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Tree shelters and weed control: Effects on protection, survival and growth of cherrybark oak seedlings planted on a cutover site

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Application. Protecting planted cherrybark oak seedlings with tree shelters and controlling herbaceous competition, reduced browse by deer and rabbits, and promoted two-year ground-line diameter, height, and stem volume growth after planting on a cutover forest. Because of costs associated with installation of tree shelters and weed control treatments, a forest owner may want to consider using tree shelters and weed control to establish a limited number of oak seedlings per hectare.

Abstract. In the southern USA oaks (*Quercus spp.*) are often favored by forest owners having multiple objectives for forest ownership as oaks provide mast for wildlife, are considered aesthetically pleasing, and are valuable for timber products. Regeneration and early seedling growth is a concern to those forest owners interested in sustaining oaks as a component of their forests. The effects of tree shelters and herbaceous weed control on second-year seedling survival, browse by deer and rabbits, and seedling growth of hand-planted cherrybark oak (*Quercus pagoda* Raf.) were examined. The study was established on a cutover mixed pine-hardwood forest in Alabama. Four treatments were: weed control only, tree shelter only, tree shelter with weed control, and a control consisting of a seedling without a tree shelter or weed control. No significant difference in seedling survival was found among the treatments after two years. Tree shelters were effective in preventing browsing. No seedlings in the tree-shelter-only treatment were browsed. There was no significant, difference, however, in the percentage of seedlings browsed between the control treatment and the weed control treatment. The use of tree shelters with weed control was the most effective treatment for promoting 2-year ground-line diameter, height, and stem volume growth.

Introduction

More than 41 million hectares of forests in the oak-pine and oak-hickory forest types cover the landscape of the southern United States (Powell et al. 1992), approximately 5 million hectares of which are found in Alabama (McWilliams 1992). These mixed-species forests are an important source of wildlife habitat, recreation, and commercial timber products. Oaks (*Quercus spp.*) are often favored by forest owners having multiple objectives as oaks provide mast for wildlife, are often considered aesthetically pleasing, and are commercially valuable for pulpwood and sawtimber. Hence, regeneration is a concern to those forest owners interested in sustaining oaks as a component of their forests.

Oak regeneration after harvesting is problematic. The causes for regeneration failure include inadequate regeneration in advance of harvest, predation and the inability of oak seedlings to compete with other vegetation for light and water (Loftis 1983; Lorimer 1989). In a study conducted in the southern Appalachians, Cook et al. (1998) concluded that following a harvest a regenerated stand will generally have 50 to 70% fewer oaks than before the harvest. Proposals for addressing oak regeneration problems include: shelterwood cuts with competition control before harvest; clearcutting using a pre-harvest herbicide and direct seeding; and the use of tree shelters.

Tree shelters were first used by Graham Tulley in Great Britain (Tulley 1985). Development of the plastic tree shelter resulted from a need for an inexpensive guard to protect oak seedlings from predation by deer (*Odocoileus spp*.) and rabbits (*Sylvilagus spp*.). Tulley's experiments at Alice Holt Lodge in 1978 demonstrated that tree shelters improved early growth rates and protected oak seedlings from deer browsing. Results of the studies led to rapid acceptance and use of tree shelters in Great Britain.

Tree survival and growth

Oak regeneration success of Tulley (1985) led to studies of tree shelters in North America. Walters (1993) studied the effects of tree shelters, fences and weed control by herbicides on the survival and height growth of northern red oak (*Quercus rubra* L.) in Pennsylvania. The study site was a 75 year-old mixed-oak stand which had a shelterwood cut six years prior to implementation of the study. After the first growing season, seedlings in tree shelters were significantly taller than seedlings in the control treatment (no shelters and no weed control). Differences in the first year survival rate among the treatments were not significant.

Minter et al. (1992) studied the effects of two types of tree shelters on the survival and early growth of northern red oak seedlings planted in harvested openings in Indiana. After three growing seasons, seedlings in tree shelters were double the height of those in control treatment (no shelter). Seedling survival was not significantly different between tree shelter and control treatments.

Clatterbuck (1999) reported seven-year results of a study that examined the effects of tree shelters on seedling growth and development of a variety of tree species including cherrybark oak. The study was established in February 1992 on an agricultural field located in Tennessee. Site preparation included cross directional disking followed by ripping in one direction. Weed control for both sheltered and unsheltered seedlings consisted of mowing the study area once or twice annually. After the second growing season sheltered seedlings had significantly greater height growth compared to unsheltered seedlings. Height growth slowed after trees emerged from the shelters. After seven growing seasons there were no significant differences in height growth between sheltered and unsheltered seedlings.

Clatterbuck (1999) noted that the decurrent crown form of many hardwood species favors crown expansion at the expense of height growth following emergence from a shelter. Consequently, the rate of height growth will typically decline once a tree emerges from a shelter. Continued strong terminal growth will be dependent on competition limiting crown spread and forcing terminal growth.

In Michigan, Lantagne et al. (1990) and Lantagne (1995) reported two- and six-year results, respectively, of a study that examined the effects tree shelters and woody brush control on the growth and survival of northern red oak seedlings planted on site where a 22 year-old shelterwood cut had inadequately regenerated oaks. The shelterwood stand was clearcut before seedlings were planted. Brush control was accomplished by a pre-harvest prescribed burn and basal applications of triclopyr and oil on species other than oak. Herbicide applications were continued for three years following harvest. After two growing seasons, northern red oak seedlings in tree shelters were significantly taller than unsheltered seedlings. Brush control did not affect height growth. After six growing seasons brush control had no significant effect on survival and total height. Sheltered seedlings had significantly greater survival and total height than unsheltered seedlings. However, average annual seedling height growth during the last three years of the study was comparable between sheltered and unsheltered seedlings. The total height advantage of sheltered seedlings was attributed to accelerated growth during the first three years when the trees were within tree shelters.

Herbivory

Stange and Shea (1998) reported on the effects of deer browsing, fabric mats (for competition control), and tree shelters on second-year growth and survival of northern red oak seedlings planted in south-central Minnesota. Tree shelters were effective in preventing browsing by deer. Unprotected seedlings grown with the use of fabric mats had a significantly greater frequency of deer browsing and than seedlings grown without mats. Survival for seedlings grown in tree shelters was significantly greater than survival for seedlings without shelters. For seedlings grown without shelters, more seedlings survived in the control than seedlings with protective mats. Second-year mean stem height was significantly less for browsed seedlings compared to unbrowsed seedlings (22.2 cm compared to 25.6 cm).

Gourley et al. (1990) examined the effectiveness of six mechanical methods and one chemical method in protecting large, transplanted 2-1 bare-root Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] from deer browsing. The study was conducted on weeded and unweeded cutover sites in western Oregon. The study also evaluated whether protection from browsing affected seedling growth. After 5 years, the protective treatments were ineffective in promoting seedling height growth. However, seedlings grown on the weeded sites were significantly taller than those grown on unweeded sites regardless of browsing or protection. Browsing of the large seedlings did occur. However, conifer seedlings grown in weeded sites were more likely to recover from browsing compared to seedlings grown in unweeded sites. Increased lammas growth (secondary midsummer flush of height growth) in the weeded treatments due to increased availability of moisture associated with the weeding may have moderated the effects of browsing by deer (Roth and Newton 1996).

Herbivory rates by deer are often attributed to plant apparency and plant nutrient concentrations (Castleberry et al. 1999; Bergquist and Orlander 1998). Ford et al. (1994) examined the nutritional quality of leafy browse of five deciduous woody species important to white-tailed deer during the spring and summer from recent clearcuts and adjacent mature forests in the southern Appalachian Mountains of northern Georgia, USA. Little difference in nutritional quality was detected in deer browse from clearcuts compared to browse in mature forests. The authors suggest that ease of foraging due to spatially concentrated nature of resources in clearcuts may explain the high use of clearcuts by deer in the spring and summer months in the study region.

Study objectives

Our study was undertaken to complement the existing literature regarding oak seedling responses by studying tree shelters in cutover forests of the southern USA. Specific objectives were to examine the effects of tree shelters and herbaceous competition control on (1) survival, (2) herbivory, and (3) early growth of cherrybark oak seedlings planted in a cutover forest.

Methods

Study site

The study was established on the Mary Olive Thomas Demonstration Forest near Auburn, Alabama. The study site was established on a mixed pine-hardwood forest that was clearcut in the summer of 1995. A mature mixed pine-hardwood forest bordered three sides of the study site. Common associated tree species on the site included loblolly pine (*Pinus taeda* L.), water oak (*Q. palustris* Muenchh.), sweetgum (*Liquidambar styraciflua* L.), yellow poplar (*Lirodendron tulipifera* L.), red maple (*Acer rubrum* L.), and flowering dogwood (*Cornus florida* L). The site is located at the toe of an upland site and is a transition area from a Piedmont upland to a bottomland having a slope of 3% with the lower portion of the site being in a floodplain. The soil on the study area is of the Chewacla series, a thermic Fluvaquentic Dystrochrept. A perched water table in the study area occurred at depths ranging from 38 to 74 cm. Average annual rainfall is 148 cm with 50% of the rainfall occurring during the growing season from April to September. The average daily temperature is 16.4 °C (USDA Soil Conservation Service 1981).

A site preparation herbicide treatment was applied to the study area in September 1996 to control established herbaceous and woody plants. A tank mix of imazapyr at a rate of 0.70 kg/ha and glyphosphate at a rate of 1.68 kg/ha was aerially applied.

Bareroot 1-0 cherrybark oak seedlings were hand planted using a planting shovel in March 1997. While seedlings were not graded before planting, only those with well-developed root systems were used in the study. Seedlings were planted in rows on a 3- by 3-m spacing with 10 per row.

Experimental design and treatments

Because of variability in the soils and water table the experimental design was a randomized complete block design with four blocks. Each block consisted of two replications of each of the four treatments. Each replicate, the experimental unit, consisted of the mean of a single row of 10 seedlings. Treatments were assigned at random to each row.

Four treatments were examined in the study. The treatments included; a control treatment consisting of no tree shelter and no weed control (CNTL), a weed control only treatment (WC), a tree shelter only treatment (TS), and a tree shelter with weed control treatment (TSWC).

Following planting, tree shelters (TREE PRO™ polyethylene tree shelters measuring 9-cm diameter by 122-cm height from Tree Pro Incorporated, LaFayette, Indiana[1]) were installed on seedlings in rows receiving a tree shelter treatment. Plastic lock ties were used to attach the shelter to a stake. Stakes were schedule 40 PVC pipes, 152 cm in height and 2.5 cm in diameter.

In May 1997, a herbaceous weed control treatment was applied to rows that received a weed control treatment. Two, 1.5-m bands of sulfometuron were applied with a backpack sprayer at a rate of 0.105 kg/ha. Each 1.5-m band application of herbicide paralleled the row of seedlings. To minimize herbicide contact with oak seedlings, one outer edge of each band was directed at the base of the seedling. No evidence of seedling herbicide damage was detected during three inspections in the two months following the herbicide treatment.

The level of weed control achieved with the herbicide treatment was not directly measured. However visual assessment during post-herbicide application seedling inspections indicated that the band application treatment was very effective in controlling herbaceous competition. The weed control treatment achieved almost total brownout of competition in the banded-strip that persisted well into the first growing season.

Measurements

Data were collected after planting in April 1997 and again in November 1998, two growing seasons after planting. Survival, ground-line diameter (GLD) and seedling height were collected. Stem volume was estimated as the volume of a cone, volume = $1/3\ \pi\ d^2\ h$, where volume is expressed in cm^3, d is seedling groundline diameter (cm), and h is seedling height (cm). Evidence of browsing was assessed using characteristics of deer and rabbit damage as described by Armstrong (1991).

Statistical analysis

Effects of treatments on percent seedling survival after the second growing season were assessed using a Chi-square analysis by combining the two replicates for each block into a two-way contingency table listing surviving seedlings by block and treatment. Expected values of the frequency of survival under the null hypothesis of no treatment effects was seedlings surviving in a block divided by four.

Some browsing did occur on seedlings that had emerged from the top of the shelters. However, deer and rabbits were essentially only able to browse seedlings without shelters. Hence, a paired *t*-test was used to test for weed control effects on the percent seedlings browsed between CNTL and WC treatments.

Analysis of variance (ANOVA) was used to examine treatment effects on the dependent variables of two-year seedling height growth, ground-line diameter growth, and stem volume growth using the following model:

$$Y_{ijk} = \mu + B_i + R_{i(j)} + T_k + \beta(X_{i,j,k} - X\ldots) + \varepsilon_{i,j,k}$$

where

Y_{ijk}	=	the dependent variable (seedling height growth, ground-line diameter growth, and stem volume growth)
B_i	=	block (i = 1, 2, 3, 4)
$R_{i(j)}$	=	replication (j = 1, 2)
T_k	=	treatment (k = 1, 2, 3, 4)
$\beta(X_{i,j,k} - X\ldots)$	=	covariate denoted by X
$\varepsilon_{i,j,k}$	=	error term

Data were pooled for analysis as blocks did not account for differences two-year growth of seedling height, ground-line diameter, and stem volume. Initial height, ground-line diameter, or stem volume was tested as covariates in the analysis. Covariates were removed from the model as they were not statistically significant in explaining two-year seedling height, ground-line diameter, and stem volume growth.

A statistical contrast between the TSWC treatment and the average of the other treatments (CNTL, WC, TS) was conducted for differences in height growth, ground-line diameter growth and stem volume growth.

Results

Survival

Second-year seedling survival rates ranged from 70.0% for the CNTL to 90.0% for the TSWC treatment (Table 1). There were no significant differences among treatments on the proportion of seedlings surviving after two growing seasons (χ^2 = 5.76, p = 0.7637). Results of the seedling survival analysis are qualified due to the number of seedling in each treatment, 80. However, our results are consistent with the findings reported by Minter et al. (1992), Walters (1993), and Strobl and Wagner (1996).

Some early-seedling mortality occurred due to mice chewing at the base of unsheltered seedlings. Within two weeks of planting, 6 seedlings in the CNTL and 6 seedlings in the WC were killed by cotton rats (*Sigmodon spp.*)

Table 1. Mean seedling survival and frequency of browsing, and height, ground-line diameter, and stem volume growth after two growing seasons, by treatment.

Treatment	Survival (%)	Browsing (%)	Height (cm)	Ground-line diameter (mm)	Stem Volume (cm^3)
Control	70.0	57.1	16.4	3.2	42.2
Weed control	75.0	70.0	10.5	3.5	36.8
Tree shelter	88.8	0.0	61.9	3.6	95.6
Tree shelter and weed control	90.0	9.9	88.2	5.3	188.8

representing 7.5% of the total number of seedlings planted in those two treatments. Hence, tree shelters were effective in preventing early mortality due to cotton rat predation.

Herbivory

Tree shelters were effective in controlling browsing by deer. No seedlings in the TS treatment were browsed even though 16% of the seedlings had emerged from the top of the shelter after two growing seasons. In the TSWC treatment, 30% of the seedlings had emerged from the shelter at the end of the second growing season. Twenty-nine percent of the emerged seedlings in the TSWC were browsed. Browsing of sheltered trees was minimal with most browsed seedlings having only one terminal or branch leader browsed. Seedlings in the CNTL and WC treatments, however, experienced high frequencies of browsing; 57.1 and 70.0%, respectively (Table 1). The terminal leader and lateral branches of many unsheltered seedlings in the CNTL and WC treatments were browsed heavily. However, there was no significant difference between the two unsheltered treatments on the frequency of browsing ($t = -0.9694$, $p = 0.4038$).

Ground-line diameter growth

Weed control and tree shelters were found to significantly affect GLD growth after two growing seasons (Table 2). The TSWC was not significant; however a trend was evident ($p = 0.0771$). The TSWC treatment with a two-year GLD growth of approximately 1.5 times greater than the other treatments was significantly different from the average of the other treatments (Table 3).

Table 2. Summary of degrees of freedom, mean square error, and probabilities of a greater *F*-value for oak seedling variables at the end of the second growing season.

Variable	Treatment	df	Mean square	*P*
Height	Weed control	1	835.54	0.0981
	Tree shelter	1	30314.05	0.0001
	Tree shelter and weed control	1	2066.09	0.0119
	Error	28	285.35	
Ground-line diameter	Weed control	1	7.95	0.0153
	Tree shelter	1	9.06	0.0102
	Tree shelter and weed control	1	4.02	0.0771
	Error	28	1.19	
Stem volume	Weed control	1	15435.88	0.0001
	Tree shelter	1	84436.61	0.0378
	Tree shelter and weed control	1	19487.92	0.0208
	Error	28	3246.31	

Table 3. Statistical contrast between tree shelters with weed control versus other treatments for height, ground-line diameter, and stem volume growth.

Growth variable	*P* value
Height	0.0001
Ground-line diameter	0.0003
Stem volume	0.0001

Height growth

The TS and the TSWC treatments were found to significantly affect seedling height growth after two growing seasons (Table 2). Weed control alone was not significant except, however a negative weeding trend was evident (p = 0.0981). Height growth of seedlings in TSWC treatment was significantly greater than other treatments (Table 3). Height growth of seedlings in the TSWC treatment was 5.4, 8.4, and 1.4 times greater than the CNTL, WC, and TS treatments, respectively (Table 1).

Within the CNTL and WC treatments, a paired t-test was used to test for browsing effects on two-year seedling height growth. In the CNTL treatment, browsed and unbrowsed seedlings averaged 14.7 and 17.8 cm of height growth, respectively. Differences in height growth were not significant (t = −0.3593, p = 0.6342). In the WC treatment, browsed and unbrowsed seedlings average 7.3 and 16.8 cm of height growth, respectively. Height growth was quite variable and differences between browsed and unbrowsed seedlings in the WC treatment were not significant ($t = -1.2743$, $p = 0.8752$).

Volume

Seedling stem volume growth in the TSWC treatment was 4.8, 5.1, and 2.0 times greater than the CNTL, WC, and TS treatments, respectively (Table 1). Tree shelters, weed control and the tree shelter with weed control treatments were found to significantly affect 2-year seedling stem volume growth (Table 2). Stem volume growth for the TSWC treatment was significantly greater than that of the other treatments (Table 3).

Discussion

Seedlings grown in tree shelters and receiving a weed control treatment had the greatest 2-year height, ground-line diameter, and stem volume growth responses of all treatment tests. Two-year growth differences between the TSWC treatment and the other treatments were quite remarkable. Our results are consistent with those of Walters (1993), the early results of Clatterbuck (1996), and Strobl and Wagner (1996).

Height, GLD and stem volume growth in the TSWC treatment may be partially attributed to increased availability of nutrients and water associated with the weed control treatments. Some studies have suggested that enhanced growth of sheltered seedlings might be related to the micro-environmental effects of the shelters (Clatterbuck 1999; Potter 1998). Peterson et al. (1994) examined the effects of micro-environment attributes (light, temperature, relative humidity, and CO_2) on two-year height and weight growth of northern red oak seedlings grown in Virginia. The authors reported that elevated relative humidities reduced the potential for moisture stress and were shown to correspond with red oak seedling height and weight growth. However, reduced concentrations of CO_2, lowered light levels, increased temperatures were not effective in explaining growth advantages of shelters.

In our study, unsheltered oak seedlings experienced high frequencies of deer browsing (Table 1). Browsing by deer was greater for unsheltered seedlings receiving weed control as compared to unsheltered seedlings without weed control. Stange and Shea (1998) reported similar results for northern red oak seedlings on a site in south-central Minnesota. It is possible that untreated vegetation bordering on the edge of the weed control treated area was partially released, and remained more palatable and nutritious later in the growing season than unweeded areas resulting in higher frequency of browsing and higher concentration of deer (Armstrong 1999). If deer were indeed attracted to the edge of the weeded/unweeded areas for browsing activities then highly apparent oak seedlings in the weeded area would have been very susceptible to browsing. High browsing frequency may have also occurred in the study site as deer will concentrate their browsing activities to areas where they can obtain browse with the least expenditure of energy (Armstrong 1999). Ford et al. (1994) concluded that that ease of foraging due to spatially concentrated resources in clearcuts may explain the high use clearcuts by deer in the spring and summer months in north Georgia.

Concerns have been expressed regarding the mechanical stability of seedlings grown in tree shelters. West et al. (1999) examined the effects on wood density of growing common southern U.S. seedlings in shelters. Wood density is an important measurement of the structural integrity of a tree. After three growing seasons, no significant differences in wood density were found between five oak species of shelter seedlings and unsheltered seedlings. Open-grown, unsheltered seedlings have tapered stems making them less susceptible to wind throw (Schuler and Miller 1996). Stems of sheltered seedlings do not taper like open-grown seedlings. However, once a seedling emerges from a shelter the main stem begins to taper. Northern red oak become windfirm usually one growing season after the seedling emerges from the shelter (Schuler and Miller 1996). Potter (1998) suggests that oaks grown in shelters will have stems sufficient of sufficient size in five years to be self-supporting.

Many of the cherrybark oak seedlings in the tree shelter with weed control had achieved a competitive second-year height advantage relative to other woody and herbaceous plants in the cutover site. These results suggests that the use of tree shelters and herbaceous weed control to enhance establishment and early growth of cherrybark oak following clearcutting is promising; however, a landowner must weigh the benefits against the costs of establishing cherrybark oaks in this manner. Kays (1995) reported a cost of $ 4.75 per seedling for labor and materials associated with planting a hardwood seedling (based on 250 seedlings per hectare), purchasing, installing and maintaining a tree shelter, and performing a release treatment. For similar operations, Schuler and Miller (1995) reported that the cost per sheltered seedling ranged from $ 2.50 to $ 5.95 based on a planting density of 175 seedlings per hectare.

Estimated costs associated with the various treatments in our study are listed in Table 4. The cost to a landowner for purchasing, transporting and planting an oak seedling with no associated cultural treatments is approximately $ 0.45. A landowner can be reasonably assured that a seedling planted under such conditions would still be alive after the second growing season.

Table 4. Estimated treatment and operation costs for the four study treatments.

Treatment	$US/seedling
Control	0.45
Weed control	0.80
Tree shelter	4.80
Tree shelter and weed control	5.15
Based on the following costs:	
Operation	
Oak seedling	0.20
Planting labor*	0.25
Weed control* (chemical + labor)	0.35
Tree shelter	2.85
Shelter stake and labor	1.50

* Adapted from Dubois et al. 1999 and based on planting 250 seedlings per hectare.

Planting an oak seedling, installing a tree shelter and treating the surrounding herbaceous competition will cost a landowner an estimated additional $ 4.70 per seedling (total cost of $ 5.15 per seedling). However the seedling will grow in an environment relatively free from deer and rabbit predation and attain significantly more height, ground-line diameter, and stem volume growth in the first two growing seasons relative to a seedling planted without a tree shelter and weed control treatment.

Establishment costs associated with use of a tree shelter and weed control will most likely limit the number of seedlings a forest owner will plant with such cultural treatments. Tree shelters alone are a good second alternative, however, the landowner will only be saving approximately $ 0.35 per seedling by not applying a weed control treatment. Because of treatment costs, a forest owner may want to consider an enrichment planting using tree shelters and weed control of a cutover site to establish a limited number of oak seedlings per hectare.

Second year survival and growth responses of planting cherrybark oak seedlings on a cutover forest are promising for forest owners desiring oaks as a component of their forested landscape. It will be important to continue monitoring this study to determine if early gains in survival and growth associated with tree shelter and weed control treatments are maintained as the forest stand develops.

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Note

1. Mention of a tradename or product does not constitute an endorsement by Auburn University.

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