Root Pruning but not Irrigation in the Nursery Affects Live Oak Root Balls and Digging Survival[1]

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Abstract

Irrigation placement and irrigation volume during field production of live oak (*Quercus virginiana* Mill.) in a sandy soil had no effect on trunk caliper [mean = 6.3 cm (2.5 in)] or tree height [mean = 3.8 m (12.4 ft)]. Root pruning had no impact on caliper and a slight (P < 0.06) impact on height. Irrigation placement and volume had little effect on number of cut roots at the edge of the root ball. Root pruning with a hand spade or in combination with root-pruning fabric placed under the liner at planting increased the number of roots at the edge of the root ball. Root pruning with fabric in combination with spade pruning increased the small-diameter (<5 mm) root weight:shoot ratio but reduced the total root weight:shoot ratio. Irrigation placement and volume during production did not affect summer nor winter digging survival. Trees that were not root pruned had poorer survival in the summer and winter digging seasons than those receiving either of the root-pruned treatments. In contrast, summer and winter survival was similar for root-pruned trees indicating that live oak can be dug in summer as well as the more traditional winter period as long as trees are root pruned during production. Trees pruned with fabric placed under the liner at planting in combination with spade pruning survived better than traditional spade root pruned trees.

Index words: irrigation placement, irrigation volume, transplanting, soil depth, nursery production, trees, root:shoot ratio.

Significance to the Nursery Industry

Some trees planted in a nursery with sandy soil can produce large horizontal and/or vertical roots that can make harvesting difficult. Root-pruning fabric placed at the bottom of liners when planting into the field nursery prevented development of large vertical roots. Inhibition of large vertical roots encouraged growth in roots close to the soil surface and was associated with excellent digging survival, even in August. Traditional lateral root pruning with a shovel also reduced the number of large diameter roots when trees were harvested at the 6.3 cm (2.5 in) caliper size and was associated with excellent digging survival. This data supports the hypothesis that increasing the ratio of small diameter to large diameter roots is important for coarsely-rooted field grown trees to survive the digging process. Total root weight per se was not important in predicting tree survival.

Introduction

Live oak trees grown in well-drained sandy nursery fields often produce large roots angled steeply down just below the trunk. These large roots can hinder harvesting the trees 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 extreme cases. Two practices that affect root system morphology that might be manipulated to control the direction and depth of root growth and size are root pruning and irrigation.

Root pruning of trees in fruit, forest, and landscape nurseries is an old and varied practice (13). 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). The timing, frequency, severity and location of root pruning are governed more by practical experience and tradition than by scientific studies. Only recently have the effects of root pruning on pre- and post-transplant tree growth been studied. Gilman and Kane (9) 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. Latter studies indicated that the larger coarse roots found on field grown trees might be very beneficial to transplant survival since trees from containers, with their abundance of fine roots, are more stressed following transplanting than field grown trees (11).

According to Kramer and Kozlowski (14), each species has a characteristic shoot:root ratio. Root pruning, while reducing shoot growth, stimulates root growth as the plant attempts to restore the pre-pruning shoot:root ratio (15, 17). Roots regenerated in response to root pruning originate primarily at or just behind the cut (5). However, a portion of regenerated roots can originate from at least 10 cm (4 in) behind the cut, depending on species (12). This probably accounts for the increase in fibrous roots within the root ball in response to root pruning reported for a number of species (9, 22). Higher root:shoot ratios were induced by root pruning seedlings (2, 21), and were associated with improved post-transplant tree seedling performance (4). However, others report no benefit to survival and post-transplant growth from pre-transplant root pruning of seedling-sized forest species (6, 16).

Drip irrigation is a common practice in the nursery industry. Compared to overhead irrigation it can reduce water usage significantly by increasing efficiency. In sandy, well-drained soils water moves down through the soil profile more than laterally, requiring 50 to 60% of the rooting zone to be irrigated by this method for production of agronomic crops (18). There is some evidence that the soil surface area to which a given volume of water is applied can influence root distribution of nursery grown trees. Gilman et al. (10) grew

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laurel oak (*Quercus laurifolia* Michx.) and 'Natchez' crapemyrtle (*Lagerstroemia indica* x *fauriei* Koehne) in fabric bags in a sandy soil with irrigation applied over varying surface areas beyond the area of an in-ground fabric bag. Confining irrigation to the area within the fabric bag resulted in more fine root (<5mm diameter) dry weight within the root ball on laurel oak. Crapemyrtle root growth was unaffected by irrigation placement.

Our objectives in this study were: 1) determine effects of root pruning in a field nursery on morphology of the root system in the root ball of seedling live oak (*Quercus virginiana* Mill.) trees, 2) determine influence of irrigation placement and volume during production on root system morphology, and 3) determine effects of root pruning and irrigation on summer and winter digging survival, and relate survival to root system morphology.

Materials and Methods

Treatments. On December 8, 1997, 540 3.8 liter (1 gal) liners of seedling (acorns) live oak (*Quercus virginiana* Mill.) were planted at a nursery in Levy County, FL (USDA hardiness zone 8), 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, the 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 potential circling roots that could cause girdling as they expanded. No soil was placed over the root balls at planting. Three root-pruning treatments, two irrigation placements, and two irrigation volumes 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) placed 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-eighth 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-eighth 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 one of two irrigation emitter types to effect two irrigation placements: a drip emitter (Toro-Ag DBK 08 E-2 emitter, 8 liters/hr at 25 psi, Toro Agricultural Irrigation, El Cajon, CA) which delivered water to the base of the trunk, or a 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. Growing season daily irrigation volumes, 22.7 or 11.4 liters, were 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 7.6 or 3.8 liters per day beginning in late November. The twelve treatments were arranged in a randomized complete block design with 45 single-tree blocks. All 12 treatment combinations (2 emitters × 2 irrigation volumes × 3 root pruning treatments) were in each block totaling 540 trees.

All trees were staked at planting to 2.5 m (8 ft) tall solid metal stakes 5/16 in diameter. 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. Shoots were pruned to develop and maintain a dominant central leader, to establish scaffold branches spaced at least 15 cm (6 in) apart, and to curtail aggressive lower branches. Shoot pruning was done in July and September 1998, April and August 1999, and April and August 2000. Tree caliper at 15.4 cm (6 in) above the soil and tree height were recorded at planting and in July and December of each year.

Root ball dissection procedure and measurements. Five blocks of 12 trees (60 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 81 cm (32 in) in diameter at the soil surface and 65 cm (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 recut 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 recut 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 (harvesting) procedure and measurements. To compare the effects of root pruning and irrigation treatments on summer and winter digging survival, twenty complete blocks of 12 trees (20 × 12 = 240 trees total) were dug with an 81 cm (32 in) 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 × 12 trees = 240 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. Three-way interactions were of no interest and were ignored.

Table 1. **Effect of irrigation volume, irrigation placement, and root pruning on survival of summer and winter dug 6.3 cm (2.5 in) caliper seedling-propagated live oak trees.**

	Significance of effect		% trees surviving	
Treatment	**summer dig**	**winter dig**	**summer dig**	**winter dig**
Irrigation volume	NS	NS		
Low			89.2[z]	93.3[z]
High			83.3[z]	92.5[z]
Irrigation placement	NS	NS		
Drip			86.7[z]	95.0[z]
Spray			85.8[z]	90.8[z]
Root pruning	**	**		
Not pruned			71.2[y]a[x]	86.2[y]a
Pruned with spade			90.3[y]b	92.5[y]b
Pruned with fabric and spade			97.5[y]c	100.0[y]c
Irrigation volume × placement	NS	NS		
Irrigation volume × root pruning	NS	NS		
Irrigation placement × root pruning	NS	*		

[z]Based on 120 trees dug for each treatment level.

[y]Based on 80 trees dug for each treatment level.

[x]Means in a column and within irrigation placement, volume, and root pruning with the same letter are not significantly different at $P < 0.05$.

**Significant effect at $P < 0.01$.

*Significant effect at $P < 0.05$.

Results and Discussion

Summer and winter digging survival. Survival data were analyzed with contingency analysis and Chi-Square. Irrigation placement and volume during production did not affect summer nor winter digging survival (Table 1). This indicates that live oak trees can be grown with the low volume irrigation rate in this sandy soil, and that either a drip emitter or spray stake can be used to deliver irrigation without affecting survival.

Root pruning during production had a significant impact on survival following digging. Trees that were not root pruned had poorer survival in both the summer and winter digs than those receiving either of the root pruned treatments. Placing root-pruning fabric under the liner combined with spade pruning resulted in significantly better survival than trees root pruned with only a hand spade. The interaction of season by root pruning was significant. This showed that trees not root pruned during production and then dug in summer had a poorer survival rate (71.2%) compared to non-pruned trees dug in winter (86.2%). In contrast, summer and winter survival was similar for root-pruned trees (90.3% was similar to 92.5%, and 97.5% was similar to 100%) indicating that live oak can be dug in summer as well as the more traditional winter period provided they are root pruned during production (Table 1).

Irrigation and root pruning effects. Irrigation placement and irrigation volume had no effect on trunk caliper [mean = 6.3 cm (2.5 in)] or tree height [mean = 3.8 m (12.4 ft)] during production in the nursery. Root pruning had no impact on caliper. However, both methods of root pruning appeared to reduce tree height [non-pruned = 4 m (13.4 ft); fabric and spade pruned = 3.8 m (12.3); spade pruned = 3.7 m (11.9 ft)] but only at the $P = 0.06$ level, which was not enough to consider statistically significant.

Irrigation placement and volume had little effect on number of cut roots at the edge of the root ball. Root pruning increased the number of roots at the edge of the root ball but this effect depended on depth in the root ball and diameter of the roots (Table 2). The interaction effect of root pruning and soil depth on number of cut root ends was significant in all size classes of roots. Trees that were not root pruned had more of their smallest roots (2–5 mm) in the top third of the rootball (11.2) than in the middle (4.75) or bottom (4.85) third. Trees whose roots were spade pruned had more of their 2–5 mm roots in the top (11.2) and middle (10.4) third than in the bottom (3.75) third of the root ball. Trees with fabric under the liner at planting combined with spade root pruning had more of their 2–5 mm roots in the top (22.05) third, fewer in the middle (14.05), and fewest in the bottom (4.85) third of the rootball. Fabric-pruning coupled with spade root pruning doubled (22.05 vs 11.2 g) the fine root production near the soil surface and reduced the amount of larger diameter roots in the bottom of the root ball. This might help explain the increased digging survival of fabric root-pruned trees compared to spade pruned and non root-pruned trees.

There were no differences in root number among soil depths for roots 5 to 10 mm in diameter on trees with no root pruning and trees with spade root pruning. For trees with fabric under the liner, most roots of this size class occurred in the top third of the rootball, fewer in the middle, and fewest in the bottom third. Trees with no root pruning and those with spade root pruning had more roots 10 to 15 mm and 15 to 25 mm in diameter in the bottom portion of the rootball than in the middle or top. However, trees with fabric under the root ball had more 10 to 15 mm roots in the top third of the rootball than in the middle or bottom, and no difference in number of 15 to 25 mm roots with depth. Roots > 25 mm in diameter were evenly distributed by depth in trees with no root pruning. Trees with spade root pruning had more of these

Table 2. Effect of root pruning and soil depth on number of root ends cut by mechanical tree spade at harvest on seedling propagated live oak trees in 5 root diameter size classes.

Root class diameter (mm)	No root pruning	Root pruned with spade	Root pruned with spade and fabric
	Top third of root ball		
2 to 5	11.20	11.20	22.05
5 to 10	3.85	3.65	6.15
10 to 15	1.40	1.55	2.50
15 to 25	0.95	0.65	0.85
> 25	0.20	0.15	0.55
subtotal root number	17.6	17.2	32.1
	Middle third of root ball		
2 to 5	4.75	10.40	14.05
5 to 10	2.40	3.35	4.25
10 to 15	1.30	0.85	0.95
15 to 25	0.80	0.35	0.20
> 25	0.45	0.00	0.05
subtotal root number	9.7	14.9	19.5
	Bottom third of root ball		
2 to 5	4.85	3.75	4.85
5 to 10	3.05	3.70	0.45
10 to 15	3.50	3.05	0.25
15 to 25	2.55	2.55	0.25
> 25	0.45	0.65	0.00
subtotal root number	14.4	13.7	5.8
total root number per tree	41.7	45.8	57.4
	Significance of treatments		
	Root pruning	Soil depth	Pruning × depth
2 to 5	**	**	**
5 to 10	NS	**	**
10 to 15	*	**	**
15 to 25	**	**	**
> 25	NS	NS	**
subtotal per section	**	**	**
total per tree	**	—	—

**Effect is significant at $P < 0.01$.

*Effect is significant at $P < 0.05$.

larger roots in the bottom third of the rootball than in the middle or top. However, trees with fabric under the root ball had more roots of this size in the top portion of the root ball than in the middle or bottom. This indicated that the fabric helped redistribute or shift roots closer to the soil surface where they could be pruned.

The interaction of irrigation volume with soil depth was significant only for number of cut root ends 5 to 10 mm in diameter (data not shown). Under low volume, roots of this size were evenly distributed with soil depth. Under high volume irrigation, most of this size class occurred in the top third of the rootball, fewer occurred in the middle third, and fewest occurred in the bottom third of the rootball.

There was no irrigation placement or volume effect on root dry weight inside the root ball except that the lowest volume irrigation resulted in less (164.2 g) 15–25 mm diameter root weight than the higher volume (216.7 g). Beeson and Gilman (3) also found no impact of irrigation placement on root (roots <10 mm diameter) dry weight inside the root ball. Total root dry weight (all root diameters combined) was reduced by root pruning with spade combined with fabric (506 g) compared to non-pruned trees (742 g). There were no other main effect differences in root weight. Root pruning with a spade combined with fabric resulted in more (82.2 g) small diameter (<5 mm) root weight than root pruning with a spade only (46.5 g) or no root pruning (36.8 g). Root pruning appeared to shift roots from the large-diameter to the small-diameter classes and this was associated with improved survival following digging.

Although there were no differences among treatments in trunk cross sectional area, root dry weight (in grams) per unit (cm^2) of trunk cross-sectional area (referred to as root:shoot ratio) was affected by root pruning treatment (Table 3). Pruning with fabric in combination with spade root pruning resulted in the greatest small diameter (<5 mm) root:shoot ratio (3.0); spade pruning had the second most (1.7); and the no root-pruning treatment had the least (1.2) root:shoot ratio. Fabric pruned trees had less large-diameter (15–25 and >25 cm) root:shoot ratio and less total root:shoot ratio compared to both other treatments. Fabric appears to dramatically shift roots to the smaller diameters.

It was apparent that the fabric placed under the liner at planting prevented roots at the bottom of the root ball from becoming large. Those roots that grew through the fabric were girdled as anticipated by the root-pruning fabric as they are when the fabric is used as an in-ground growing container. This fabric allowed root initials to grow through freely but the holes do not expand as roots increase in girth to become the same diameter as the hole. This inhibition of deeper roots encouraged growth in roots close to the soil surface, especially the smallest diameter roots, resulting in greater root number in the top third of the root ball.

Some roots grew around the edge of the fabric and then down at an angle. Most of these oblique roots were cut as the root systems were pruned with the hand spade. The result was a root ball with 1) fewer large roots at the bottom and 2) more small diameter roots at the top compared to non-pruned

Table 3. Root dry weight:trunk cross-sectional area ratios for 3 root pruning treatments.[z]

Root class diameter (mm)	No root pruning	Root pruned with spade	Root pruned with spade and fabric
	Root pruning treatment: root dry weight (g):trunk cross-sectional area (cm^2)		
2 to 5	1.2c[y]	1.7b	3.0a
5 to 10	1.8a	2.6a	2.4a
10 to 15	4.2a	4.0a	3.2a
15 to 25	7.3a	8.1a	3.9b
> 25	7.9a	7.8a	5.1b
All roots in root ball[x]	22.4a	24.2a	17.6b

[z]Each is a mean of 20 trees per root pruning treatment.

[y]Means in a row followed by different letters are significantly ($P < 0.05$) different from each other.

[x]Total weight of all roots in root ball except those in the original 1 gallon container.

plants. Excellent (significantly better than spade pruning or no root pruning) digging survival for fabric-pruned trees may be due to fewer large roots and more small diameter roots compared to the other two treatments. There were also more small-diameter roots on spade-pruned trees than non-pruned trees. In agreement with Struve et al. (20) and Struve and Moser (19) in USDA hardiness zones 5 and 6, this data supports the hypothesis that more small-diameter roots and less large-diameter roots (or increasing the ratio of small diameter to large diameter roots) is important for field grown trees to survive the digging process. For much smaller seedling trees, retaining many small diameter roots in the root ball on field grown trees has been correlated with increased shoot growth (1) or not correlated (23). Root pruned landscape sized trees [6 cm (2.5 in) caliper] have been shown to survive drought following transplanting to the landscape better that trees that were not root pruned during nursery production (7). Under adequate irrigation, which is not common in the landscape, trees not root pruned during production establish at the same rate as root pruned trees (7, 8).

In conclusion, irrigation placement and irrigation volume during field production had no effect on trunk caliper, tree height, number of roots at the edge of the root ball, or digging survival. Root pruning had no impact on caliper and only a slight ($P < 0.06$) impact on tree height during the production period, but increased the number of roots at the edge of the root ball. This effect depended on depth in the root ball and diameter of the roots.

Trees not root pruned had poorer survival following digging than those receiving either of the root-pruned treatments. Trees root pruned with a spade in combination with fabric placed under the liner at planting survived better than other treatments, perhaps due to the reduction in amount of large-diameter roots and the increase in small-diameter roots within the root ball. Despite having the least total root weight in the root ball and the smallest total root weight:shoot ratio, fabric pruned trees survived the best.

Trees not root pruned during production and then dug in summer had a poorer survival rate (71.2%) compared to those dug in winter (86.2%). In contrast, summer and winter survival was similar for root-pruned trees indicating that root-pruned live oak can be dug in summer as well as the more traditional winter period.

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