Effect of Tree Shelters on Growth and Gas Exchange of Four Tree Species Under Field and Nursery Conditions[1]

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Abstract

One-year-old seedlings of sawtooth oak, white oak, green ash and flowering dogwood were evaluated to determine the effect of tree shelters on survival, growth and gas exchange. Trees were grown under both field and container nursery conditions. Shelters had a significant impact on survival of field-grown trees, but not on containerized, nursery-grown seedlings. Overall survival was approximately 75 and 40% for sheltered and non-sheltered, field-grown trees, respectively. Sheltered plants had approximately a 90% survival rate and non-sheltered trees exhibited approximately 80% survival in a nursery situation. In the field, sheltered trees had greater height growth and biomass production than non-sheltered trees. However, sheltered plants exhibited a decrease in total biomass in the nursery study, the majority of which was reflected in an overall 62% reduction in root production in the sheltered trees. Photosynthesis of sheltered trees averaged 65% of non-sheltered trees and internal leaf CO_2 was approximately 11% greater in sheltered trees. Shelters appear to benefit field-planted seedlings by providing physical protection and shade therefore, enabling the tree to better survive stresses from ambient conditions. In nursery situations, shelters may only be helpful in training attractive trees with less labor.

Index words: tree shelters, tree tubes, biomass, seedling growth, photosynthesis.

Chemicals used in this study: Roundup™ (glyphosate), Rout™ (oryzalin + oxyfluorfen).

Species used in this study: white oak (*Quercus alba* L.); sawtooth oak (*Q. acutissima* Carruthers); green ash (*Fraxinus pennsylvanica* Marsh.); and flowering dogwood (*Cornus florida* L.).

Significance to the Nursery Industry

Results from this study indicate that tree shelters increase growth and survival of certain tree species under field conditions. Tree shelters, however, did not improve growth and survival of containerized trees. Increased growth and survival may prove beneficial to field-stock (bare-root), nursery-crop producers, but may not be useful with containerized stock. A cost comparison of expenses related to field and container production of trees with and without shelters may be helpful to nursery producers interested in using tree shelters during nursery crop production.

Introduction

Tree shelters are plastic, translucent cylinders placed around tree seedlings for protection, environmental enhancement, and improved survival and growth (1, 2, 17). The idea behind the development of tree shelters (10) began in Great Britain in 1978, resulting in the Tuley Tube (16). About one million shelters were in use in 1983–1984, and this number has increased dramatically in recent years (14, 16).

Research has mainly focused on improving survival and early growth of tree seedlings (1, 4, 7, 15, 17). First available in the United States in 1989, tree shelters accelerate the growth of some tree species (15, 17). Shelters are also reported to protect seedlings from injury due to lawnmowers (2, 14), herbicide drift (15), and wildlife browse (1).

At present, oaks (*Quercus spp.*) have generally exhibited the greatest increases in growth of the species tested (10, 16, 17). Ponder (12) noted that shelters do not affect the growth potential of the locale, that is, the shelter will not overcome a poor site/species combination. However, tree shelters can be especially useful in establishing a site-adapted species to a poor quality location (4, 18). Shelters tend to prolong the growing season for the seedling, giving it more degree-days in which to grow (12) and longer chlorophyll retention (9). This factor may result in a decrease in cold hardiness of some species (5).

Kjelgren (3) grew Kentucky coffee tree (*Gymnocladus dioica* L.) in containers with shelters to study water relations in sheltered trees. He reported increased air temperature, vapor pressure and 70% less solar radiation, suggesting that trees respond to shelters as they do shade. He also deemed trunk diameter growth to be insufficient for trees grown in tree shelters. West et al. (17) reported that shelters had a negative effect on basal diameter growth of flowering dogwood (*Cornus florida* L.) and Chinese elm (*Ulmus parvifolia* Jacq.) after two years growth in the field, and a positive effect on diameter growth of swamp chestnut oak (*Q. michauxii* Nutt.) during the first growing season. After three growing seasons there were no differences in diameter growth between sheltered and non-sheltered trees for all 10 tree species that were tested.

Most research on tree shelters has been conducted to evaluate success in harvested forest regeneration or land reclamation. Inadequate upland oak regeneration after a harvest has been a problem in the south-central hardwood region of the United States (1, 9, 12, 13). Planting efforts have been unsuccessful due to wildlife browse, competition and physiological factors. Some researchers (1, 9) have suggested us-

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ing tree shelters as an integral part of forest regeneration of hardwood seedlings.

Due to their ability to protect trees in regeneration efforts, tree shelters should also prove useful in urban reforestation (2, 17). Jones et al. (2) determined tree shelters provided a low cost alternative to larger, more expensive transplants, and were suitable for planting in certain urban settings (undeveloped portions) in southern U.S. cites. Shelters have been used to establish small trees, and at least one study indicates that small, transplanted seedlings may out-perform larger transplants over time (8).

Nursery growers may benefit from planting trees they intend to grow to larger sizes using tree shelters. West et al. (17), working with several tree species in Alabama, found that shelter-grown trees had accelerated growth, better survival and better form than non-sheltered trees. Additionally, sheltered trees have been reported in certain situations to reduce water stress, therefore potentially decreasing irrigation costs (7).

Our overall goal in this study was to determine if tree shelters affected overall survival and growth of selected tree species, and to develop a better understanding of the physiological mechanisms underlying the benefits of shelter use. Specific objectives were: 1) determine whether tree shelters improve growth and survival of field-planted and container-grown seedlings; 2) determine if four tree species commonly used in southern cities differ in their response to tree shelters; and 3) determine impacts of shelters on leaf gas exchange.

Materials and Methods

Field study. Eight, uniform, one-year-old, bare-root seedlings of four species [sawtooth oak (*Q. acutissima* Carruthers), green ash (*Fraxinus pennsylvanica* Marsh.), flowering dogwood and white oak (*Q. alba* L.)] were randomly field planted in four blocks totaling 32 seedlings each in April 1994 and harvested in December. Plastic tree shelters were placed around four seedlings of each species in each block at random. Trees were harvested in December of 1994, and the study was repeated in 1995. Each study was conducted at the Alabama Agricultural Experiment Station on the Auburn University Campus, Auburn, AL (USDA Hardiness Zone 7). The study site used was an eroded, east facing slope with Typic Hapludult soils (Pacolet Series), with a dense sod of grasses and forbs. Site characteristics are described in greater detail in West et al. (17). The site was used as a peach orchard [*Prunus persica* (L.) Batsch.] until 1992.

Tree tubes used were polyethylene tree shelters (TreePro® company, Lafayette, IN). Shelters were 8.9 cm (3.5 in) diameter, 122 cm (48 in) tall, and pre-drilled at three locations so that plastic lock ties could attach the shelter to a stake. The stakes were 3.8 cm (1.5 in) outside diameter schedule 40 PVC pipe cut into 152 cm (59.8 in) lengths. Trees were mulched with 0.05 m^3 (0.07 yd^3) pine bark spread in a 30-cm (11.8 in) radius around each seedling. The area was mowed on a regular basis. No supplemental irrigation was supplied during the study. Roundup™ herbicide was used as needed to control weeds directly adjacent to the shelters.

Heights and basal stem diameters were measured and recorded at the time of planting (initial) and the end of the growing season in 1994. Tree height was measured using a meter stick from 1 cm (0.4 in) above-ground line to the tip of the living terminal shoot. If the terminal leader died during the growing season, height was measured to the tip of the dominant lateral shoot. Due to this factor, negative height growth was calculated in some cases. Basal diameters were measured using digital calipers. Trees were harvested at the end of each growing season and fresh weights determined, then oven-dried [60–70C (140–158F), 2–3 days] to a constant weight. Only biomass data for 1995 are reported. An accidental fire in 1994 destroyed all biomass samples.

Nursery study. Four, uniform, one-year-old bare-root seedlings of the same species used in the field studies (sawtooth oak, white oak, flowering dogwood and green ash) were randomly planted in each of four blocks in 18.9 liter (5 gal) containers in April 1995. Tree shelters were placed around two of each species in each block at random. Trees in containers were potted in pine bark screened to 0.95 cm (0.37 in). Micromax™, dolomitic limestone, and Osmocote™ were incorporated at 0.9 kg (1.98 lbs), 3.5 kg (7.7 lbs), and 0.6 kg N respectively per m^3 (1.3 lbs/yd^3). One week after planting, Rout™ herbicide was applied at 1 g (0.4 oz) per container and reapplied per label recommendation. Each seedling was labeled as to block and sample. Seedling containerization aided in the in the measurement of shelter impact on root growth. Trees were produced under nursery conditions and irrigated to reduce water stress as a component of tree survival. At the termination of the study all trees were harvested (roots, stem and branches) and dried to determine plant biomass above and below ground.

To gain a better understanding of the physiological mechanisms behind any growth alterations, leaf gas exchange for each seedling was measured on one randomly selected, fully-mature, mid-canopy leaf, mid-morning and mid-afternoon (approximately 1000 and 1400 h, respectively), on a typical, partly cloudy summer day (July) using a LI-COR 6250 Portable Photosynthesis System (LI-COR, Inc., Lincoln, NE). Ambient temperatures varied less than 1C (1.8F) over the course of the measurements. Ranges for environmental conditions over the two observation periods were: photosynthetically active radiation (186.1–814.7 $\mu E \cdot m^{-2} \cdot sec^{-1}$), leaf temperature (27–32C, 81–90F), chamber temperature (28–32C, 82–90F), CO_2 (368–405 ppm), and RH (50–69%).

Experimental design and statistical analysis. The field experiment was organized as a factorial design with two shelter treatments (sheltered and non-sheltered) and four species arranged as a randomized complete block with four blocks and four tree replications per factorial combination [(2 treatments × 4 seedlings per treatment × 4 species × 4 blocks = 128 seedlings (16 trees/species/shelter treatment)], and repeated over two growing seasons (1994 and 1995). Growth data were analyzed by paired *t*-tests ($p \leq 0.05$) between shelter treatments (shelter vs non-shelter) by year. Due to non-normal distribution of the data, % survival was analyzed at the end of each growing season by chi-square analysis ($p \leq 0.05$). The % survival per block between treatments was compared in the analysis ($n = 4$) both years of the study. Due to differences in the source of trees obtained and variability of the data, the 1994 and 1995 field experiments were analyzed separately.

A randomized block design with treatment combinations of two tree shelter treatments and 4 tree species was employed in the nursery study. The experimental design consisted of four blocks with two replications (trees) per shelter

Table 1. Percent survival of four tree species grown under field conditions with and without shelters during the 1994 and 1995 growing seasons.[z]

	% Survival			
Species	Sheltered	Non-sheltered	Sheltered	Non-sheltered
Sawtooth oak	100a	67b	81a	50b
Green ash[y]	17a	25a	88a	44b
White oak	92a	42b	75a	56b
Flowering dogwood	83a	25b	50a	0b[y]
Overall mean	73a	40b	73a	38b

[z]Treatment means in each year followed by the same letter are similar (χ-square) at $p \leq 0.05$; n = 4 (n = 3 in 1994 due to elimination of one block because of suspected vandalism).

[y]No survival due to poor seedling quality.

treatment [2 treatments × 2 seedlings per treatment × 4 species × 4 blocks = 64 seedlings (8 trees/species/shelter treatment)]. Biomass and gas exchange data were analyzed by analysis of variance (ANOVA) and mean separation was performed using LSD ($p \leq 0.05$). Percent survival was analyzed by chi-square (n = 4) at the end of the growing season (1995).

Gas exchange data were collected by removing one twist-tie from the shelter, placing the cuvette next to the shelter and inserting a leaf through the shelter opening into the chamber. This procedure was done in an effort to limit leaf response to environmental changes and provide a more accurate measurement of changes in gas exchange that may occur within chambers.

Results and Discussion

Weather data. Total rainfall for 1994 (140 cm, 55.1 in) was similar to the 30-year average (144 cm, 56.7 in) for the Auburn area (NOAA, pers. comm.), however, the 1995 value was 25 cm (9.8 in) < the 30-year average. Average monthly temperatures for 1995 were greater than both the 1994 and 30-year averages (NOAA, pers. comm.). Average monthly temperatures in 1995 were at least 5C (9F) higher than temperatures recorded in 1994 for all months during the growing season.

Survival. Shelters had a positive impact on survival of the four species of young trees grown under field conditions during 1994 and again in 1995 (Table 1). No species × shelter interaction occurred during the study, therefore, the data are presented both by and across species. Overall, tree survival was 73% in 1994 and 1995 for sheltered seedlings and 40 and 38% in 1994 and 1995, respectively, for non-sheltered trees. These results were similar to those observed by West et al. (17). After two years, they reported that overall survival of the ten tree species tested was approximately 85% and non-sheltered trees 50%. The low survival that we observed regarding green ash in 1994 may be explained by the desiccated condition of the seedlings upon receipt.

Sheltered trees grown under field conditions had a greater survival percentage than unsheltered trees (approximately 35% both years), and due to labor costs of replanting, are probably worth consideration for this reason alone. Tree shelters may be a relatively inexpensive alternative to other methods for tree establishment in urban environments. Replacement of dead trees is time consuming and expensive. Jones et al. (2) reported planting costs were significantly lower for tree shelters compared with other planting methods.

Increased relative humidity (11) and reduced transpiration rates (5) in shelters should also aid in seedling establishment. Tree shelter microclimate is similar to that of a greenhouse (6). This may explain, in part, why sheltered trees survive better in certain locations (7).

In the containerized nursery study, shelters did not have a significant impact on overall survival of trees (data not shown). Although not significant, dogwood survival was 37% lower in non-sheltered vs sheltered treatments. Trees in the nursery study were under ideal growing conditions, and not subjected to any water stress, therefore, the ameliorating effects of the shelters would have less significance on seedling survival.

Although there were no differences in survival of sheltered and non-sheltered seedlings in the container nursery study, nursery managers may consider shelters as tree training devices. Observations from a three-year study on field-grown trees (West, personal observation) indicate that shelters may produce an attractive tree with limited investment in pruning and staking labor. Containerized, nursery-grown trees may or may not follow this trend. More research needs to be conducted to explore financial benefits of tree shelter use in the nursery production industry.

Growth. In 1994, the sheltered field-grown trees performed better regarding overall height growth (Table 2). Trees on average, grew more than 17 times taller in shelters. Height growth was significantly greater ($p \leq 0.05$) for sheltered sawtooth oaks and green ash, but not white oak and dogwood. The mean change in height for sawtooth oaks in a shelter was more than 11 times greater than for sawtooth oaks outside the shelter. The mean height change for ash inside shelters was +10.5 cm (4.1 in) vs –15.0 cm (5.9 in) for trees grown without shelters. No significant differences in height growth were observed for white oak or flowering dogwood. White oak was previously reported (2, 17) to grow better in tree shelters. Although the data were not significant (probably due to variability among individual trees) a trend in increased growth in shelters (p = 0.12) did exist. West et al. (17) found that shelters did not have a positive influence on dogwood growth after three years in the field. In general, oaks have performed better than other species in tree shelters (16, 17). Sawtooth oak appears to be very responsive to tree shelters as demonstrated in our study and other reports (2, 17).

Table 2. Mean height growth of four tree species grown under field conditions with and without shelters during the 1994 growing season.[z]

	Height growth (cm)[y]	
Species	Sheltered	Non-sheltered
Sawtooth oak	39.92a	3.59b
Green ash	10.50a	–15.00b
White oak	15.50a	–0.50a
Flowering dogwood	–4.40a	–5.50a

[z]Means with the same letter in a row are similar at $p \leq 0.05$ LSD.

[y]Negative numbers reflect die-back during the growing season; n = 16.

Table 3. Mean total biomass of four container-grown tree species with and without tree shelters during the 1995 growing season.[z]

	Biomass (g)					
	Shoot		Root		Total	
Species	Sheltered	Non-sheltered	Sheltered	Non-sheltered	Sheltered	Non-sheltered
Sawtooth oak	38.25a	41.95a	82.87a	148.68a	121.12a	190.62a
Green ash	10.42a	12.82a	21.16a	76.68a	31.58a	89.50a
White oak	14.21a	28.34a	25.02a	89.59a	39.23a	117.92a
Flowering dogwood	13.60a	14.11a	17.71a	42.17a	31.32a	56.27a
Overall mean	19.49a	27.21a	37.96b	100.13a	57.44b	127.34a

[z]Means with the same letter in a row for each variable are similar at $p \leq 0.05$; n = 8.

There was no significant difference in diameter growth for any species examined (data not shown). West et al. (17) reported similar results; there were no differences in overall diameter growth between sheltered and non-sheltered trees for all ten species that were tested after three years in the field.

Shelters had no significant effect on aboveground tree biomass production for the four species tested, in the 1995 field study (data not shown). These findings were similar to results reported by West et al. (17). They found that trees within shelters tended to be taller, while non-sheltered trees tended to have more branches; therefore, there were no differences in woody biomass.

There were no significant differences ($p \leq 0.05$) in biomass between treatments for the four individual species tested in the nursery study (Table 3). However, when tested across species, sheltered trees grown under containerized nursery conditions had less root and total biomass than trees grown without shelters under nursery conditions for one year. Shoot biomass was not affected by treatment. Due to the protected tree environment within shelters, trees need not develop extensive root systems for support. In addition, root to shoot ratios for non-sheltered trees were 4 to 1, while sheltered trees were more balanced, averaging a root shoot ratio of 2 to 1. Ponder (13) noted that sheltered trees had fewer roots than did unsheltered trees for the first couple of years, then sheltered trees began to reverse this trend.

Overall, total biomass was more than two times greater in trees without a shelter (Table 3) which is probably a reflection of the decreases observed in root biomass for trees growing in shelters. Kjelgren and Rupp (5) reported that growth of Norway maple (*Acer platanoides* L.) and to a lesser extent green ash was decreased in shelters compared to non-sheltered trees grown in containers.

Leaf gas exchange. Shelters had an overall negative impact on photosynthesis in the containerized nursery study (Table 4). Sheltered trees photosynthesized at 64% of the rate of non-sheltered trees. Shelters raised leaf intercellular CO_2 (Ci) by 11%. Although not significant, a trend in decreased Pn was observed for all of the individual species growing in shelters compared to those outside. Shelters had no significant effect on leaf conductance (Table 4). Kjelgren et al. (6) observed that gas exchange exhibited significant variation among species and treatment. Stomatal conductance was found to be greater within shelters for both Norway maple and green ash. However, the results regarding photosynthesis were highly variable. Photosynthesis did not differ among treatments for Norway maple, but was significantly higher for green ash grown outside shelters. The variability in results reported in our study and others (6) indicates the need for further research in this area.

Peterson et al. (11) found low mid-day CO_2 levels in shelters, so increased levels of CO_2 in leaves are apparently not due to increased shelter CO_2. Increased CO_2 levels are likely related to decreased photosynthetic activity. This decrease is probably due to the 70% shade provided by shelters as reported by Kjelgren (3). In addition, air temperatures are significantly higher in shelters (5, 11), possibly resulting in leaf temperatures above the photosynthetic optimum. These results may change once trees emerge from shelters into ambient light and moisture levels.

In summary, shelters increased the growth and survival of seedlings under field conditions while decreasing total one-

Table 4. Leaf gas exchange of four container-grown tree species with and without tree shelters in July 1995.[z]

	Gas exchange					
	Ci (ppm)		Pn (μmole·m^{-2}·sec^{-1})		gs (cm·sec^{-1})	
Species	Sheltered	Non-sheltered	Sheltered	Non-sheltered	Sheltered	Non-sheltered
Sawtooth oak	327.59a	305.02a	5.61a	7.33a	0.35a	0.28a
Green ash	323.28a	299.47a	6.90a	11.05a	0.37a	0.40a
White oak	331.27a	269.99a	4.94a	10.02a	0.32a	0.68a
Flowering dogwood	333.32a	310.72a	5.43a	6.58a	0.46a	0.27a
Overall mean	328.56a	293.14b	5.75a	9.03b	0.37a	0.44a

[z]Means with the same letter in a row are similar at $p \leq 0.05$ LSD; Ci = intercellular CO_2, Pn = net photosynthesis and gs = stomatal conductance; n = 8.

year biomass of trees grown in a containerized nursery setting. This appears to be the result of a decrease in photosynthesis and lack of root growth. However, results are inconclusive and further mechanistic studies in this area are required.

Based on our results and others (2, 5, 17) shelters are recommended for establishment of sawtooth oak and green ash in the field. Dogwood does not appear to be a good candidate for planting within tree shelters. Results of other tree shelter trials have generally shown that shelter effects are species and site specific (5, 11, 17). Tree shelters may provide a good alterative to other planting methods in certain urban environments.

At present, shelters do not appear to be useful in containerized, nursery situations. They may prove beneficial, however, in bare-root nurseries due to accelerated growth and reduced pruning. Performance of trees in shelters of different sizes was not considered and should be investigated to make recommendations of shelter size for a specific species. An assessment of costs relative to field and container production of trees with and without shelters may be helpful to nursery producers interested in using tree shelters during nursery crop production.

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