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Effects of Light Regime and Season of Clipping on the Growth of Cherrybark Oak, White Oak, Persimmon, and Sweetgum Sprouts

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Abstract.—A mixture of cherrybark oak (*Quercus pagoda* Raf.), white oak (*Q. alba* L.), persimmon (*Diospyros virginiana* L.), and sweetgum (*Liquidambar styraciflua* L.) seedlings was grown in shadehouses to simulate light conditions beneath a canopy. After the first growing season, two release treatments were implemented (released and not released), and treatments were conducted during two seasons (winter and spring). All seedlings were clipped at 2.5 cm from the groundline in height when treatments were imposed. Survival of persimmon and sweetgum was 100% following clipping. There appeared to be a weak seasonal effect on oak survival, especially for white oak; survival was 100% for winter clipping and 93% for spring clipping. The oaks were considerably smaller in height, diameter, and above-ground biomass than their competitors, and the competitors also produced more stems per rootstock than the oaks. Cherrybark oak was more productive than white oak especially in the released treatment. The oaks tended to have a higher percentage of their total biomass in foliage when compared with their competitors. Stem wood density of the oaks was considerably greater than that of their competitors. Leaf characteristics of all species were very responsive to the treatments; specific leaf area was consistently greater for the no-release treatment for all species. Results of this study suggest that for oak sprouts to grow faster than their competitors they must begin with an initial size advantage.

Key words:—Cherrybark oak, white oak, persimmon, sweetgum, shadehouses, clipping, light.

Introduction

Oaks are one of Arkansas's most important forest resources for timber, wildlife management, and a multitude of ecosystem services, and they make up about one-third of the growing stock volume for the state's forests (Rosson 2002). Yet, the sustainability of this resource is uncertain because the oaks are notoriously difficult to regenerate (Smith 1992; Spetich 2004). Oak seedlings do not grow well under a closed forest canopy because they are shade intolerant to intermediately intolerant (Johnson et al. 2002). In addition, advanced oak reproduction needs adequate light after establishment to grow faster than competing vegetation (Bey 1964; Sander 1972; Johnson 1979). Light conditions under a canopy can be very complex and are difficult to study under field conditions. For example, direct and partial sunlight may reach seedlings during certain times of a day, but seedlings may be fully shaded at other times. Shadehouses have been effectively used to create different light regimes so that growth relationships of oak seedlings can be studied under controlled conditions (Gardiner and Hodges 1998; Guo et al. 2001). In this research we used shadehouses both to simulate light conditions occurring beneath a forest canopy and to investigate how the timing of release and the amount of sunlight affects growth, characteristics, and competitive status of oak sprouts. Two important oaks, cherrybark oak (*Quercus pagoda* Raf.) and white oak (*Q. alba* L.), and two common competitors, persimmon (*Diospyros virginiana* L.) and sweetgum (*Liquidambar styraciflua* L.), were selected for the study. These species are widely distributed in Arkansas and throughout the southeastern United States (Burns and Honkala 1990). Cherrybark oak, white oak, and sweetgum are commercially important within the region, while persimmon is an important wildlife food species with specialty markets for its wood. Persimmon and sweetgum are potentially major competitors with the oaks because of their widespread occurrence.

Materials and Methods

The study site was located in Drew County, Arkansas, in the West Gulf Coastal Plain. The soil is an Amy silt loam (Fine-silty, siliceous, thermic Typic Ochraquult). Site index for sweetgum and cherrybark oak is about 26 m at the base age of 50 years. Before study establishment the area was an open field, but native vegetation is classified as mixed pines and hardwoods (Larance et al. 1976). Annual precipitation averages 134 cm, with most occurring in winter and early spring.

This study compares the effects of two light regimes (shaded and full sunlight) simulating released and non-released seedlings. Additionally, sprouting was measured one growing season after clipping 1-year-old, shade-grown seedlings during two seasons (winter and spring) to compare the effects of simulated top-kill. Treatments were imposed on 1-year-old seedlings that were clipped at 2.5 cm above groundline in height when treatments were implemented. Seedlings were grown their first year under sixteen 2.4 by 2.4 m shadehouses that were 1.6 m tall. The shade cloth provided 27% of full sunlight. Shade cloth was present on top and on all but the north side. Shadehouses were extended to 2.7 m in height for the no-release treatment when seedlings were clipped. The winter season treatment was implemented on January 23, 2002, and the spring treatment was initiated on April 19, 2002. The seedlings had fully leafed out, and height and diameter growth had initiated when the spring treatment was implemented.

Seeds from 12 open-pollinated trees for each species were collected in Drew County, Arkansas, in October and November 2000, float tested, and stored in a refrigerator at 4 °C. Seeds were stratified in moist sand at 4 °C for 10 weeks for cherrybark oak and persimmon and 3 weeks for sweetgum; white oak acorns were not stratified. On February 7 and 8, 2001, seeds were removed from stratification and sown in a commercial potting soil mixture under greenhouse conditions. Seedlings were field planted from April 22 to 24, 2001.

Six seedlings of each species were planted in each bed with a 0.3 by 0.3 m spacing in four rows by six columns for a total of 384 seedlings in the study. One seedling of each species was randomly located within each column. During the first month after the planting, dead seedlings were replanted with live seedlings of the same species. Weed-free mat covered by a mulch of leaf-litter was used to prevent herbaceous vegetation from growing within the beds. Herbaceous vegetation outside of the beds was periodically controlled with a foliar-applied herbicide. During their first growing season, beds were occasionally watered after periods of low rainfall, but no watering was done during the second growing season. Seedling height and diameter at 5 cm in height were measured on September 24-28, 2001. On April 19, 2002, seedling height was measured on four of the spring-treatment beds just before that treatment was implemented.

Stems were measured for height and diameter (at 5 cm in height) during September 9-13, 2002. Stems were defined as sprouts developing from the residual stump and being within 45° from vertical. Biomass was sampled by foliage, branch, and stem components during September 17-30, 2002. A minimum of 40 fully developed leaves were randomly collected for surface-area determination from each species and bed. Stems were cut at 2.5 cm above ground. Branches and foliage were collected and dried together. Approximately one-half of the samples were considered small enough such that the entire foliage/branch sample was separated into components and then weighed. Subsampling was conducted on the remaining samples before separation. After weighing the bulk foliage/branch material, a subsample averaging 42% of the total was withdrawn and separated into foliage and branches to determine their proportional contribution. All material was oven-dried to a stable weight at 70 °C.

After weighing stems, 30 representative stem sections with an average length of 12 cm were withdrawn from the stem biomass sample for each species and bed. Diameter at the midpoint and length were measured for each stem section so that volume could be calculated as a cylinder; sections were also weighed. Stem density was then calculated from the total volume and weight of all stem sections subsampled for each bed and species.

To determine species effects, we initially analyzed the data as split-plot design with release and season as main effects and species as subeffects and with four randomized complete blocks. Species effects were always highly significant, and many of the species-treatment interactions were also significant. Therefore, data for each species were analyzed separately as a 2 by 2 factorial design with four blocks using SAS procedure GLM (SAS 1990). Replicates were the values determined for each species from each treatment bed. Treatment effects were deemed significant at $P \leq 0.05$.

Results

Pre-treatment Conditions.—At planting during spring 2001, height averaged 15.6 cm for cherrybark oak, 15.9 cm for white oak, 11.6 cm for persimmon, and 6.6 cm for sweetgum. At the end of the growing season, however, persimmon was the tallest species and had the largest diameter, while white oak was the smallest species in both height and diameter (Fig. 1). Cherrybark oak and sweetgum were about equal in height, but sweetgum was 58% larger in diameter than cherrybark oak. The small differences between the fall 2001 and spring 2002 values reflected growth occurring in the early spring before the spring treatment was implemented. The early height growth of the oaks exceeded that of persimmon and sweetgum. Also interesting was

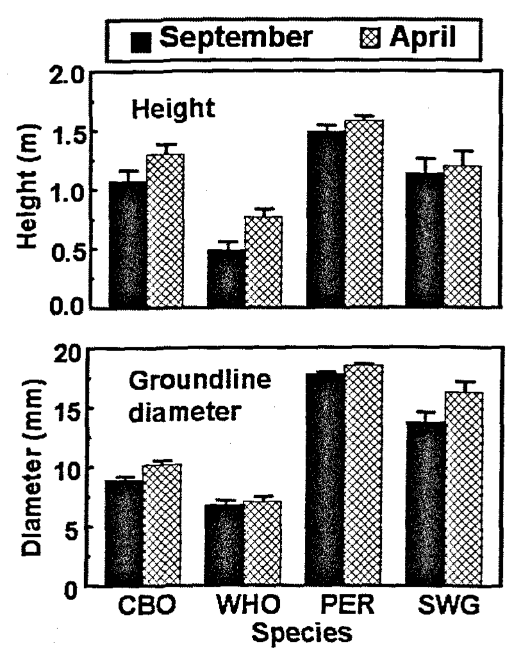

Fig.1. Mean height and diameter of cherrybark oak (CBO), white oak (WHO), persimmon (PER), and sweetgum (SWG) seedlings before treatments at the end of the first growing season (September 2001) and when the spring treatment was implemented (April 2002). (Mean plus one standard error).

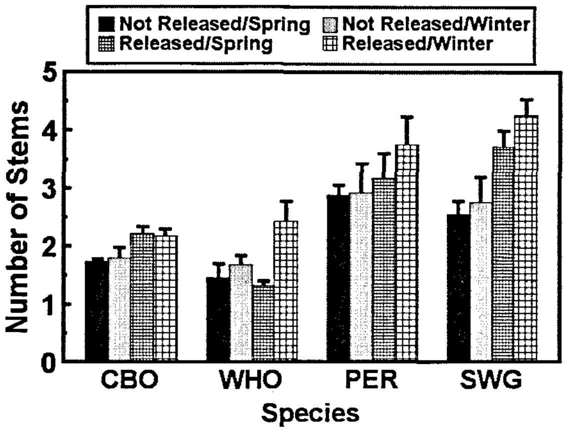

Fig. 2. Number of stems developing from rootstocks of cherrybark oak (CBO), white oak (WHO), persimmon (PER), and sweetgum (SWG) one growing season after implementing release and clipping treatments. (Mean plus one standard error).

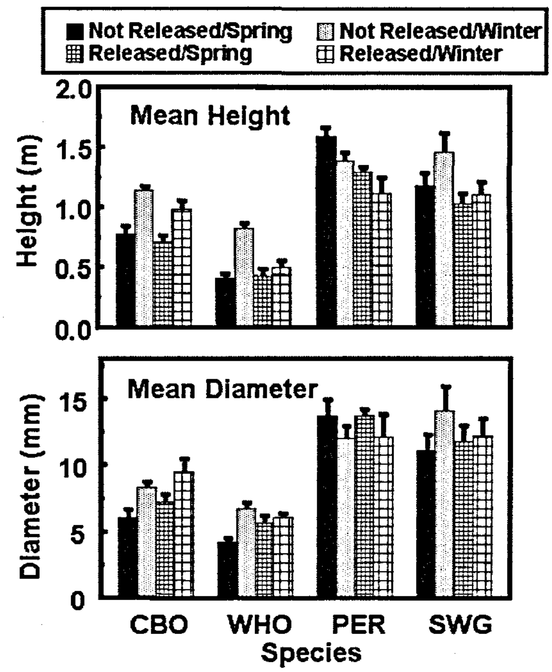

Fig. 3. Mean height and diameter of all stems of sprout clusters of cherrybark oak (CBO), white oak (WHO), persimmon (PER), and sweetgum (SWG) one growing season after implementing release and clipping treatments. (Mean plus one standard error).

the high rate of early diameter growth displayed by sweetgum.

Survival.—One growing season after treatments were initiated, survival of persimmon and sweetgum was 100% for all treatments. Survival for cherrybark oak was 100%, except for the no-release/spring treatment which averaged 92%. White oak had the poorest survival of any species, and there appeared to be a weak seasonal effect ($P = 0.06$); the spring clipping averaged 88% for the no-release treatment and 92% for the released treatment. However, both release treatments averaged 100% when white oak was clipped in winter.

Sprout Number.—A stem was considered any sprout arising from the clipped stump and within 45° from vertical. There were multiple stems on most rootstocks (Fig. 2). The number of stems per rootstock was less for the oaks than for their competitors, averaging 2.0 for cherrybark oak, 1.7 for white oak, 3.2 for persimmon, and 3.3 for sweetgum. Season of clipping significantly affected the number of stems for white oak (winter > spring), while the released treatment produced a significantly higher number of sprouts for cherrybark oak and sweetgum (Table 1).

Stem Dimensions.—The oaks were considerably shorter than their competitors. The ranking for the overall mean height of all stems was: persimmon (1.3 m) > sweetgum (1.2 m) > cherrybark oak (0.9 m) > white oak (0.5 m). Season of clipping significantly affected height for cherrybark oak (Table 1); winter-clipped sprouts were taller than spring-clipped sprouts (Fig. 3). For white oak, season, release, and their interaction were all significant, which reflected the considerably taller sprouts in the no release/winter treatment. The release treatment had significant effects on persimmon and sweetgum, where sprouts of the no-release treatment were taller than the released sprouts.

Mean diameter of all stems was ranked as follows: persimmon (12.9 mm) > sweetgum (12.3 mm) > cherrybark oak (7.8 mm) > white oak (5.7 mm). Both release and season treatments were significant for cherrybark oak, with the higher values occurring for the released/winter treatment (Table 1; Fig. 3). For white oak, season and the season-release interaction were significant. This interaction probably reflects the considerably higher diameter when the no-release treatment was clipped in winter when compared to spring. By contrast, mean diameter of all stems for persimmon and sweetgum did not vary significantly with the release and season treatments. The higher number of multiple stems occurring on persimmon and sweetgum rootstocks probably reduced mean diameter of all stems because the multiple stems were usually smaller in diameter.

Above-Ground Biomass.—Total biomass was ranked across species as follows: sweetgum (257 g/rootstock) > persimmon (231 g/rootstock) > cherrybark oak (95 g/rootstock) > white oak (28 g/rootstock). The effects of season of clipping were significant for cherrybark oak, white oak, and sweetgum (Table 1). In each case, the winter-clipped sprouts had more total biomass than those from rootstocks clipped in the spring (Fig. 4). The release treatment only significantly affected cherrybark oak biomass, where the released sprouts had more biomass

Table 1. Analysis of variance for selected properties of cherrybark oak, white oak, persimmon, and sweetgum sprouts grown under two levels of simulated release (released and not released) one growing season after clipping 1-year-old, shade-grown seedlings during two seasons (winter and spring).

	Release		Season		Release* Season	
Variable	MS[*]	*P>F*	MS	*P>F*	MS	*P>F*
			---Cherrybark oak---			
Number of sprouts	7.30E-1	0.009	4.34E-4	0.938	1.09E-2	0.697
Mean height all stems	4.87E-2	0.069	4.00E-1	0.000	8.66E-3	0.406
Mean diameter all stems	5.49E0	0.023	2.15E1	0.000	3.91E-3	0.944
Total biomass	5.78E3	0.046	1.54E4	0.004	1.08E2	0.758
Stem density	1.23E-2	0.008	3.73E-4	0.568	7.36E-4	0.427
Specific leaf area	9.41E3	0.000	7.60E2	0.042	3.88E0	0.869
			---White oak---			
Number of sprouts	3.70E-1	0.219	1.71E0	0.019	7.95E-1	0.085
Mean height all stems	9.58E-2	0.001	2.27E-1	0.000	1.17E-1	0.000
Mean diameter all stems	6.16E-1	0.089	8.69E0	0.000	4.50E0	0.001
Total biomass	1.18E2	0.440	3.34E3	0.002	1.63E0	0.926
Stem density	1.16E-2	0.008	6.28E-4	0.453	3.39E-3	0.101
Specific leaf area	5.25E3	0.000	5.77E2	0.025	2.01E2	0.148
			---Persimmon---			
Number of sprouts	1.27E0	0.118	3.91E-1	0.362	2.93E-1	0.427
Mean height all stems	3.26E-1	0.014	1.55E-1	0.066	1.30E-3	0.852
Mean diameter all stems	2.11E-2	0.947	1.12E1	0.148	1.40E-2	0.957
Total biomass	1.52E0	0.989	1.07E4	0.266	1.14E4	0.252
Stem density	3.74E-2	0.001	1.84E-5	0.920	3.92E-6	0.963
Specific leaf area	1.29E4	0.000	9.37E0	0.824	3.07E2	0.221
			---Sweetgum---			
Number of sprouts	7.11E0	0.001	5.62E-1	0.184	1.11E-1	0.539
Mean height all stems	2.56E-1	0.014	1.35E-1	0.055	4.13E-2	0.253
Mean diameter all stems	1.29E0	0.546	1.17E1	0.091	6.28E0	0.200
Total biomass	1.20E2	0.896	3.64E4	0.043	1.74E4	0.139
Stem density	2.97E-3	0.017	1.40E-8	0.995	1.73E-6	0.945
Specific leaf area	2.10E4	0.000	6.22E2	0.123	5.01E1	0.641

[*] Mean square. Degrees of freedom are: release (1), season (1), release x season interaction (1). Block effects are not shown.

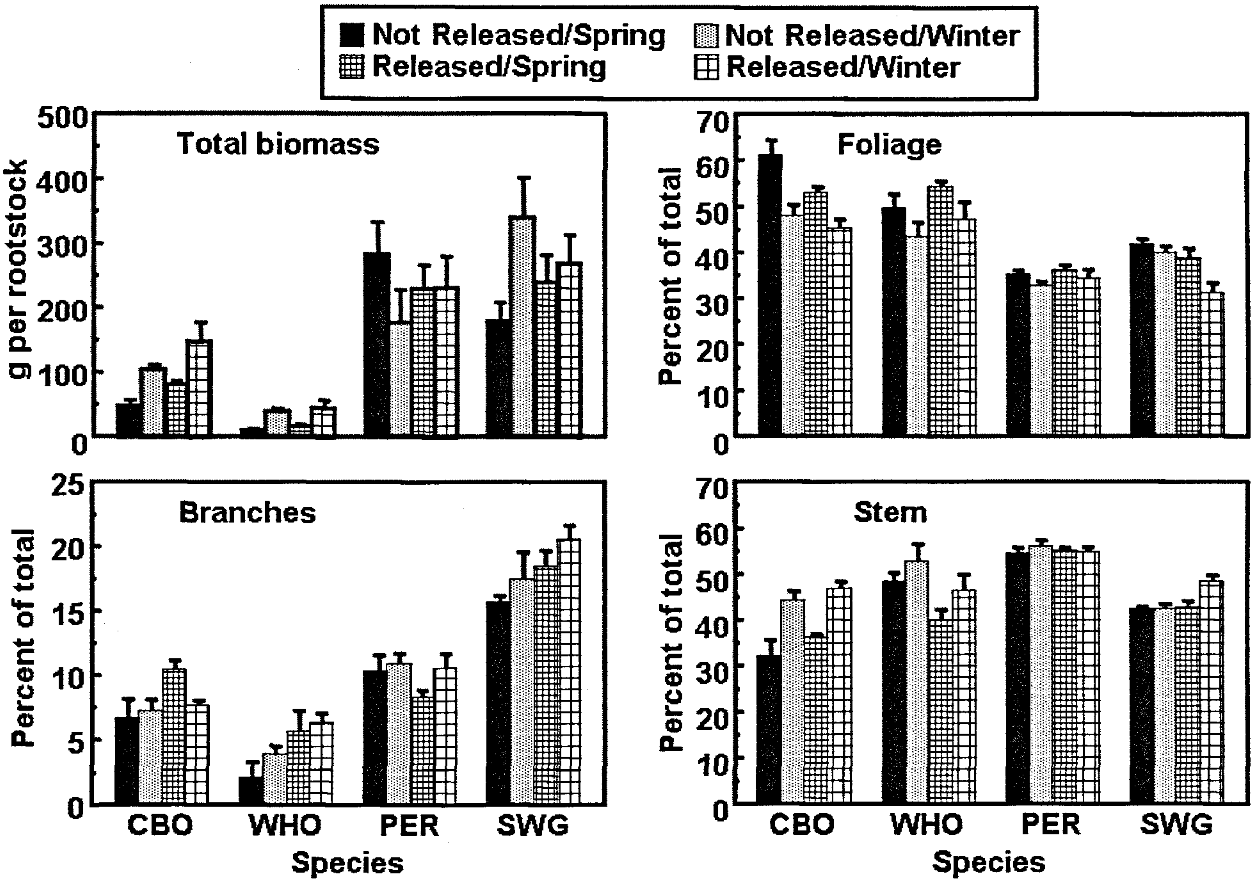

Fig. 4. Total biomass and the percentage distribution among components of cherrybark oak (CBO), white oak (WHO), persimmon (PER), and sweetgum (SWG) sprouts one growing season after implementing release and clipping treatments. (Mean plus one standard error).

than those not released. In contrast, neither release or season treatments significantly affected the biomass of persimmon.

The distribution of biomass among foliage, branches, and stem is also shown in Fig. 4; the small standard errors showed that there was relatively little variation in the distribution of biomass among components. Comparing the species, the oaks tended to be higher in foliage than their competitors but lower in branches and stems. The mean distribution of total biomass for the oaks was foliage (50%), branches (6%) and stems (44%), while the distribution for their competitors was foliage (36%), branches (14%) and stems (50%). However, it is not clear whether these differences are due directly to species or to the height and diameter differences between species.

Stem Wood Density.—Stem density was ranked across species as follows: white oak (0.99 g/cm^3) > cherrybark oak (0.92 g/cm^3) > persimmon (0.74 g/cm^3) > sweetgum (0.67 g/cm^3). For all species, released sprouts had a significantly higher stem density than sprouts that were not released (Table 1); this was one of the few relationships that was consistent across all species (Fig. 5). This relationship seemed logical, since lower stem densities would be needed to support the seedling's mass in the more protected environment provided by the shadehouses in the no-release treatment. It probably reflects a response of the sprouts to agitation by wind and rain and subsequent compression wood formation.

Foliar Characteristics.—The specific leaf area ranged from a minimum of 99 cm^2/g for persimmon in the released/spring treatment to a maximum of 205 cm^2/g for sweetgum in the no-release/spring treatment (Fig. 6). This range in values is typical of that observed for a wide variety of tree species (McClendon and McMillen 1982). The large differences in leaf areas for sweetgum in the no-release treatment are consistent with physiological plasticity that permits adaptation to shaded conditions, which has also been observed by others (Guo et

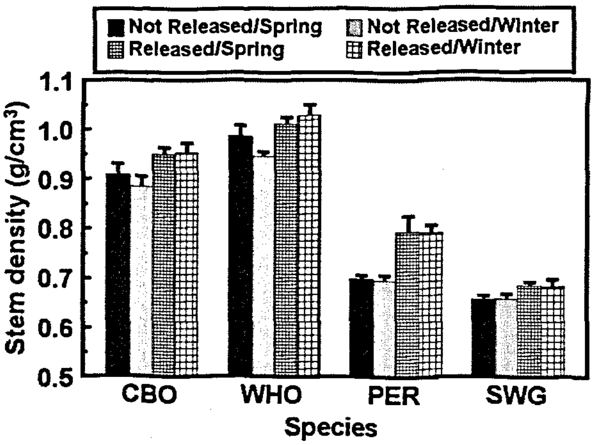

Fig. 5. Stem density of cherrybark oak (CBO), white oak (WHO), persimmon (PER), and sweetgum (SWG) sprouts one growing season after implementing release and clipping treatments. (Mean plus one standard error).

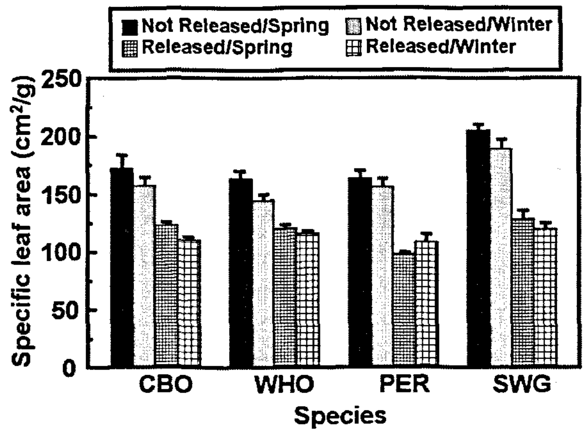

Fig. 6. Specific leaf area of cherrybark oak (CBO), white oak (WHO), persimmon (PER), and sweetgum (SWG) sprouts one growing season after implementing release and clipping treatments. (Mean plus one standard error).

al. 2002). For all species, specific leaf area was significantly higher in the no-release treatment (Table 1). Season of clipping significantly affected only the specific leaf area of the oaks with higher values occurring in the spring clipping.

Discussion

This study offers an interesting look at the growth rates of species which are normally thought of as being competitors. Of all the factors tested in this study, species was the most important factor affecting growth. For example, the biomass of persimmon at the conclusion of the experiment was about 10 times that of white oak. These differences reflect both the reproductive and growth strategies that occur among species and shape their development. When the seedlings in this study were planted, the differences among species correlated well with the size of each species' seeds (Schopmeyer 1974). White oak had the biggest seeds and produced the biggest seedlings at planting time, while sweetgum had the smallest seeds and had the smallest seedlings. However, this initial growth advantage of the oaks was offset by the rapid first-season growth exhibited by the competitors, and the oaks were considerably smaller than their competitors at the end of the first growing season. The size differences that existed among species after the first growing were essentially maintained after the study's clipping and release treatments were imposed and sprouts developed from the clipped rootstocks during their second year.

The oaks were more responsive to the released treatments imposed in this study than their competitors, especially when they were clipped in winter. This treatment response may reflect the greater intolerance of oaks to shade when compared to their competitors. The response of the oaks to light conditions appears to be dependent on seedling age. For example, Guo et al. (2001) observed that cherrybark seedlings responded favorably to the more intensive light regimes during their second growing season but not during their first growing season. Gardiner and Hodges (1998) found that height of 2-year old cherrybark oak seedlings was greatest with moderate levels of sunlight (27% and 53% of full sunlight); diameter showed a similar pattern, except that it was maximized at 53%. In addition, Guo and Shelton (2004) found that 2 to 3 hours of direct sunlight resulted in about the same biomass production in 2-year old cherrybark oaks as in more intensive light regimes. For cherrybark oak seedlings the more intensive light regimes have also been observed to result in greater levels of root production in relation to stem production (Gardiner and Hodges 1998). Sung et al. (1998) showed that the increased biomass allocation to an oak seedling's roots was mainly associated with the lateral roots rather than the tap root. This shift to greater below-ground productivity undoubtedly reflects the higher soil moisture stresses that develop when seedlings are exposed to long periods of direct sunlight (Guo et al. 2002).

Oak seedlings appear to produce maximum early growth at moderate levels of shade when grown in pure populations. However, less is known about the light requirements of the oaks when grown in mixture with competing species. Because oaks are often shorter than their competitors, oak seedlings are shaded by competing understory vegetation in addition to the overstory and midstory trees occupying the site. This subordinate position may make more intensive light regimes favorable in such situations. For example, Guo et al. (2002) showed that high levels of sunlight were necessary for water oak (*Quercus nigra* L.) seedlings to remain competitive with sweetgum when grown in mixtures. In our study, both cherrybark oak and white oak produced the greatest above-ground biomass when under the full sunlight provided by the released treatment. However, these oak sprouts were undoubtedly partially shaded by their taller persimmon and sweetgum competitors.

Season of clipping was a significant determinant of the growth of sprouts for the oaks, but seasonality effects were marginal for sweetgum and non-significant for persimmon. For the oaks, sprouts developing from winter clipped rootstocks exhibited greater growth than those clipped in the spring. Cain and Shelton (2000) also observed that the sprouts developing from oak seedlings top-killed by controlled fire in winter grew more that those top-killed during the summer. One obvious reason for the seasonal effects is that recovery from the winter clipped treatment had a head start on the spring clipped treatment. According to our field notes, above ground recovery was initiated on all species of the winter clipped seedlings, except persimmon, in late March. Thus, the winter clipped treatment had at least a several-week growth advantage on the spring clipped treatment. In addition, Huddle and Pallardy (1999) reported that the starch reserves in the root system at the time of top-killing are important for the subsequent growth of sprouts. The winter clipping treatment of this study was imposed when the starch reserves of the roots were at a maximum while the seedlings were dormant and leafless. In contrast, the spring clipping treatment was applied when starch reserves were reduced due to the recent initiation of spring growth and foliation. Starch reserves were also probably a factor in the slightly better survival of oak rootstocks when they were clipped in the winter.

Sprouts of cherrybark oak and white oak did not grow as fast as their competitors under the environmental conditions tested in this study. These results suggest that for the oaks to successfully compete with their competitors, the oaks have to start out with an initial size advantage. The ranking of species for seedling size at the end of the first growing season was essentially the same as the sprouts one growing season after clipping, and this trend was true regardless of the level of shade or the season of clipping. However, the oaks seemed to be more competitive when clipped in the winter than in the spring. Thus, silvicultural treatments resulting in top-killing advanced regeneration, such as prescribed fire or harvesting, would be more favorable to oak regeneration if conducted during the dormant season. One of the reasons that the oaks are at a size disadvantage with their competitors is associated with their much denser stems. Although the oaks were clearly smaller on average than their competitors, there were exceptions for individual stems, and some oaks achieved dominant positions. Thus, the relative density of the oaks and their competitors and the stocking goals in the regenerated stand are important considerations in evaluating the adequacy of advanced oak regeneration.

Conclusions

Successful regeneration of oak species in Arkansas is important from both ecological and financial perspectives. Several studies have documented the ability of oaks to sprout after being top-killed by harvesting activities, browse, or fire. The resilience of oaks to the loss of aboveground tissues also is directly correlated with storage of carbohydrates in root systems in amounts sufficient to provide the energy necessary for new sprouts to develop. Moreover, oaks are known to respond to increased light availability following the creation of gaps in the forest canopy, and many of the current oak-hickory dominated forests in Arkansas resulted from the ability of oaks to become the dominant overstory species even after extended periods in the understory. The results of this study improve our understanding of the interaction between two oak species and two other hardwood species which often compete for light, moisture, and nutrient resources.

Our findings suggest that the season in which top-kill occurs may affect the survival of oak regeneration, since spring clipping of seedlings resulted in a slightly higher mortality rate than did clipping during the dormant season. These findings are in agreement with our understanding of photosynthate allocation by oaks and the energetics of sprouting. Oak sprouts were found to have higher density stems and greater foliar biomass as a percentage of total biomass than their competitors (sweetgum and persimmon). Reciprocally, the competitors allocated more photosynthate to height and diameter growth and woody biomass. Despite the ability of oaks to sprout following top-kill, the results of this study suggest that when regenerated stands include rapid growing competitive species, it is critical for oak reproduction to have a size advantage relative to their competitors in order for the oaks to dominate the future forest canopy.

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