in) trunk diameter measured 15 cm (5.9 in) above substrate surface in 3.7 liter (1 gal) smooth-sided containers (#1, Classic 300S, Nursery Supplies Inc. Chambersburg, PA) were planted into 57 liter (15 gal) smooth-sided black plastic containers (#15, Classic 6900, Nursery Supplies Inc.). Prior to potting, the three root pruning treatments were imposed on 100 plants each: 1) All roots were cut from the sides of root balls using

Table 1. Root [> 2 mm (0.09 in) diameter] attribute definitions for Royal poinciana and trumpet-trees in 25 liter (6.6 gal) container root ball at harvest[z].

- Percent trees with good root system: a visual rating of entire root system as a whole with 5 = few kinked, circling, or descending roots at the position of the 3.7 liter (1 gal) container and 1 = most roots kinked, circling, or descending.
- Percent root culls: percent of trees rated as culls at the position of the 3.7 liter (1 gal) container according to Florida Grades and Standards for Nursery Plants (1).
- Straight root rating: a visual rating of root form at the interface of the 3.7 (1 gal) and 25 liter (6.6 gal) container substrates with 5 = most roots grew in a more or less straight manner with less than a 60 degree turn and 1 = most roots deflected up, down, or around at the position of the 3.7 liter (1 gal) container.
- Mean diameter 5 main roots: diameter of the 5 largest roots measured 2 cm (0.8 in) inside the position of the 3.7 liter (1 gal) container periphery to the tenth of a mm.
- Percent trunk circled: percent of root ball circumference (in top half of ball only) with roots growing around in a circle at < 45 degree angle to horizontal at the position of the 3.7 liter (1 gal) container wall.
- Number of roots top half: number of roots growing from the top half of the original 3.7 liter (1 gal) root ball.
- Number of roots bottom half: number of roots growing from the bottom half of the original 3.7 liter (1 gal) root ball.
- Percent trees > 5 adventitious roots: percent of trees with more than 5 adventitious roots > 2 mm (0.09 in) diameter growing from the buried portion of the trunk.
- Percent 5 largest roots circling: percent of the 5 largest diameter roots that deflected and grew in a circle (at < 45 degree angle from horizontal) at the position of the 3.7 liter (1 gal) container wall.
- Percent 5 largest roots descending: percent of the 5 largest diameter roots that deflected and grew downward (at > 45 degrees from horizontal) at the position of the 3.7 liter (1 gal) container wall.
- Percent 5 largest roots fanning: percent of the 5 largest diameter roots that were not deflected by the 3.7 liter (1 gal) container and grew in a fan-like manner into 25 liter (6.6 gal) substrate away from the trunk +/– 90° (180 degrees total) azimuth relative to the lateral mother root.
- Percent 5 largest roots ascending: percent of the 5 largest diameter roots that deflected and grew upward (at > 45 degrees from horizontal) at the position of the 3.7 liter (1 gal) container wall.
- Percent 5 largest roots straight: percent of the 5 largest diameter roots that were not deflected by the 3.7 liter (1 gal) container wall.

[z]Data reported in Tables 3, 4, 5, and 6.

hand pruning shears to remove the outer 2 cm (0.8 in) of substrate and roots prior to planting (shaved); 2) Roots along the sides were pulled away from the periphery 2 cm (0.8 in) of the 3.7 liter (1 gal) root ball using a three-pronged hand rake and spread by hand in a straight radial fashion in the substrate of the 57 liter (15 gal) container (teased). A few roots on most trees were long enough to reach the wall of the 57 liter (15 gal) container in which case they were cut just short of the wall. We attempted to distribute roots throughout the top 15 cm (5.9 in) of substrate in a radially symmetrical manner. 3) A third set of trees was not manipulated in any way prior to planting (not pruned). Top of substrate in the 3.7 liter (1 gal) container was positioned even with the substrate surface in the 57 liter (15 gal) container. The 300 trees were arranged 0.9 m (2.9 ft) apart on woven black plastic nursery ground cloth in a completely randomized design.

Controlled-release fertilizer was incorporated into the substrate (pine bark: Florida peat:sand, 60:30:10, by vol) as standard practice in the region to maintain rapid growth. Trees were overhead irrigated with enough volume to maintain active growth which was three times daily in the growing season, less in the dormant season. Roots remained inside containers without rooting into the ground. Shoots were pruned once to maintain a dominant leader until harvested. In November 2009, distance between substrate and terminal bud on the leader was measured as tree height, and trunk diameter 15 cm (5.9 in) from substrate surface (caliper) trees was measured. Five trees with a trunk caliper closest to the mean caliper for each treatment were chosen for root excavation. A pruning saw was inserted vertically into the root ball on each tree 2.5 cm (1 in) inside the periphery of the 57 liter (15 gal) container. The saw was pushed up and down all around the root ball for two complete rotations (720 degrees) to ensure all roots were cut to the bottom of the root ball. The root ball was lifted out of the container and the peripheral 2.5 cm (1 in) of substrate and roots was peeled free and discarded. The bottom 2.5 cm (1 in) of the root ball was removed. Substrate was washed from the root system, including that within the volume of the propagation container with city water pressure and mechanical manipulation with hands. Each root system was labeled and photographed from the top and sides. Roots were measured for many attributes to characterize morphology (Table 2).

Two-way factorial analysis of variance in a randomized complete block design, with single-tree replicates of two planting depths and three root pruning treatments as main effects in each of 6 blocks, was used to analyze data from study one (2 depths × 3 pruning × 6 blocks = 36 trees per species) using SAS GLM procedure (SAS Institute, version 9.2, Cary, NC). Least squares means procedure was used to separate interaction means. One way analysis of variance in a completely randomized design was used to analyze data from the three root pruning treatments in study two. Main effect means were separated with Duncan's multiple range test in both studies when interactions were not significant.

Results and Discussion

Study 1: Height and caliper on Royal poinciana [110 cm (43 in) and 35 mm (1.4 in)] and trumpet-tree [149 cm (58.7 in) and 18.6 mm (0.7 in)] planted from 3.7 liter (1 gal) containers were not affected by root pruning. This suggests that cutting root balls, either by slicing or shaving followed by frequent irrigation typical for nursery containers, did not affect their growth or marketability under conditions of this study. Similar results were reported with the same two genera plus five other taxa when root balls on trees in 10 liter (2.6 gal) containers were shaved as they were planted into larger containers (21) or when root balls of live oak in 10 liter (2.6 gal) containers were vertically sliced when planted into larger containers (18). Krasowski (29) reported no difference in shoot growth in response to root pruning container grown liners as they were planted into field soil and Harris et al. (26) saw similar results with plants in larger containers.

Planting depth had no impact on Royal poinciana or trumpet-tree trunk caliper or tree height. Brown and Tilt

Table 2. Root [> 2 mm (0.09 in) diameter] attribute definitions for live oak trees in 57 liter (15 gal) containers measured at harvest[z].

- Percent trees with clearly visible imprint: a visual rating with 5 = no apparent imprint from the 3.7 liter (1 gal) root ball and 1 = trees with a clearly visible imprint.
- Percent trees with good root system: a visual rating with 5 = roots growing primarily radially away from the trunk with no large circling roots and 1 = most roots deflected down, up, or around at the position of the 3.7 liter (1 gal) container wall.
- Percent root culls: percent trees rated as culls at the position of the 3.7 liter (1 gal) container according to Florida Grades and Standards for Nursery Plants (1).
- Root ball symmetry: visual rating with 5 = a symmetrical root system with some deep and some shallow lateral roots and 1 = a one-sided root system or one with most roots growing downward.
- Number roots > 2 mm (0.09 in) top (or bottom) half of root ball: number of roots > 2 mm (0.09 in) diameter measured just beyond the periphery of the original 3.7 liter (1 gal) root ball that grew from the top half [7 cm (2.8 in)] or bottom half [7 cm (2.8 in)] of the original 3.7 liter (1 gal) root ball.
- Diameter 5 largest roots top (or bottom) half of root ball: mean diameter of the 5 largest roots measured just beyond the periphery of the original 3.7 liter (1 gal) root ball growing from the top or bottom half of the 3.7 liter (1 gal) root ball.
- Total deflected root length at position of 3.7 liter (1 gal) container: length of all roots > 2 mm (0.09 in) diameter growing around, up, or down at the position of the original 3.7 liter (1 gal) container wall.
- Percent radial roots 7 largest: percent of the 7 largest roots measured just beyond the periphery of the original 3.7 liter (1 gal) root ball that grew radially away from the trunk without deflecting or turning at the position of the original 3.7 liter (1 gal) container.
- Percent (or diameter) 7 largest roots growing from circling roots in 3.7 liter (1 gal) container: percent (or diameter) of the 7 largest roots measured just beyond the periphery of the original 3.7 liter (1 gal) root ball that grew primarily along the 3.7 liter (1 gal) container wall at a horizontal angle < 45 degrees prior to growing into the 57 liter (15 gal) substrate.
- Percent (or diameter) 7 largest roots growing from descending roots in 3.7 liter (1 gal) container: percent (or diameter) of the 7 largest roots measured just beyond the periphery of the original 3.7 liter (1 gal) root ball that grew primarily along the 3.7 liter (1 gal) container wall at a downward angle > 45 degrees prior to growing into the 57 liter (15 gal) substrate.

[z]Data reported in Table 7.

(8) and Fare (14) also found trunk and shoot growth was not affected by planting depth in containers except for *Cornus florida* which grew slower when planted deeply. Although Giblin et al. (15) found that two of four species grew less in caliper when planted in containers 15 cm (5.9 in) deep than at grade, there was no effect from planting depth on the other two species tested. In one of the most detailed studies on the subject, Bryan et al. (11) showed a mixed effect of planting depth on growth, with at-grade planting often showing good growth.

Shallow planting depth resulted in an increased percentage of Royal poinciana trees with good root systems (a visual rating of root ball quality), and compared to deeper planting, dramatically reduced the percentage of root culls due to roots growing in a circling manner or growing tangent to the trunk (Table 5, middle). Many of these roots grew up toward the substrate surface as they emerged from the 3.7 liter (1 gal) root ball giving rise to abundant circling and tangent roots close to the substrate surface in the 25 liter (6.6 gal) container. Gilman et al. (20) reported the presence of stem girdling roots and roots positioned tangent to the trunk in elm (*Ulmus parvifolia* Jacq.) and magnolia (*Magnolia grandiflora* L.) in 170 liter (45 gal) containers increased with planting depth from smaller containers. Roots growing in this manner provide less stability than radially oriented straight roots when loaded in tension (13, 24) or compression (19), and contribute to physiological stress should they become embedded into the trunk.

Relative to non-pruned Royal poinciana (Table 3) and trumpet-tree (Table 4), root pruning impacted percent trees with good root systems; percent trunk circled; and percent of the 5 largest roots that circled, descended, branched into a

Table 3. Analysis of variance of root attributes of Royal poinciana.

Source of variation	Trees with good root system (%)	Root culls (%)	Straight root rating (1–5)[z]	Mean diameter of 5 main roots [mm (in)]	Trunk circled (%)	No. roots top half (#)
Mean[y]	36	31	3.0	10.5 (0.4)		14
Root pruning	**[w]	n.s.	n.s.	n.s.	**	n.s.
Planting depth	**	**	**	n.s.	**	n.s.
Prune × depth	n.s.	n.s.	n.s.	n.s.	**	n.s.

Source of variation	No. roots bottom half (#)	Trees > 5 adventitious roots (%)	% of 5 largest roots circling	% of 5 largest roots descending	% of 5 largest roots ascending	% of 5 largest roots fanning	% of 5 largest roots straight
Mean	19	53	—	—	—	—	—
Root pruning	n.s.	n.s.	**	**	**	**	**
Planting depth	n.s.	n.s.	**	**	**	**	**
Prune × depth	**	n.s.	**	**	**	**	**

Note: see Table 1 for detailed description of attributes.

[z]5 = most roots straight; 1 = few roots straight.

[y]Mean of 36 trees for the non-significant (n.s.) sources of variation.

[x]Not significant at P < 0.05.

[w]Statistically significant at P < 0.05.

Table 4. Analysis of variance of root attributes of trumpet-tree.

Source of variation	Trees with good root system (%)	Root culls (%)	Straight root rating (1–5)[z]	Mean diameter of 5 main roots [mm (in)]	Trunk circled (%)	No. roots top half (#)
Mean[y]	39	44	2.8	4.8 (0.2)	—	8.5
Root pruning	**[w]	**	**	n.s.	**	**
Planting depth	n.s.	n.s.	n.s.	n.s.	**	n.s.
Prune × depth	**	**	n.s.	n.s.	**	n.s.

Source of variation	No. roots bottom half (#)	Trees > 5 adventitious roots (%)	% of 5 largest roots circling	% of 5 largest roots descending	% of 5 largest roots ascending	% of 5 largest roots fanning	% of 5 largest roots straight
Mean	11	14	—	—	—	4.2	—
Root pruning	**	n.s.	**	**	**	**	**
Planting depth	**	**	**	**	**	n.s.	**
Prune × depth	n.s.	n.s.	**	**	**	n.s.	**

Note: see Table 1 for detailed description of attributes.
[z]5 = most roots straight; 1 = few straight roots.
[y]Mean of 36 trees for the non-significant (n.s.) sources of variation.
[x]Not significant at P < 0.05.
[w]Statistically significant at P < 0.05.

fan-like manner, ascended, or grew straight at the interface of the 3.7 and 25 liter (1 and 6.6 gal) container substrates. Root pruning trumpet-tree also impacted percent trees graded as culls, straight root rating, and number of roots growing from the top and bottom half of the original 3.7 liter (1 gal) root ball. In addition to these main effects, numerous interactions between planting depth and root pruning were significant for both species.

Table 5. Effect of root pruning and planting depth, and interactions, on root system attributes of Royal poinciana in 25 liter (6.6 gal) containers.

Effect of root pruning averaged across planting depths[z].

Root pruning	Trees with good root system (%)
None	8[y]b[x]
Slicing	50a
Shaving	50a

Effect of planting depth averaged across root pruning treatments[z].

Planting depth [cm (in)]	Trees with good root system (%)	Root culls (%)	Straight root rating (1–5)[w]
2 (0.8)	61[v]a	6b	3.6a
10 (3.9)	6b	59a	2.4b

Effect of interaction of root pruning with planting depth.

Root pruning	Planting depth [cm (in)]	Trunk circled (%)	No. roots bottom half (#)	% of 5 largest roots circling	% of 5 largest roots descending	% of 5 largest roots fanning	% of 5 largest roots ascending	% of 5 largest roots straight
None	2 (0.8)	11[u]c	2a	26b	42a	16bc	6b	10c
	10 (3.9)	32b	17b	36a	37a	15c	9ab	3d
Slicing	2 (0.8)	11c	17b	3d	21b	15c	3c	58a
	10 (3.9)	33ab	19b	21b	22b	30a	10a	18b
Shaving	2 (0.8)	2d	16b	3d	12c	19bc	3c	63a
	10 (3.9)	39a	20ab	12c	3d	20b	3c	62a

[z]No interactions were significant for these factors.
[y]Based on 12 trees per treatment.
[x]Means in a column with a different letter are statistically different at P < 0.05.
[w]5 = most roots straight; 1 = few roots straight.
[v]Based on 18 trees per treatment.
[u]Based on 6 trees per treatment combination.

Either slicing or shaving root balls of Royal poinciana resulted in a dramatic six-fold increase in the percentage of trees judged visually to have a good root system averaged across planting depths (Table 5, top). The deeper planting depth [10 cm (4 in)] reduced, by an order of magnitude (10-fold), the percent of trees generating a good root system, and similarly increased the percent of trees graded as culls for all root pruning treatments (Table 5, middle). Straight root rating was also reduced by planting deeply. All other impacts of root pruning or planting depth depended on the level of the other factor. For example, shaving the root ball reduced the percent of trunk circled by roots, but only for trees planted 2 cm (0.8 in) deep indicating that shaving was not effective when trees were planted 10 cm (4 in) deep (Table 5, bottom). Planting the 3.7 liter (1 gal) root ball 10 cm (4 in) deep in the 25 liter (6.6 gal) substrate resulted in a larger percentage of the 5 largest roots growing in a circling fashion (around the trunk) compared to planting 2 cm (0.8 in) deep for all root pruning treatments. Slicing or shaving the root ball resulted in the least circling roots for both planting depths, but the effect was most pronounced for shaving (Table 5, bottom). Slicing or shaving reduced the percent of roots growing down (descending) at the position of the 3.7 liter (1 gal) container, but the reduction was greatest for trees that were shaved. Slicing or shaving increased the percent of roots that developed a fan-like pattern (percent of 5 largest roots fanning) at the position of the 3.7 liter (1 gal) root ball indicating that roots were growing away from the trunk in a more natural position, but only when planting depth was 10 cm (4 in). The least amount of roots ascended the 3.7 liter (1 gal) root ball periphery, and the largest number of roots grew straight away from the trunk, when trees were shaved when planted at either depth or when sliced and planted 2 cm (0.8 in) deep into the 25 liter (6.6 gal) container.

Either slicing or shaving trumpet-tree resulted in a higher straight root rating and fewer roots that grew upwards (ascended) at the position of the 3.7 liter (1 gal) container (Table 6, top). Shaving increased the number of roots growing into the 25 liter (6.6 gal) substrate from the top and bottom half of the 3.7 liter (1 gal) root ball compared to slicing, and from the top half of the root ball compared to the non-pruned controls. Increased root number and cross-sectional area of roots growing outside the original container has corresponded with better anchorage after planting landscape-sized trees (19, 23). Planting deeply [10 cm (4 in)] increased the number of roots growing from the bottom half of the 3.7 liter (1 gal) root ball and increased the percent of trees with more than 5 adventitious roots growing from the buried portion of the trunk compared to planting 2 cm (0.8 in) deep (Table 6, middle). Previous research with Cathedral Oak® live oak showed adventitious roots developed along the buried portion of the stem following deep planting into containers (17). All other impacts of root pruning or planting depth for trumpet-tree depended on the level of the other factor.

None of the trumpet-trees grown without root pruning had root systems rated as good; most were graded as culls due

Table 6. Effect of root pruning and planting depth, and the interaction, on root system attributes of trumpet-tree in 25 liter (6.6 gal) containers.

Effect of root pruning averaged across planting depth[z].

Root pruning	Straight root rating (1–5)[y]	% of 5 largest roots ascending	No. roots top half (#)	Roots bottom half (%)
None	1.7[x]b[w]	10a	7b	12ab
Slicing	3.2a	1b	8b	9b
Shaving	3.7a	2b	11a	13a

Effect of planting depth averaged across root pruning treatments[z].

Planting depth [cm (in)]	No. roots bottom half (#)	Trees > 5 adventitious roots > 2 mm (0.08 in) (%)
2 (0.8)	9[v]b	0a
10 (3.9)	13a	28b

Effect of interaction of root pruning with planting depth.

Root pruning	Planting depth [cm (in)]	Trees with good root system (%)	Root culls (%)	Trunk circled (%)	% of 5 largest roots circling	% of 5 largest roots descending	% of 5 largest roots fanning	% of 5 largest roots straight
None	2 (0.8)	0[u]c	100a	67a	48a	31b	7d	8d
	10 (3.9)	0c	83a	63ab	33b	27bc	22c	7d
Slicing	2 (0.8)	83a	0b	15cd	5d	39a	31b	22b
	10 (3.9)	17bc	67a	38bc	26c	39a	20c	16c
Shaving	2 (0.8)	50ab	0b	4d	3d	11d	56a	30a
	10 (3.9)	83a	17b	17dc	3d	24c	3b	36a

[z]No interactions were significant for these factors.

[y]5 = most roots straight; 1 = few roots straight.

[x]Based on 12 trees per treatment.

[w]Means in a column with a different letter are statistically different at $P < 0.05$.

[v]Based on 18 trees per treatment.

[u]Based on 6 trees per treatment combination.

to large roots circling the trunk near the substrate surface (Table 6, bottom). Shaving root balls prior to planting at either depth dramatically increased the percentage of root systems rated as good, and almost eliminated culls and circling roots. Slicing resulted in the same changes in the root system as shaving but only when trees were planted at the 2 cm (0.8 in) depth. In contrast to slicing root balls which increased the percent of the 5 largest roots that descended at the position of the 3.7 liter (1 gal) compared to non-pruned controls, shaving reduced occurrence of descending roots when trees were planted 2 cm (0.8 in) deep. Shaving trees when planting 2 cm (0.8 in) deep resulted in more roots growing in a fan-like manner into substrate of the 25 liter (6.6 in) container than all other treatment combinations. The fan-like arrangement resulted from the shaving process which severed roots by cutting tangent to the trunk encouraging pruning-induced new roots to grow away from the trunk (27). Shaving when planting at either depth resulted in more roots growing in a straight manner across the position of the 3.7 liter (1 gal) container than either of the other root pruning treatments. Although not measured, trees from this treatment appeared better secured in the 25 liter (6.6 gal) container than the other root pruning treatments. This fan-like and straight arrangement of roots growing from cut roots into landscape soil has been associated with improved anchorage 1, 2, and 3 years later (19, 23, 33). It appears clear that abundant large-diameter roots that grow straight from the trunk in a radial position without first curving down, around, or upward in the shape of the container are an important component for anchorage.

In general, Royal poinciana and trumpet-tree responded to both planting shallow and root pruning by increasing attributes associated with good root systems and reducing attributes associated with poor root systems. Shaving the root ball periphery was also found to be consistently effective at reducing circling and descending roots on 7 temperate and tropical species (two of which were Royal poinciana and trumpet-tree), and resulted in more straight roots in the root ball (21). Slicing root ball sides vertically in an effort to cut circling roots on live oak at each step-up to a larger container resulted in straighter roots inside the final 170 liter (45 gal) container root ball compared to not slicing (18). However, like trumpet-tree in the current study, significant root deflections on the interior of the root ball remained in that study following slicing due to abundant roots growing downward. Although vertical root ball slicing cut circling roots which probably slowed their growth, downward growing roots remained uncut because they were growing parallel to the slicing. The intact downward growing roots may have been encouraged to grow more in response to suppressed growth on cut circling roots. Shaving in the manner described appeared more effective than vertical slicing to encourage roots to grow straight away from the trunk, and to reduce the amount of circling roots, although this may add to cost of production. As landscape contract specifications include more detail about root system quality, growers will adapt techniques that result in fewer root deflections. This study shows that quality can be greatly improved by shaving the root ball periphery without affecting top growth.

Study 2: The roots and substrate growing on the periphery and bottom of the finished Cathedral Oak® 57 liter (15 gal) root balls were removed because the main objective of the project was to characterize the morphology of roots as they emerged from the liner; root mass and total root length was not of interest. The teased and shaved live oak root ball treatments resulted in identical trunk caliper [27 mm (1.1 in)] and tree height [261 cm (103 in)], and identical root system attributes (Table 7). The imprint in the root system from root deflection by the 3.7 liter (1 gal) container was clearly visible on trees without root treatment (Fig. 1), and only one of the five trees washed had a root system rated as good. All non-treated trees were rated as culls according to Florida Grades and Standards for Nursery Plants (1). The root pruning and teasing treatments both increased the number or roots > 2 mm (0.08 in) diameter and mean diameter of the 5 largest roots growing from the top half of the original 3.7 liter (1 gal) root ball. Moreover, both treatments cut in half the number of roots growing from the bottom half of the root ball. Total deflected root length at the position of the 3.7 liter (1 gal) container was an order of magnitude greater for non-treated trees compared to either one of the root treatments which clearly showed the effectiveness of both teasing and shaving the root balls. This mimicked the response of 7 other species to shaving root balls including live oak (21) and resulted in a root system with considerably more woody roots and root tips positioned close to the surface of the substrate of the 57 liter (15 gal) container (Fig. 1).

In previous research, trees with roots more evenly distributed top to bottom along the sides of the root ball became better anchored after planting than trees with a deeper root system in the root ball (9). In contrast, Weicherding et al. (35) found that trees with roots either teased away from the root ball periphery or those that received vertical cuts along the periphery resulted in nearly identical root systems as trees not treated. Because there were many roots > 5 mm (0.2 in) diameter at the root ball periphery in that test, they would not have been straightened out into the substrate of the larger container by the teasing treatment because they would be too stiff. Instead, most of the teased roots would have been small-diameter secondary roots, not structural roots capable of growing into the main root system. This probably explains the lack of impact from teasing in that study. Roots on live oaks in the current study had a smaller diameter and were flexible so they could easily be teased away from the periphery without breaking. Teasing may only benefit trees with small, flexible roots at the periphery.

Nearly all of the 7 largest-diameter roots growing from the 3.7 liter (1 gal) container root ball were oriented more or less straight or radially away from the trunk in response to root ball teasing or shaving (91 and 94 %, respectively, Table 7); whereas, only 31 percent grew in this manner on trees not treated. This indicated that both root treatments shifted a considerably portion of the woody part of the root system from inside the 3.7 liter (1 gal) root ball volume to the substrate of the 57 liter (15 gal) root ball. Repositioning more of the woody root length and mass into a horizontal orientation, and farther from the trunk, instead of downward should help the tree become more stable after planting (9, 19). Teasing or shaving roots from the periphery of the 3.7 liter (1 gal) root ball also prevented any of the 7 largest roots from growing into the 57 liter (15 gal) substrate from roots that circled or descended the 3.7 liter (1 gal) root ball (Table 7) indicating a root system comprised of straighter roots.

By almost every measure, root systems on teased, sliced, or shaved root balls of tested tree species had superior attributes

Table 7. Shoot and root attributes of finished Cathedral Oak® in 57 liter (15 gal) containers for three root treatments.

Root treatment	Trees with clearly visible imprint[z] (%)	Trees with good root system (%)	Root culls (%)	Root ball symmetry (1–5)[y]	No. roots > 2 mm (0.08 in) top half of root ball (#)	No. roots > 2 mm (0.08 in) bottom half of root ball (#)
None	100[x]a[w]	20b	100a	2.2	9b	12a
Teased	20b	100a	0b	4.4	16a	6b
Shaved	20b	100a	0b	4.4	18a	6b

Root treatment	Diameter 5 largest roots top half of root ball [mm (in)]	Diameter 5 largest roots bottom half of root ball [mm (in)]	Total deflected root length at position of 3.7 liter (1 gal) container [mm (in)]	% 7 largest roots growing radially
None	3.0 (1.2)b	3.9 (1.5)	771 (30.3)a	31b
Teased	5.4 (2.1)a	3.5 (1.4)	62 (2.0)b	94a
Shaved	5.2 (2.0)a	3.5 (1.4)	37 (1.5)b	91a

Root treatment	% 7 largest roots growing from circling roots in 3.7 liter (1 gal) container	Diameter 7 largest roots growing from circling roots in 3.7 liter (1 gal) container [mm (in)]	% 7 largest roots growing from descending roots in 3.7 liter (1 gal) container	Diameter 7 largest roots growing from descending roots in 3.7 liter (1 gal) container [mm (in)]
None	40a	3.8 (1.5)a	26a	2.4 (0.09)a
Teased	3b	1.0 (0.4)b	0b	0.0b
Shaved	0b	0.0b	0b	0.0b

Note: see Table 2 for detailed description of attributes.

[z]5 = visible imprint; 1 = no imprint from 3.7 liter (1 gal) container.

[y]5 = symmetrical; 1 = asymmetrical.

[x]Mean of 5 trees per treatment.

[z]Means in a column with a different letter are statistically different at $P < 0.05$.

compared to those growing in the non-pruned treatment. However, teasing appears to be appropriate only for root balls with small diameter roots on the periphery; i.e. trees in a particular container for a short period of time. Shaving root balls appears to produce a root system with fewer defects than vertical slicing, but unlike slicing it also works well on trees with larger, stiff roots at the periphery. Planting deeply in a container resulted in an increase in root attributes associated with poor quality. These results corroborate the work of others showing a benefit from cutting roots when shifting from one container to the next larger size, and from planting trees with the root flare at, or close to, the surface. As many others have found, caliper and height growth were not affected by any root pruning treatments.

Roots in 3.7 liter (1 gal) container not treated going into 57 liter (15 gal) container showing a visible container imprint.

Roots in 3.7 liter (1 gal) container teased going into 57 liter (5 gal) container showing no imprint from 3.7 liter (1 gal) container.

Roots in 3.7 liter (1 gal) container shaved going into 57 liter (15 gal) container showing little imprint from 3.7 liter (1 gal) container.

Fig. 1. One Cathedral Oak® tree in 57 liter (15 gal) container from each of the three root manipulation treatments. Note that only deep roots formed on non-treated plants; whereas, deep and shallow roots formed on treated trees.

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