Pruning Lower Branches of Live Oak (*Quercus virginiana* Mill.) Cultivars and Seedlings during Nursery Production: Balancing Growth and Efficiency[1]

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Abstract

Tree production requires time for pruning to meet customer expectations, yet pruning can slow growth and increase the time (and cost) to prepare trees for market. Our research quantifies trade-offs between growth and pruning. In two separate locations, over two time periods, we found no difference in caliper growth between trees with only the largest one or two low branches removed at each pruning, compared with trees having all lower branches shortened. Acorn-propagated and Cathedral Oak® *Quercus virginiana* (Mill.) with all branches removed from the lower 1.37 m (4.5 ft) of trunk (temporary branches destined to be removed to produce a trunk clear of branches and a distinct canopy) by 18 months after planting had smaller caliper than other pruning treatments; however, pruning these branches had no impact on the Highrise® cultivar. Removing the largest one or two low branches at each pruning was the most efficient pruning method tested. Removing all temporary branches in February of the last year of production (2004) did not reduce caliper, height, or canopy spread compared to removing half in February and half in October. Since there was no difference in time required for pruning, we suggest removing branches early in the last growing season for more completely closed wounds and enhanced customer appeal.

Index words: tree nursery, production protocol, shoot pruning, temporary branches, *Quercus virginiana*, Highrise®, Cathedral Oak®, *Ramalina stenospora*, lichens.

Significance to the Nursery Industry

Tree growers are faced with balancing customer preferences and production costs against the return on investment. Often, customers expect, city arborists and urban landscapers specify, and horticultural grades and standards describe shade trees with canopies that begin well above ground level. Yet misapplied early pruning of temporary branches from the lower 1.37 m (4.5 ft) of trunk can potentially slow tree growth and reduce quality, while pruning near the point of sale can leave an unattractive stem. This study provides information to help maximize efficiency of pruning field and container-grown live oak seedlings and cultivars. During our research, we also observed variation among treatments in lichen density on tree stems and the effects of tropical storm force winds on root firmness and degree of leaning.

Introduction

Tree pruning crafts canopy structure and shape by removing and shortening branches and encouraging growth in selected areas of the crown. Misplaced and ill-timed pruning can lead to wood defects and exterior scars, but proper pruning can be essential for a tree's marketability, health, structural integrity, and symmetry as outlined in nursery stock standards (1, 2) and landscape industry standards (1, 7). Trees grow and maintain their health with energy provided through the products of photosynthesis, and generally, increased leaf area increases photosynthesis and growth (5). Since pruning reduces the leaf area of a tree, pruned trees are considered slower growers than unpruned trees. Still, greater leaf area does not always equate to more growth. Under some conditions, trees may respond to pruning by increasing the rate of photosynthesis in the remaining branches, and this can increase the rate of tree growth (3, 13). Trees regularly lose branches through self-pruning when the energy gained from leaves on a branch is less than the energy required to maintain the health of the branch, usually because of shading or mechanical damage (6, 17, 18).

Finding the optimum balance of maximum tree growth, minimal pruning time, and ideal tree form is a challenge for shade tree growers, and the balance may vary not only from species to species, but from one cultivar to the next. We know from studies of orchard trees and timber trees that this balance is also a concern for maximizing fruit production or wood production. Although trees may respond to moderate pruning with temporary increased photosynthetic rate on remaining foliage (18), this increased rate results in greater leaf area, not greater tree size as measured in trunk diameter or stem caliper growth (19, 23). In studies of peach (*Prunus persica*) production, researchers found that severe pruning can reduce tree growth and fruit yields (e.g., 22). In other studies, forest researchers interested in pruning to improve timber quality (by reducing knots in tree stems) have provided information on the effects of pruning on a number of species. For example, Funk (9) reduced crown size to 60% of the original leaf area without decreasing the tree diameter growth rate. Forest researchers have also found that some timber species self-prune (dead branches fall off), reducing the potential for decay after pruning (21).

Industry standards for highest quality shade trees include both pruning for a single leader and for clearance above ground level (1, 2, 14, 15). Nursery owners often prefer to avoid large scars by pruning young trees, removing temporary branches that grow too low to become part of the permanent nursery tree canopy (10). Unfortunately, if too many branches are pruned or removed at one time, growth may be slowed and tree trunks may be weakened. Growers have tried

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using tree shelters to eliminate branches low on tree trunks, but after the shelters were removed, some species could not support their own weight due to weak trunks or poor roots (4, 12, 16). Another technique to avoid the need for extensive pruning is to select cultivars with growth forms that are closer to the ideal standard. Both the live oak (*Quercus virginiana* Mill.) cultivars named Highrise® and Cathedral Oak® grow with a habit that could reduce the need for pruning codominant leaders to maintain a single central leader.

Our objective in this research was: 1) to demonstrate the impact of retaining branches on the lower 1.37 m (4.5 ft) of the trunk on tree growth rates for field and container-grown nursery trees 2) to quantify the pruning requirements for live oak seedlings and cultivars and 3) to address the trade-off between leaving temporary branches to store carbon in young nursery trees and pruning those branches for efficiency and aesthetic reasons.

Materials and Methods

We conducted Experiment I on acorn-propagated live oak (referred to as seedlings) and two cutting-propagated cultivars. Later, the experiment was refined and refocused on a single cultivar for Experiment II.

Experiment I. In January 2001, we planted 104 #1 (3.8 liter) liners of each of the following: seedling (acorns) live oaks, 'QVTIA' Highrise® PP # 11219, and 'SDLN' Cathedral Oak® PP #12015 at Marshall Tree Farm in Levy County, FL (USDA hardiness zone 8). Trees were placed in a single field 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 36 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 potentially circling roots that might cause girdling. No soil was placed over the root balls at planting.

Trees received irrigation through 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. Growing season daily irrigation volume (22.7 liters) was split into 3 applications (morning, noon and mid-afternoon) beginning in late March or early April; dormant season irrigation was delivered in one daily application of 7.6 liters beginning in late November.

All trees were staked at planting to 2.5 m (8 ft) long solid metal wire 8 mm (5/16 in) diameter. Staking was adjusted and maintained as needed to develop a straight central trunk. In April 2001, we fertilized at a rate of 130 g per tree using a Graco slow-release granular formula 8:10:10 ($N:P_2O_5:K_2O$; Graco Fertilizer Company, Cairo, GA). Thereafter we applied Graco 18:4:10 ($N:P_2O_5:K_2O$) five to six times per year, from March or April through September each year. Fertilizer amounts started at 32.5 g of 18:4:10 ($N:P_2O_5:K_2O$) per tree, increasing as trees grew to 130 g in the first year, 260 g (first fertilization) to 390 g (last fertilization) in second year, and 390 g per tree in the third year.

In all treatments, shoots above 1.37 m (4.5 ft) on all trees were pruned identically to develop and maintain a dominant central leader, to establish scaffold branches spaced at least 15 cm (6 in) apart, and to suppress upright lower branches. All shoot pruning, including the treatments described below, was done in July and September 2001, April and August 2002, and April and August 2003. Trunk caliper at 15.4 cm (6 in) above the soil and tree height were recorded at planting and in December of each year. We summed the time required to prune each tree at each pruning to determine total pruning time.

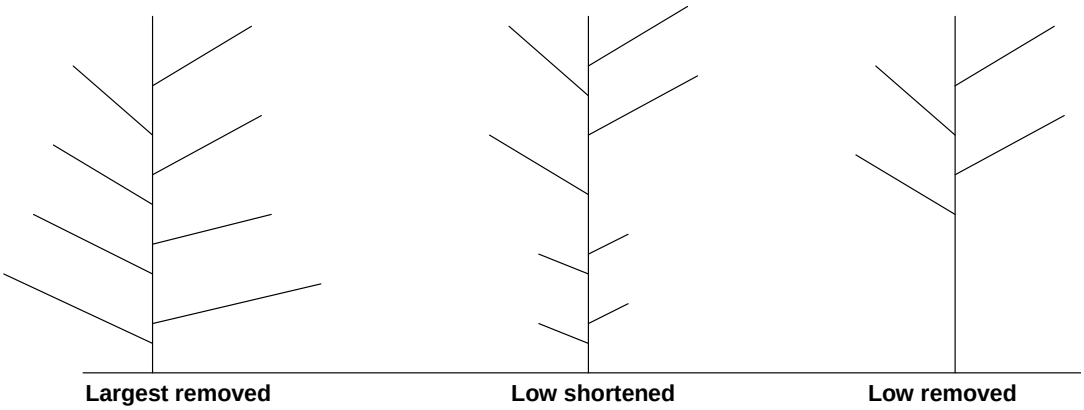
Lower branch pruning treatments. In January 2001, just before planting all trees, we removed 1/2 the length of all branches that were rapidly growing upright and competing with the leader. At each pruning, all branches that originated on the lower 1.37 m (4.5 ft) of the trunk on all trees were cut in a flat plane parallel to the ground 1.37 m (4.5 ft) from the ground. This point was just below the lowest part of the developing permanent nursery canopy. The following pruning treatments on branches of the lower 1.37 m (4.5 ft) of trunk were completed by the same person to standardize procedures (Fig. 1):

1) Largest removed: All branches within 20 cm (8 in) of the soil line were removed at the first pruning; at each subsequent pruning, we removed the largest one or two branches on the lower 1.37 m (4.5 ft) of the trunk. All low branches were removed August 2003. Rationale: This strategy allows photosynthesis to occur on low branches, and keeps the number of pruning cuts to a minimum and pruning wounds small by removing the largest branches at each pruning.
2) Low shortened: All branches within 20 cm (8 in) of the soil line were removed at the first pruning; at each subsequent pruning, we removed 1/2 the length of all branches, creating a cylinder of low branches centered on the lower 1.37 m (4.5 ft) of the trunk. All low branches were removed August 2003. Rationale: This strategy allows photosynthesis to occur on low branches.
3) Low removed: All branches within 52 cm (20 in) of the soil line were removed at the first pruning; at each subsequent pruning we removed all branches from an additional 30 cm (12 in) of trunk until all branches in the lower 1.37 m (4.5 ft) of trunk were removed (this occurred by August 2002); and at each pruning we also removed 1/2 to 2/3 of the length of the most aggressive two or three lower branches. All low branches were removed by August 2002. Rationale: This treatment simulates current nursery practice in many regions of the U.S. and serves as a comparison for the experimental treatments.

Experimental design and data analysis. The three pruning treatments were arranged in a randomized complete block design with 33 blocks for each of the three taxa for a total of 3 treatments × 3 taxa × 33 blocks = 297 trees. One-way ANOVA and Duncan's MRT were performed on each taxa individually using SAS (SAS Institute Inc., Cary, NC, 2004) to separate pruning treatment effects. Taxa were not to be compared with each other. A significance level of $P < 0.05$ was used for all analyses.

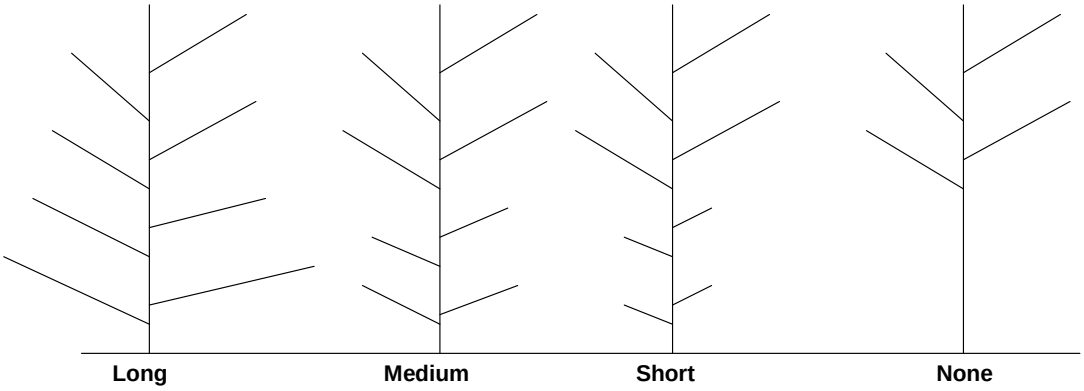
Experiment II. In August 2001, we planted eighty cutting-propagated #1 liners of Cathedral Oak® in a field with sandy soil (Millhopper sand) and the same number into #15 smooth-sided, black plastic containers 50 m (165 ft) from the field plot. Both field and container trees (160 total) were located at the University of Florida Great Southern Tree Conference demonstration site in Alachua County, FL (USDA hardiness zone 8), spaced on 2.4 m (8 ft) centers in eight rows 3.6 m (12 ft) apart. Irrigation and fertilizer appropriate for field or container production were applied, rather than a single pro-

Experiment I



Largest removed : longest 2-3 low branches removed at each pruning
Low shortened: remove ½ the length of low branches
Low removed: all branches on the lower 1.37 m (4.5 ft) removed by 2 ½ years after planting.

Experiment II



Long: longest 1-2 temporary branches removed twice/year
Medium: temporary branches cut to 25.4 – 30.5 cm (10-12 in) long twice/year.
Short: temporary branches cut to 7.6 – 10.2 cm (3-4 in) long twice/year.
None: all branches on the lower 1.37 m (4.5 ft) removed by 2 years after planting.

Fig. 1. Graphic representation of pruning treatments in Experiments I and II.

tocol for both production methods. The differences reflect standard nursery production methods for the two techniques. These different protocols should not limit our ability to detect differences in growth among pruning treatments, because in other studies, we found that production method had no impact on early growth of live oak in the nursery (11). In addition, we did not intend to make direct comparisons between production methods.

All trees were irrigated three times daily in the growing season, less often in the cooler months. Field trees received irrigation through one drip emitter (Toro-Ag DBK 08 E-2, 8 liters/hr at 25 psi, Toro Agricultural Irrigation, El Cajon, CA) which delivered water to the base of the trunk. Container trees received irrigation through two irrigation emitters (Roberts Irrigation Products, SS-AG160BLK, San Marcos, CA) per container, then spray stakes (Netafim Irrigation, Inc., 01SSBK-B, Fresno, CA) were used after trees were potted into smooth-sided black #45 containers in December 2002. Substrate in containers was a 5:4:1 (by vol) pine bark:peat:sand compost (Florida Potting Soil, Inc., Orlando, FL). All trees were pruned to one central leader and secured to 3 m (10 ft) long, 9.5mm (3/8 in) diameter galvanized metal wire stakes on May 14, 2002.

Field-grown trees were fertilized using 16:4:8 ($N:P_2O_5:K_2O$; Parker's Super Soilife, Chemsico Inc., Division of United Industries Co., St. Louis, MO). In January 2002, the amount applied was 65 g; in May 2002, 210 g; and July 2002, 300 g. Thereafter, trees received 400 g three times per year, in February or March, May or June, and August or September in each of the following years. Container trees were fertilized with 17:7:8 ($N:P_2O_5:K_2O$; Nutricote, Arysta LifeScience, San Francisco, CA) until 2005. The amount was 211 g in December 2001, May 2002, and February 2003. They received 203 g in June 2003 and February 2004. In March

and June 2004, 105 g were applied. In 2005, Peters 20:20:20 ($N:P_2O_5:K_2O$; The Scotts Company (formerly OM Scott and Sons Company) Marysville, OH) was applied at the rate of 1 g/liter approximately once per week from April through July, then once a month in August and September. The first two applications were 900 ml; all others were 1800 ml. In May, an additional 203 g 17:7:8 (Nutricote) were applied.

Pruning treatments. Beginning in May 2002 and continuing until October 2004, branches were pruned on the lower 1.37 m (4.5 ft) of the trunk of 80 container and 80 field trees by one of four techniques. The same person pruned all trees. In all treatments, the portion of the tree above 1.37 m (4.5 ft) was pruned identically, to a single central trunk, on the same day that lower branches were pruned to treatment specifications. Low-branch pruning treatments included none, short, medium, and long low branches.

Trees were pruned as follows (Fig. 1):

1) None (none of the low branches remained after pruning): All branches on the lower 40.6 cm (16 in) (August 2002), 71 cm (28 in) (October 2002), 115 cm (45 in) (May 2003), 1.37 m (4.5 ft) (August 2003) were removed; remaining branches in the lower 1.37 m (4.5 ft) were cut to 7.6–10.2 cm (3–4 in) long at each pruning. Any emerging sprouts were removed from the lower 1.37 m (4.5 ft) in May and August 2003 and 2004.
2) Short (low branches shortened to form a narrow cylinder): All branches on lower 15 cm (6 in) (August 2002) and 30 cm (12 in) (October 2002) were removed; branches on the lower 1.37 m (4.5 ft) of trunk were cut to 7.6–10.2 cm (3–4 in) long in May and August 2002 and 2003; one or two of the largest branches were removed from the lower 1.37 (4.5 ft) in August 2003; all lower branches were removed February 2004 on even numbered trees and half the lower branches (the largest ones) were removed on odd numbered trees; all remaining temporary branches on the lower 1.37 m (4.5 ft) of trunk were removed October 2004.
3) Medium (low branches shortened to form a wide cylinder roughly three times longer than the 'Short' treatment): All branches on lower 15 cm (6 in) (August 2002) and 30 cm (12 in) (October 2002) were removed; branches on the lower 1.37 m (4.5 ft) of trunk were cut to 20.4–30.5 cm (10–12 in) long in May and August 2002 and 2003; one or two of the largest branches were removed from the lower 1.37 m (4.5 ft) in August 2003; all lower branches were removed February 2004 on even numbered trees and half the lower branches (the largest ones) were removed on odd numbered trees; all remaining temporary branches were removed October 2004.
4) Long (only the longest 1 or 2 branches were removed): All branches on lower 15 cm (6 in) (August 2002) and 30 cm (12 in) (October 2002) were removed; the longest one or two branches on the lower 1.37 m (4.5 ft) of trunk were removed back to the trunk May and August 2002 and 2003; all lower branches were shortened to 50.1–60.1 cm (20–24 in) long May and August 2003; all lower branches were removed February 2004 on even numbered trees and half the lower branches (the largest ones) were removed on odd numbered trees; we removed all remaining temporary branches October 2004.

After two strong tropical storms passed through the research plots in fall 2004, field-grown trees were rated for trunk leaning (1 = no lean, 2 = slight lean, 3 = more lean) and root firmness (1 = firm, 2 = loose, 3 = very loose), which was determined by pushing back and forth on the trunk. We also assessed both container and field grown trees to determine the density of lichens (*Ramalina stenospora*) on trunk bark in fall 2004 (0 = few to none; 1 = some; 2 = moderate; 3 = many).

Tree measurements. On all pruning dates, we recorded the total time required to prune each tree's canopy to develop and maintain a dominant central leader, to establish scaffold branches, to shorten rapidly growing upright branches, and to prune lower temporary branches. Tree height, caliper at 15.4 cm (6 in) above soil, and canopy spread were recorded for all trees at planting and in November or December of each year. We also counted the number of pruning wounds that were not closed on the lower 1.37 m (4.5 ft) of the trunk at the end of the study (fall 2004).

Experimental design and data analysis. The experiment was a complete block design with 10 replicates (trees) in each of 4 pruning treatments in 2 blocks for a total of 80 trees in the field. The same design was used for the 80 trees produced in containers. Container trees were grown in a plot 50 m (160 ft) from the field grown trees. Evaluations of root firmness, leaning, and lichen cover were based on the average of ratings from observations by two independent researchers. Analysis of variance, Duncan's MRT and chi^2 were performed using SAS statistical software (SAS Institute Inc., Cary, NC, 2004). When data were inappropriate for analysis of variance, chi^2 was used. The significance level of $P < 0.05$ was used for all analyses.

Results and Discussion

Experiment I. By 18 months after planting, seedlings and Cathedral Oak® with all lower branches removed (low removed) had smaller caliper than other pruning treatments; however, temporary branch pruning treatments had no impact on Highrise® caliper development (Table 1). This may have resulted from sparse branching on the lower portion of the trunks on this particular set of Highrise® liners; this lack of lower branches does not appear indicative of the cultivar (11). There was no significant difference in caliper growth between trees with the largest one or two low branches removed (largest removed) and those with shortened low branches (low shortened) for any taxa tested. For both cultivars, the largest removed treatment required significantly less pruning time during the three year production period than the low shortened. The trunk caliper produced per minute of pruning was also higher for the largest removed than for the low shortened treatment on all three taxa. Thus, removing only the largest one or two low temporary branches at each pruning was the most efficient pruning method on these live oaks.

In another study, we found that cutting propagated *Quercus virginiana* Highrise® and seedling live oak required the same amount of time to prune to a dominant leader in the nursery (11). Data from the current study indicate that caliper per pruning minute showed a similar pattern among treatments for Cathedral Oak®, Highrise®, and seedling live oak (Table 1) with largest removed having a higher ratio than low shortened ($P < 0.05$).

Some nursery growers continue to remove low branches on very young trees early in the production period for a variety of reasons, including avoiding large scars. To better understand the effects of early pruning of low branches on

Table 1. Final caliper, time required for pruning, and final caliper per minute of pruning from 2001 through 2003.

Treatment	Cathedral Oak®	Highrise®	Seedlings
	2003 Final caliper (cm)[w]		
Largest removed[z]	7.60a	5.75	7.44a
Low shortened[y]	7.43a	5.9	5.62ab
Low removed[x]	6.26b	5.7	4.70b
	2001–2003 Total pruning time (min)[v]		
Largest removed[z]	6.65a	5.35a	6.48a
Low shortened[y]	8.08b	7.17b	6.97a
Low removed[x]	6.43a	5.25a	5.25b
	Ratio (caliper (cm)/pruning minute)[u]		
Largest removed[z]	1.14a	1.07a	1.15a
Low shortened[y]	0.92b	0.82b	0.81b
Low removed[x]	0.97ab	1.09a	0.89ab

[z]Lower branches 8" from bottom removed at first pruning; the 2–3 largest temporary branches removed twice/year.

[y]Lower branches 8" from bottom removed at first pruning; half the length of all temporary branches removed twice/year.

[x]Lower branches 20" from bottom removed at first pruning and an additional 12" was removed at each subsequent pruning until the lower 4.5 ft was clear; 1/2 to 2/3 length of aggressive temporary branches removed at each pruning.

[w]Caliper at the end of the experiment (Dec 2003); means in a column with the same letter were not significantly different.

[v]Mean number of minutes spent pruning throughout the experiment (2001–2003); means in a column with the same letter are not significantly different.

[u]Mean caliper per minute of pruning time; means in a column with the same letter are not significantly different.

growth, pruning efficiency, and stem qualities, we designed Experiment II with Cathedral Oak®. This cultivar showed a response to low branch pruning treatment, and there was less variability among these clonal trees (data not shown) than with trees grown from seed (11).

Experiment II. Pruning time, height and caliper were least for trees with all low branches removed (none), and caliper was largest on medium low branch treatments (Table 2). Final canopy spread of Cathedral Oak® was not affected by temporary branch pruning treatments (data not shown). Removing only the largest one or two temporary branches (long) appears to be most efficient because it resulted in greater mean caliper (6.69 cm for container-grown; 8.24 cm, field) with a medium pruning time (8.38 and10.42 minutes respectively). However, tree growth per pruning minute was similar for all four low branch management strategies (Table 2).

Removing all temporary branches from the clear trunk in February of the last year of production (2004) did not reduce caliper, height, canopy spread or pruning time, compared to removing half in February and the other half in October (data not shown). Since there was no difference in time required to prune the trees, it is probably more efficient to remove branches early in the last growing season, allowing wounds to close more completely and enhance customer appeal. This also saves a trip to the field.

The abundance of long low branches on the trunk appeared to help build strength in the structural root system resulting in less trunk lean and firmer attachment to the soil following strong tropical storm force winds in late 2004 (Table 3). Trees with all low branches removed within 18 months after planting had significantly fewer open pruning wounds than other treatments, but given the slower caliper growth and susceptibility to wind damage of trees in this treatment, our research suggests the benefit of a smoother trunk is a costly one.

There were differences among treatments in lichen growth along trunks of Cathedral Oak®. Lichen cover can be of interest to the nursery industry because customers sometimes mistakenly think that lichens are a sign of disease, lack of vitality, or weakness, but in fact, loss of lichen populations has been used as an indicator of air pollution (20). We found mean lichen cover greatest on trees with temporary branches removed early for both field and container-grown trees (Table 3). Increased light exposure on stems with lower branches removed could explain the increase in lichen cover. In a study of edge effects on epiphytic lichens, increase in some lichen species was attributed to increased available light (8).

The diversity in responses to pruning in this study suggests that the story is not as simple as might be expected. Removing low temporary branches on live oak early in production has the advantage of requiring less time to prune, producing fewer noticeable wounds, and perhaps providing trees with more customer appeal. Unfortunately, these trees grow more slowly, appear to have weaker roots, and have greater lichen cover.

Table 2. Mean caliper and height, time required for pruning over the production period 2001–2004, and ratios of final size to total pruning time for field and container-grown Cathedral Oaks®.

Treatment	Caliper (cm)		Height (m)		Total pruning time (min)		Caliper (cm)/ pruning minute		Height (m)/ pruning minute	
	Container	Field	Container	Field	Container	Field	Container	Field	Container	Field
None[z]	6.33a	7.17a	3.55a	4.33a	7.53a	8.73a	0.84	0.82	0.47	0.50
Short[y]	6.51ab	7.80b	3.81b	4.67b	9.15b	11.27bc	0.71	0.69	0.42	0.41
Medium[x]	6.74b	8.41c	3.64a	4.73b	9.13b	12.38c	0.74	0.68	0.40	0.38
Long[w]	6.69b	8.24bc	3.66a	4.64b	8.38b	10.42b	0.80	0.79	0.44	0.45

[z]None: all branches on the lower 1.37 m (4.5 ft) removed by 2 years after planting.

[y]Short: temporary branches cut to 7.6–10.2 cm (3–4 in) long twice/year.

[x]Medium: temporary branches cut to 25.4–30.5 cm (10–12 in) long twice/year.

[w]Long: longest 1–2 temporary branches removed twice/year.

Note: Means in a column with different letters indicate statistical differences.

Table 3. Mean ratings of trunk appearance on field-grown and container Cathedral Oaks® and stability of field-grown trees for each low branch treatment.

	Lichen cover[z]		Tree lean[y]	Root firmness[x]	Unclosed wounds[w]	
Treatment	Container	Field	Field	Field	Field	Container
None	1.45b	2.45b	1.45b	1.58b	5.95a	7.00a
Short	0.83a	0.89a	1.33b	1.58b	25.65b	16.63b
Medium	0.68a	1.08a	1.35b	1.58b	27.50b	20.16b
Long	1.10ab	1.08a	1.00a	1.13a	27.80b	17.60b
Chi-square	26.69 p < 0.0001	59.51 p < 0.0001	15.08 p = 0.0017	12.38 p = 0.0062	41.80 p < 0.0001	24.86 p < 0.0001

[z]Lichen cover rating: 0 = few; 1 = some; 2 = moderate; 3 = abundant; n = 20 per treatment in containers; n = 19 per treatment in the field grown trees for all means. Means within a column with the same letter are not significantly different.

[y]Tree lean rating: 1 = none; 2 = some; 3 = more.

[x]Root firmness rating: 1 = firm; 2 = loose; 3 = very loose.

[w]Mean number of unclosed wounds.

We found the most efficient technique was the long low branch treatment (few temporary branches shortened and only the longest one or two branches removed at the time of semi-annual formative pruning for leader and canopy development) until the last year of production when all temporary branches (from lower 1.37 m (4.5 ft) of trunk) were removed. Research to fine tune the trade offs between pruning, growth, root firmness, and aesthetics of trees should continue to be a priority among horticulturists to assist growers in meeting expectations of customers for high quality, attractive trees.

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