Production Techniques for Highrise™ and Seedling Live Oak[1]

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Abstract

Cutting propagated *Quercus virginiana* 'QVTIA' Highrise™ PP #11219 and seedling live oak required the same amount of time to prune to a dominant leader in the nursery. Highrise™ live oaks were more uniform in caliper, height and root ball characteristics than the seedling crop. Finished seedling trees had larger caliper than cutting propagated Highrise™ but height was similar. Root pruning horizontal roots alone or in combination with placing root pruning fabric under the liner at planting reduced dry weight of roots in the root ball by reducing large-diameter root weight and increasing small-diameter root weight. Trees produced by both methods of root pruning survived the digging process better than non root-pruned trees in the summer digging season. Seedlings had more root weight in the root ball and a higher root:shoot ratio than Highrise™ live oak. But Highrise™ had a 45% greater small diameter root:shoot ratio than seedling live oak, and more Highrise™ survived the digging process than seedlings. Highrise™ may not need root pruning during production if dug in the dormant season.

Index words: tree nursery, production protocol, root ball, root pruning, shoot pruning.

Significance to the Nursery Industry

Cutting propagated live oak cultivars are coming into the nursery trade in the warmest climatic zones in the United States, but their root system and pruning requirements are largely unknown or undocumented. Root systems, caliper, and height on finished Highrise™ nursery stock were less variable than on seedlings. This was associated with a higher percentage of Highrise™ trees surviving the digging process. Root pruning live oak seedlings and Highrise™ lead to improved survival compared to non-pruned trees dug (harvested) in summer. All Highrise™ survived winter digging regardless of root pruning treatment. Shoot pruning requirements were nearly identical for Highrise™ and seedlings.

Introduction

Shade trees with the best quality are trained to one leader in the central portion of the canopy (1, 2, 3). This is accomplished in the nursery in a number of ways including subordination of codominant leaders (6, 11). At least three cutting propagated cultivars of live oak (*Quercus virginiana* Mill.) have been selected and named for their unique, consistent habit. This feature might make it easier to prune into a central leader form than live oaks grown from acorns. Fewer cuts and less time may be required to prune the cultivar to quality form in the nursery and landscape. The canopy on live oaks propagated from seed is extremely variable, requiring training and skill to prune correctly. Seedling grown trees end the production period with differing sizes and shapes making harvesting and marketing more difficult.

Root pruning of trees in fruit, forest, and landscape nurseries is an old and varied practice (14). It has been used as a horticultural tool to produce a sturdier tree, force development of a more compact, fibrous root system, retard top growth and increase transplant survival and post-transplant growth (16). Higher root:shoot ratios were induced by root pruning seedlings (4, 18), and were associated with improved post-transplant tree seedling performance (5). However, others report no benefit to survival and post-transplant growth from pre-transplant root pruning seedling-sized forest species (7, 16).

Only recently have the effects of root pruning on pre- and post-transplant growth of landscape-sized trees been studied. Gilman and Kane (12) hypothesized that post-transplant tree growth may be related to the distribution of roots among diameter classes within the root ball and that transplanted trees might benefit from treatments encouraging a high fine-root:coarse-root dry-weight ratio (17). Later studies indicated that the larger coarse roots found on field grown trees might be more beneficial than previously thought to transplant survival since trees from containers, with their abundance of fine roots, are more stressed following transplanting than field grown trees (9).

Live oak trees grown in sandy nursery fields often produce large roots angled steeply down just below the trunk (13). These large, deep roots can hinder harvesting operations with a tree spade because the blades do not always cut through them. This necessitates the extra labor of cutting those roots with a shovel during harvest and can result in loose root balls or tree death in certain cases. Root pruning during the nursery production period might generate a finer root system by reducing the number of large diameter roots and could improve survival when trees are dug.

Nursery grown trees have been marketed for their fibrous root system. For instance, *Magnolia grandiflora* Alta™ and 'Hasse II' are reported to have a more branched, fibrous root system than the species (personal communication, Select Trees, Inc. Athens, GA). Certain species within a genus have more fibrous root systems than others (8) and this could lead to better transplanting (17).

The objectives of this study were to: 1) compare root system responses of two live oak propagation types, seedlings and cuttings, from three root pruning treatments, 2) evaluate

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the impact of root pruning treatments and propagation type on digging survival in summer and winter, and 3) compare time required to prune the canopies of seedling and Highrise™ live oak to a dominant central leader in the nursery.

Materials and Methods

Treatments. On December 8, 1997, 135 3.7-liter (1 gal) liners each of seedling and Highrise™ live oak (*Quercus virginiana* Mill. 'QVTIA' Highrise™, PP #11219) were planted at a nursery in Levy County, FL, on 1.8 m (6 ft) centers within rows and 3.6 m (12 ft) between rows in a sandy soil (Orlando fine sand) and grown for 32 or 37 months. At planting, liner root balls were sliced from top to bottom about 2.5 cm (1 in) deep in four places around the plant to sever any potentially circling roots that could cause girdling as they expanded. No soil was placed over the root balls at planting. Three root-pruning treatments were applied to trees during a three-year field production period.

Root pruning treatments consisted of no root pruning, traditional hand spade root pruning, or placement of a 30.5 cm (12 in) square of a proprietary knit fabric (made of polyester fibers interlocking so the openings will not enlarge; Rootmaker Products Company, LLC, Huntsville, AL) directly under the root ball at planting combined with traditional hand spade root pruning. Spade root pruning was accomplished by slicing a square-tipped balling shovel 36 cm (14 in) long into the soil at an angle similar to that of a mechanical tree spade. North and South one-eigth circumference segments (12.5 percent of circumference each, totaling 25% circumference) were pruned in April 1999 20 cm (8 in) from the trunk and East and West one-eigth segments were root pruned in May. Root pruning was repeated in August (NW and SE segments) and September (NE and SW segments) 27 cm (11 in) from the trunk. The bottom of the hand spade did not reach far enough into the soil to overlap adjacent slices so any roots growing directly down under the trunk were not cut.

Trees received irrigation from one micro spray jet (Antelco 360 degree, Antelco Pty, Ltd, Murray Bridge, Australia), which delivered a 360 degree spray pattern, mounted 15.4 cm (6 in) above the ground set to apply water over the area of the root ball to be harvested — approximately a 81 cm (32 in) circle. Treatments were arranged in a randomized complete block design with 45 blocks. All 6 treatment combinations (2 propagation types × 3 root pruning treatments) were in each block totaling 45 × 6 = 270 trees.

Growing season daily irrigation volume [11.4 liters (3 gal)] was split into 3 applications (morning, noon and mid-afternoon) beginning in late March or early April, and dormant season irrigation was applied in one application to total 3.8 liters (1 gal) per day beginning in late November. All trees were staked at planting to 2.5 m (8 ft) tall solid galvanized steel 8 mm (5/16 in) diameter stakes. Staking was adjusted and maintained as needed to develop a straight central trunk. Trees were fertilized using 8–10–10 in April 1998. Thereafter they received 20–6–12 five to six times per year, March or April through September each year. Fertilizer amounts started at 130 g 8–10–10 per tree, then 32.5 g 20–6–12, increasing as trees grew to 130 g 20–6–12 in the first year, 260 g (first fertilization) to 390 g (last fertilization) in second year, and 390 g in the third year. Fertilizer was applied to the approximate area of the 81 cm (32 in) diameter root ball.

Shoots were pruned to develop and maintain a dominant central leader, to establish scaffold branches spaced at least 15.4 cm (6 in) apart, and to curtail aggressive upright branches on the lower 1.5 m (5 ft) of the trunk. All slower growing branches on the lower trunk were left intact during production. All lower branches were removed from the trunk in June 2000. Shoot pruning was done in July and September 1998, April and August 1999, and April and August 2000. The time required to prune each tree was recorded at each pruning. The need for a subordination cut (shortening a stem back to a lateral branch or simply heading the stem) on competing upright leaders in order to generate one dominant leader was also recorded at each pruning. Tree caliper at 15.4 cm (6 in) above the soil and tree height were recorded at planting and in July and December on each year. The same person pruned all trees at each of the six pruning times in the study. Presence of included bark was recorded for the two largest branches on 50 seedling-propagated and 50 Highrise™ trees in October 2001.

Root ball dissection procedure and measurements. Five blocks of 6 trees (30 trees total) were harvested July 11 through July 19, 2000, and their root systems dissected. Root balls to be dissected each day were dug with a hydraulic tree spade that removed a cone of soil 81cm (32 in) in diameter at the soil surface and 65cm (26 in) deep. Trunks were removed with a chainsaw, and soil was gently shaken and washed from the root systems. Washed, intact root systems were marked at 22 cm (9 in) and 43 cm (17 in) below the soil surface, to divide them into equal thirds by depth. All root ends greater than 2 mm in diameter that were severed by the tree spade were re-cut perpendicular to the long axis of the root 2.5 cm (1 in) from the tree spade cut. The diameter of these pieces was measured at the re-cut end. The number of cut ends in each of five diameter categories (2 to 5 mm, 5 to 10 mm, 10 to 15 mm, 15 to 25 mm, > 25 mm) was recorded for each depth increment. The rest of the root system, not including the original 3.7-liter (1 gal) liner, was divided into five diameter categories (< 5 mm, 5 to 10 mm, 10 to 15 mm, 15 to 25 mm, and > 25 mm) and dried at 70C for 7 days. Root dry weight was recorded by diameter category.

Digging procedure and measurements. To compare the effects of root pruning and propagation type on summer and winter digging survival, twenty complete blocks of 6 trees (20 × 6 = 120 trees total) were dug with an 81 cm (32 in) diameter hydraulic tree spade August 24 to August 31, 2000. The root balls were immediately wrapped in burlap, placed in 81 cm (32 in) wire baskets, and replaced in the holes from which they were removed. Regular irrigation was applied after digging to encourage survival. The remaining 20 blocks (20 × 6 trees = 120 trees) were dug and treated the same way January 30 to February 1, 2001. Mortality was recorded for six months after digging each set of trees.

Data analysis. Analysis of variance, Chi-Square, and contingency table analyses were performed using SAS statistical software (SAS Institute Inc., Cary, NC). A significance level of $P < 0.05$ was used for all analyses unless indicated.

Results and Discussion

Shoot pruning. Based on contingency table analysis and the Chi-Square statistic, the first time the trees were pruned

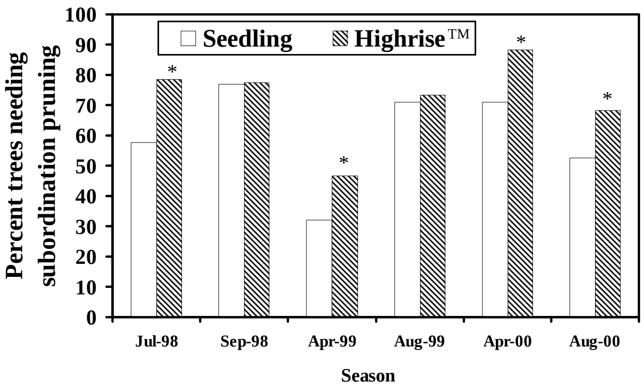

Fig. 1. Percent trees needing corrective subordination pruning cuts to encourage development of a dominant leader. * Indicates greater percentage of Highrise™ required pruning than seedlings based on pruning 135 trees on each type.

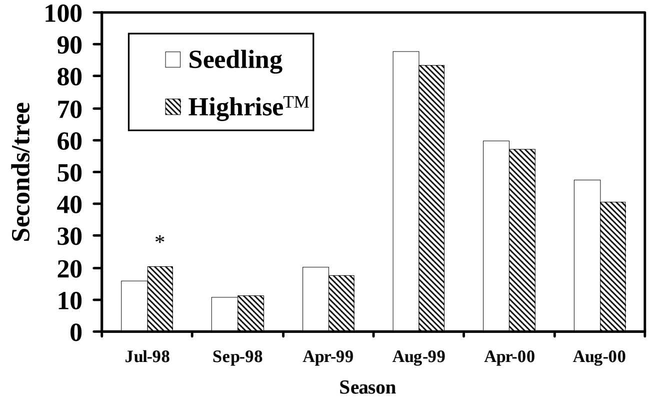

Fig. 2. Time required to prune Highrise™ and seedling live oak trees in the nursery to a dominant leader. * Indicates more time to prune Highrise™ than seedlings based on pruning 135 trees of each type.

in July 1998, more Highrise™ trees (78%) required subordination cuts on competing leaders to train them to a dominant leader than did the seedlings (58%). This was also true in April 1999, April 2000, and August 2000 (Fig. 1). This was not surprising since the Highrise™ tree was selected for its upright habit so many stems on young trees grow more or less upright parallel to each other. Even though Highrise™ required more subordination cuts, analysis of variance showed that only at the initial pruning (July 1998) did Highrise™ trees require more time to prune per tree (Fig. 2). Pruning times were comparable for both propagation types for the other five prunings.

Two annual prunings were required to develop nice canopies in these trees. Had the trees been pruned less frequently, large voids would have been created when codominant stems and branches were shortened with subordination cuts in order to produce a leader. In the first year and the early part of the second year, only stems and branches that competed with the leader were shortened. This was a fairly simple process requiring about 15 seconds per tree (Fig. 2). The second pruning in the second year required the most time. This is the time when trees were about 2.4 m (8 ft) tall with several main lateral branches forming in the permanent nursery canopy [1.5 m (5 ft) above the ground and higher]. Main lateral branches were spaced apart by shortening any that were within 15 cm (6 in) of other laterals. This is the technique used to help create the best quality trees (1). This process took much more time than simply shortening aggressive branches and stems in the lower portion of the trunk which was the main purpose of the first three prunings. Pruning in the third year took less time compared to the second pruning in the second year because good structure was well established. The cuts made in the third year simply maintained the structure developed in year two. It appears crucial that the second pruning in the second year be done correctly with your most highly trained employees for seedling and cutting propagated live oak. This might extend into the third year in cooler climates with a slower growth rate.

Summer and winter digging survival. Cutting propagated Highrise™ survived better (100%) than seedlings (93.3%) in the winter dig but not in the summer dig (Table 1). Trees that were root pruned by either method survived summer digging better than non root-pruned trees but there was no statistically significant effect in the winter dig. All Highrise™ not root-pruned and dug in winter survived; whereas only

Table 1. Survival of Highrise™ and seedling live oaks receiving three root pruning treatments during production then dug in either summer or winter.

	Significance of effect		% trees surviving	
Treatment	summer dig	winter dig	summer dig	winter dig
Propagation type	NS	*		
Seedling			90.0[z]	93.3[z]
Highrise™			93.3[z]	100.0[z]
Root pruning	**	NS		
Not root pruned			80.0[y]	92.5[y]
Spade pruned			97.5[y]	97.5[y]
Pruned with fabric			97.5[y]	100.0[y]

[z]Based on 60 trees dug.

[y]Based on 40 trees dug.

*Numbers in a column significantly different at $P < 0.05$

**Numbers in a column significantly different at $P < 0.01$

85% of non root-pruned seedlings survived the winter dig (data not shown).

Fabric placed under the liner in combination with traditional spade root pruning did not statistically increase survival compared to spade root pruning alone, probably because trees that were spade root pruned had such high survival rates (97.5%) compared to non-pruned trees (80% summer dig; 92.5% winter dig) (Table 1). However, only one tree (a seedling-propagated summer-dug tree) with fabric under the liner died following digging in this study or the companion study (13). Fabric under the liner might enhance survival for larger caliper trees because reaching the large roots with a hand shovel at the bottom of the root ball would be more difficult than it was to reach the deep roots on the smaller trees in this study. Post-transplant growth of surviving trees has been found to be similar regardless of root pruning treatment (10, 12) or other tree production methods (15).

Eight of 100 seedling branch unions had included bark whereas nine unions had included bark on Highrise™. This difference was not statistically significant.

Canopy and root ball effects. Seedling trees were significantly larger in caliper [6.07 cm (2.4 in)] than Highrise™ trees [5.19 cm (2 in)] three years after planting from liners, but there was no tree height difference. Highrise™ trees were more uniform in caliper [coefficient of variation (COV) = 7.1] and height (COV = 9.8) compared to seedlings (caliper COV = 15.8; height COV = 14.1). This indicated that the tree-to-tree variability was greater for seedling trees than Highrise™. Trees whose roots were not pruned were significantly taller [4 m (13.18 ft)] than trees whose roots were pruned traditionally without fabric [3.4 m (11.47 ft.)]. However, pruning with fabric under the liner combined with spade root pruning did not reduce height compared to non root-pruned controls. There was no significant difference in caliper among root pruning treatments. Perhaps the intense irrigation management in this study, which is typical in many southern shade tree nursery operations, was able to compensate for the potential growth reduction effects from root pruning typical for seedling forest nurseries (16).

Highrise™ produced more 2 to 5 mm diameter roots than seedling trees (Fig. 3). The increase in root number for Highrise™ was in the middle third of the root ball only. Seedlings had more roots at the edge of the root ball than Highrise™ for all of the larger size classes: 10.1 vs 6.6 for 5 to 10 mm roots, 4.3 vs 2.4 for 10 to 15 mm roots, and 0.9 vs only 0.06 for roots >25 mm diameter. However, there was no difference between Highrise™ and seedlings in total root number intersecting the edge of the root ball. This indicated that the Highrise™ cultivar of live oak had a more fibrous root system than seedlings. They both had the same number of roots at the edge of the root ball but Highrise™ had more of them in the small diameter class. More small-diameter and fewer large-diameter roots may have led to the increase in digging survival for Highrise™ compared to seedlings.

Root pruning either traditionally with a spade (59.1 total roots per tree) or with fabric under the liner combined with spade pruning (55.0 total roots per tree) resulted in greater root (2 to 5 mm diameter, 15 to 25 mm diameter, and total root number) number at the edge of the root ball than trees that were not root pruned (36.4 total roots per tree). Root pruning interacted significantly with soil depth for the number of largest roots (roots > 25 mm in diameter). As shown in Fig. 4**,** traditional spade root pruning eliminated all roots of this size in the top and middle portions of the root ball, but shifted them to the bottom of the root ball. This probably occurred because roots toward the top were cut with the spade during root pruning before they reached 25 mm diameter. Deeper roots could not be reached with the spade and this may have encouraged them to grow larger than 25 mm. The fabric at the bottom of the liner eliminated the deep large roots and the tree adjusted by shifting large roots to the top third of the root ball where they were easily cut with a spade. Some of these surface roots may have been missed (see Fig. 4) and not cut during root pruning operations so they were allowed to grow larger than 25 mm diameter. A more rigorous root pruning protocol, such as overlapping root-pruning patterns, might have cut all surface roots and eliminated these large roots.

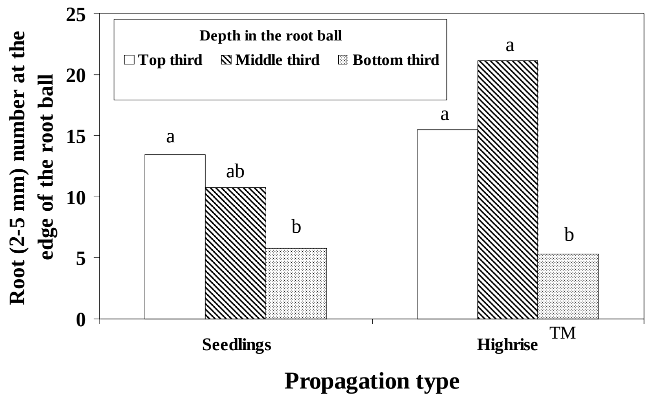

Fig. 3. Number of cut root ends 2 to 5 mm diameter for seedling and Highrise ™ live oak at different depths within the root ball. Note: Bars within a propagation type with different letters are significantly different at P < 0.05. Means based on 15 trees for each propagation type.

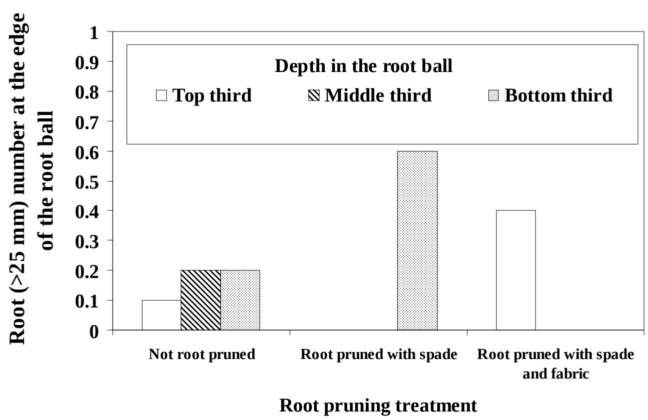

Fig. 4. Number of cut root ends >25 mm diameter at the outside edge of the root ball on seedling and Highrise™ live oak. Note: Means based on 15 trees for each propagation type.

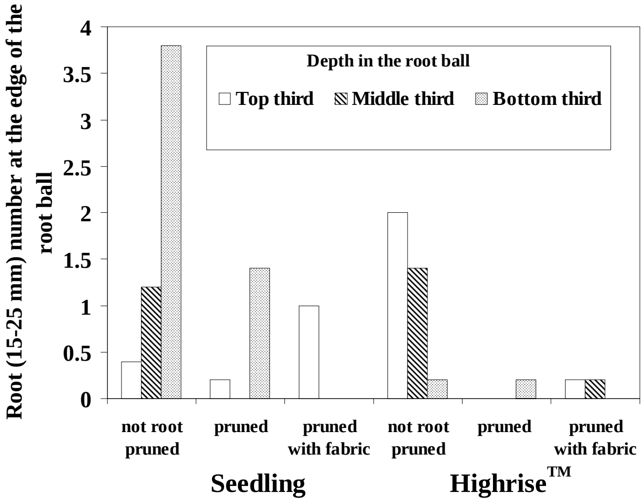

Fig. 5. Number of cut root ends 15 to 25 mm diameter at the outside edge of the root ball on seedling and Highrise™ live oak. Note: Means based on 15 trees for each propagation type.

The three-way interaction of root pruning by propagation type by soil depth was significant for roots 15 to 25 mm diameter intersecting the edge of the root ball. This showed that on non root-pruned seedlings the number of these large roots increased with increasing soil depth; the reverse was true for Highrise™ with most roots of this size close to the surface (Fig. 5). Root pruning Highrise™ with a spade almost eliminated large roots; this did not occur for seedlings which still had about 1.5 roots of this size in the bottom third of the root ball. Root pruning with fabric combined with spade root pruning eliminated all roots of this size in the bottom third of the ball on both seedlings and Highrise™. However, fabric pruned seedlings still had about one 15 to 25 mm diameter root in the top third of the root ball whereas roots of this diameter were rare on Highrise™ trees. The trees adjusted to the restriction in deep root growth caused by the fabric by shifting large roots to the soil surface. Highrise™ appears to produce few large diameter roots under any circumstances in this soil type.

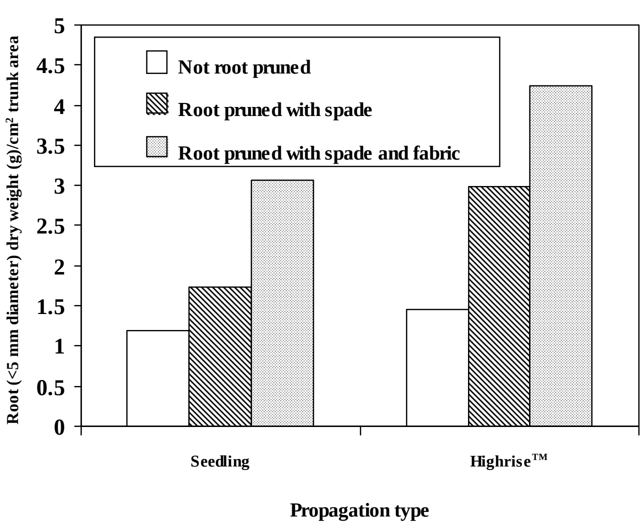

Fig. 6. Root dry weight (roots <5 mm diameter) per cm² trunk cross-sectional area for seedling and Highrise™ live oak. Note: Means based on 15 trees for each propagation type.

Total root weight in the root ball for seedlings and Highrise™ was greater for non root-pruned trees (seedlings = 835.6 g; Highrise™ = 390.2 g) than fabric pruned trees (seedlings = 421.0 g; Highrise™ = 245.6 g) (Table 2). However, traditional spade pruned trees had similar root weight as the non-pruned and the fabric pruned trees. Root pruning with fabric combined with spade pruning resulted in greater small-diameter (<5 mm) root weight than spade pruning alone, and spade pruning resulted in greater small-diameter root weight than no root pruning. Except for the smallest diameter roots (<5 mm diameter) seedling trees had significantly more root weight in the root ball than Highrise™ trees. Root weight for the <5 mm diameter roots was similar for both propagation types. Both root-pruning treatments shifted roots from the large diameter classes to the smaller diameter classes. Coefficient of variation for root weight inside the root ball was lower for Highrise™ (27.4) than seedlings (47.8) indicating less tree-to-tree variability in Highrise™ root systems.

Because seedling trees were larger in caliper than Highrise™ trees at the end of the 3-year production cycle, and root weights in the root ball were correlated with trunk

Table 2. Effect of root pruning on dry weight (g) of roots in the root ball in 5 root diameter size classes on seedling and Highrise™ live oak trees.

	Seedlings		
Root class diameter (mm)	No root pruning	Spade pruned	Pruned with fabric
2 to 5	37.70	50.42	74.38
5 to 10	58.86	67.90	63.22
10 to 15	118.72	98.68	76.74
15 to 25	310.32	139.36	54.36
> 25	310.04	310.18	152.26
total	835.64	666.50	420.96
	Highrise™		
	No root pruning	Spade pruned	Pruned with fabric
2 to 5	35.23	59.22	80.36
5 to 10	32.20	51.42	34.36
10 to 15	102.54	54.68	39.74
15 to 25	134.28	77.64	68.18
> 25	86.00	43.10	22.98
total	390.25	286.06	245.62
	Significance of treatments		
	Root pruning	Propagation	Prune × Propagation
2 to 5	**	NS	NS
5 to 10	NS	**	NS
10 to 15	*	*	NS
15 to 25	**	*	*
> 25	NS	**	NS

**Effect is significant at P < 0.01.

*Effect is significant at P < 0.05.

Note: Means based on 15 trees for each propagation type.

cross-sectional area, root weights were expressed as grams per cm^2 trunk cross-sectional area. This allowed an evaluation of the effect of treatments on root:shoot ratio. On this basis there were significant root pruning effects on root:shoot ratios in 2 root-size classes. Traditional spade root pruning resulted in greater (2.4) small-diameter root:shoot ratio (roots <5mm diameter) than no root pruning (1.3) on both propagation types. Placing fabric under the liner in addition to traditional spade root pruning resulted in still greater root:shoot ratio (3.7). In the 15 to 25 mm diameter size class, trees whose roots were not pruned produced more root dry weight per cm^2 trunk area (7.4) than those with spade pruned roots (4.5) or with fabric combined with spade pruning (3.0) indicating lower large-diameter root:shoot ratio for root pruned trees. Root pruning essentially shifted roots from the large diameters to the smaller diameters resulting in a greater small-diameter root:shoot ratio and reduced the large-diameter root:shoot ratio. This corresponded to increased digging survival.

Highrise™ trees produced greater fine root (<5 mm diameter) weight per cm^2 trunk area (2.89) than seedling trees (1.99) indicating a 45% larger fine-root:shoot ratio on Highrise™ (Fig. 6). Seedlings had a much greater (7.6) large diameter (>25 mm) root:shoot ratio than Highrise™ (2.3).

Non root-pruned trees had more total root ball weight than fabric pruned trees yet survival was lower for the non-pruned trees. Seedling trees also had more total root weight than Highrise™ yet survival was lower for seedlings. This indicates that root weight alone was not an important factor for survival, and other mechanisms are at work.

In summary, cutting-propagated Highrise™ and seedling live oak required the same amount of time to prune to a dominant leader in the nursery. The Highrise™ live oak crop was more uniform in caliper, height, and root ball characteristics than the seedling crop. In other words, there was less variation from one tree to the next for Highrise™.

Root pruning horizontal roots alone or in combination with placing root pruning fabric under the liner at planting reduced dry weight of roots in the root ball by reducing large-diameter root weight and increasing small-diameter root weight. This shift in roots corresponded with more trees surviving the digging process in the nursery, especially when summer digging.

Pruning horizontal roots with a square-tipped pruning shovel (spade pruning) reduced number of large roots in the top and middle portion of the root ball but did not reduce number of large roots in the bottom third of the root ball. Installing root-pruning fabric under the root ball when planting the liner eliminated this problem but did not correspond to statistically significant increased digging survival.

The largest-diameter roots on seedlings were located in the middle and bottom third of the root balls; whereas they were in the top and middle on Highrise™. Seedlings had more root weight in the root ball and a higher total root:shoot ratio than the cutting propagated Highrise™ live oak. But Highrise™ had a 45% greater small diameter root:shoot ratio (i.e., a more fibrous root system) than seedling live oak, and more Highrise™ survived the digging process than seedlings. Highrise™ did not require root pruning for 100% survival in the winter dig; whereas, only the root-pruning fabric placed under the liner at planting in combination with spade root pruning resulted in 100% survival in seedling live oak. The need for root pruning live oak during production in a field nursery might be reduced or eliminated by planting cutting-propagated trees.

Literature Cited

1. Anonymous. 1998. Florida grades and standards for nursery stock. Florida Department of Agriculture and Consumer Services. Gainesville, FL.

2. American National Standards Institute. 1996. American Standard for Nursery Stock. (ANSI Z60.1). Amer. Assoc. Nurserymen. Washington, DC. 57 p.

3. American National Standards Institute. 2001. American National Standard for Tree Care Operators — Tree, Shrub and Other Woody Plant Maintenance — Standard practices (ANSI A300). National Arborist Assoc., Manchester, NH.

4. Bacon, G.J. and E.P. Bachelard. 1978. The influence of nursery conditioning treatments on some physiological responses of recently transplanted seedlings of *Pinus caribaea*. Mor. var. *hondurensis* B&G. Australian For. Res. 8:171–183.

5. Benson, A.D. and K.P. Shephard. 1977. Effects of nursery practice on *Pinus radiata* seedling characteristics and performance: II. Nursery root wrenching. New Zealand J. For. Res. 7:68–76.

6. Costello, L. 1999. Training young trees for structure and form. Intern. Soc. of Arboriculture. Champaign, IL. (video)

7. Duryea, M.L. and D.P. Lavender. 1982. Water relations, growth and survival of root-wrenched Douglas-fir seedlings. Can. J. For. Res. 12:545–555.

8. Fare, D.C., C.H. Gilliam, and H.G. Ponder. 1985. Root distribution of two field-grown *Ilex*. HortScience 20:1129–1130.

9. Gilman, E.F., R.J. Black, and B. Dehgan. 1998. Comparing live oak planted from containers with those planted B&B. J. Arboriculture. 24:1–9.

10. Gilman, E.F. 2001. Effect of production method, irrigation and mycorrhizae on transplanted live oak. J. Arboriculture 27:30–39.

11. Gilman, E.F. 2002. An Illustrated Guide to Pruning. 2nd edition. Delmar Publishers. Albany, NY. 330 p.

12. Gilman, E.F. and M.E. Kane. 1990. Effect of root pruning at different growth stages on growth and transplantability of *Magnolia grandiflora*. HortScience 25:74–77.

13. Gilman, E.F., A, Stodola, and M.D. Marshall. 2002. Root pruning and irrigation in the nursery affects live oak root balls. J. Environ. Hort. 20:122–126.

14. Hawley, R.C. and D.M. Smith. 1954. The Practice of Silviculture. 6th Edition. John Wiley and Sons, NY. 525 p.

15. Marshall, M.D. and E.F. Gilman. 1999. Effects of nursery container type on root growth and landscape establishment of *Acer rubrum* L. J. Environ. Hort. 16:55–59.

16. Mullin, R.D. 1966. Root pruning of nursery stock. Forest. Chron. 42:256–264.

17. Struve, D.K., T.D. Sydnor, and R. Rideout. 1989. Root system configuration affects transplanting of honeylocust and English oak. J. Arboriculture 15:129–134.

18. Tanaka, Y., J.D. Walsted, and J.E. Borrecco. 1976. The effect of wrenching on morphology and field performance of Douglas fir and loblolly pine seedlings. Can. J. For. Res. 6:453–458.