EFFECTS OF SHADE ON THE GROWTH OF NATURAL AND ARTIFICIALLY ESTABLISHED WHITE OAK (*QUERCUS ALBA* L.) REGENERATION

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Abstract—-Treatments, such as mid-story removal, have been designed to enhance the vigor of advance oak regeneration through the increase of diffuse light levels reaching the forest floor. In order for these treatments to be successful, proper light levels are crucial in order to maximize oak seedling growth while simultaneously suppressing the growth of shade intolerant species. This study was designed to assess light levels needed to maximize the growth potential of white oak advance regeneration and artificially established white oak seedlings. Shade frames using shadecloth were used to impose shading treatments. Thirty natural advance regeneration and thirty 1-0 bare root seedlings were monitored in each plot (720 total). Results for white oak advance regeneration indicate that the 21 percent and the full sunlight resulted in significantly greater height growth than the other treatments. However, ground line diameter growth did not differ among the 21, 45, and 100 percent treatments.

INTRODUCTION

Regenerating oak (*Quercus* spp.) on intermediate to high quality sites (upland oak site index >65 ft, base age 50) has proven difficult to achieve (Deen and others 1992; Janzen and Hodges 1985; Lockhart and others 1992; Lockhart and others 1999; Loftis 1983; Loftis 1990a, 1990b, 1992; Lorimer and others 1994; Miller and others 2004). Forest conditions have changed from pre-settlement times allowing mid-stories of shade tolerant species, such as maple (*Acer* sp.) and American beech (*Fagus grandifolia*), to develop (Abrams 2003, Clark 1992, Lorimer and others 1994) in many of our oak dominated forests resulting in significant competition for oak regeneration.

The oak shelterwood system is designed to enhance the size and vigor of small low-vigor advance regeneration growing under intact canopies (Stringer 2005a, 2005b). The system is composed of a mid-story removal designed to increase diffuse light to intact advance regeneration followed by full or substantial canopy removal after the advance regeneration has reached adequate size. This system has been explored in northern red oak dominated ecosystems (Loftis 1990b, Lorimer and others 1994) and in bottomland cherrybark oak stands (Lockhart and others 1992, 1999). However, research involving white oak (*Q. alba*) response to the oak shelterwood system has not been undertaken.

White oak is one of the most shade tolerant oak species in the eastern United States (Abrams 2003). Significant research on physiological attributes of fast growing commercially important oak species such as northern red oak and cherrybark oak has been completed to determine optimal regeneration strategies for these species. However, optimal light levels and stand conditions needed to encourage natural white oak regeneration are yet to be determined.

Artificial shading studies using shade cloth have been used to determine ideal light levels for maximizing growth of northern red oak, black oak, and cherrybark oak (Gottschalk 1994, Gardiner and Hodges 1999). Gottschalk (1994) performed shading studies in a garden plot where seedlings of northern red oak, black oak, black cherry (*Prunus serotina* Ehrh.) and red maple (*A. rubrum* L.) were grown under eight levels of shade. Results indicated that light levels of greater than 20 percent produced more vigorous oak seedlings than did light levels less than 20 percent. Gardiner and Hodges (1999) also performed an artificial shading study on cherrybark oak in a garden plot at four levels of shade. They reported that maximum biomass

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was accumulated and the highest seedling vigor was obtained at 53 percent of full sunlight. Both studies were conducted in garden plot settings and used seedlings grown from seed. While these studies focused on the response of artificially reared seedlings, oaks are typically regenerated naturally through the release of advance regeneration. Unfortunately less is known about the light response of natural advance regeneration.

The focus of this study was to determine the response of *in situ* white oak advance regeneration and artificially established seedlings growing under differing levels of shade. This study provides an assessment of the light regimes needed to increase the vigor of intact natural oak advance regeneration and can be used to provide guidelines for the use of the oak shelterwood system in white oak dominated stands.

MATERIALS AND METHODS

The study site was located in central Kentucky (Madison County) on the western edge of the Cumberland Plateau. The site is at the base of a south-facing slope, typical of "intermediate" quality sites (upland oak site index >65-75 feet). White oak dominated the pre-harvest canopy, while the mid-story was dominated by red maple, beech (*Fagus grandifolia)* and minor components of other associated species. Numerous cohorts of white oak advance regeneration were present on the site.

A four acre commercial clearcut was completed in November 2003 and all residual stems >1 inch dbh were felled in January and February of 2004. Undesirable species were treated with Garlon 4® or 100 percent Roundup Pro®. In February of 2004 a total of twelve 14'x14'x4' plots were established in the harvested area and were located based on the presence of advance regeneration. The plots were cleared of all logging debris and thirty white oak advance regeneration seedlings were flagged, labeled, and measured in each plot (360 seedlings total). Additionally, thirty white oak 1-0 bare root seedlings were planted on each plot in February and March 2004 (360 total). All undesirable species larger than the size of the seedling in the study plots were cut with a chainsaw and stumps were sprayed with 100 percent Roundup Pro® to prevent re-sprouting.

Four light treatments were randomly assigned to the twelve plots resulting in 3 replicates of each treatment. Three of the treatments were shaded (9 plots) and one treatment was not shaded (3 plots). Shade treatments were selected to span the range of photosynthetically active radiation (PAR) created by management practices to encourage oak regeneration. The light levels under shade cloth were developed to simulate a mid-story removal, a traditional shelterwood, and a clearcut.

Shade frames (14'x 14' x 4') were erected before the start of the growing season in 2004. Shade cloth (Ecologic Technologies®) at 10, 30, and 60 percent transmittance was used to establish the shading treatments. Shade cloth was draped over the 14' x 14' x 4' shade frames to within 1 foot of the ground. Shade cloth was left in place throughout the growing season and was taken down in November of 2004 after leaf fall. Shade cloth resembling an intact canopy (<2 percent sunlight) was not available and a control plot under an intact canopy directly adjacent to the clearcut was established for pairwise comparisons among treatments (light levels). Fifty white oak advance regeneration and seventy bare root seedlings were monitored under the intact canopy.

Initial measurements of all seedlings in the 12 plots were taken before the beginning of the growing season including total height, length of all internodes (growth flushes), and ground line diameter (gld). Survival, total height, gld, and length of current season flushes were determined at the end of the first growing season after treatment. Total height was taken from ground line (mineral soil) to the base of the terminal bud. All growth flushes, or internodes, were measured between bud scale scars. Ground line diameter (gld) was measured at the surface of the mineral soil and determined from two perpendicular measurements using a digital caliper.

PAR was measured at one foot above the ground in each of the 12 plots using a Li-cor® light wand. Measurements were taken on cloudless days between 12:00 and 2:00 pm. Thirty readings were taken at random locations at each of the twelve plots.

Survival data was analyzed using Proc genmod and Proc logistic (SAS Institute 2000). Odds ratios were used to detect significant differences between treatments. Growth data was analyzed using Analysis of Variance (ANOVA) and multiple comparisons were performed using Least Significant Difference (LSD) pairwise tests at the $p \leq 0.05$ level.

RESULTS

Photosynthetically Active Radiation

The mean PAR for each treatment was 178, 390, 825, and 1862 µmol/m2/s corresponding to 10, 21, 45, and 100 percent full sunlight respectively. Mean PAR under the intact canopy was 46 µmol/m2/s corresponding to 2 percent full sun.

Advance Regeneration Growth and Survival

Height growth of advance regeneration exhibited a significant treatment response. The 21 percent treatment resulted in significantly greater height growth ($p=0.0004$) than other treatments with the exception of the full sun treatment where the difference was not significant (fig. 1). The seedlings in the intact canopy treatment performed significantly worse ($p=0.0128$) than other treatments with the exception of the 45 percent treatment.

There was no significant difference in gld growth among the 10 percent, 21 percent, and 100 percent treatments (fig. 2). However, the 45 percent treatment produced significantly greater gld than the 10 percent and the intact canopy treatment ($p=0.0001$). Seedlings of all treatments exhibited significantly greater gld growth than the seedlings in the intact canopy treatment ($p=0.0002$) (fig. 2).

Ten percent of all advance regeneration monitored experienced top death. However, 45 percent of these were able to resprout. Four percent of all advance regeneration experienced some top dieback and 3 percent of all advance regeneration was browsed.

1-0 Bare Root Seedling Growth and Survival

First year survival of bare root stock by treatment ranged from 70 to 90 percent. Seedlings in the 10 percent treatment had the highest percent survival (~90 percent) while the 45 percent treatment had the lowest survival (~70 percent) (fig. 3).

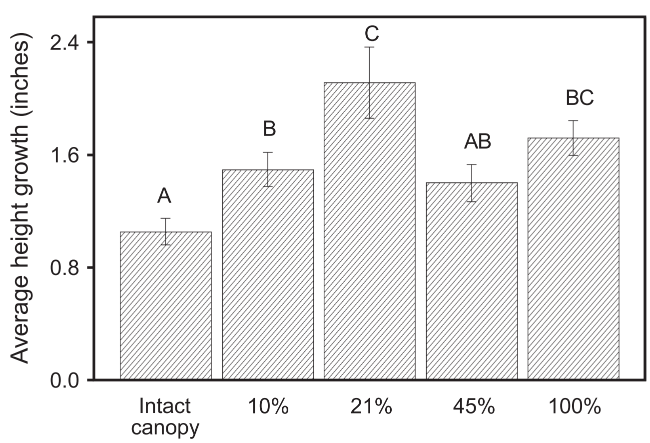

Figure 1—Height growth of advance white oak regeneration by treatment (percent full sunlight). Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

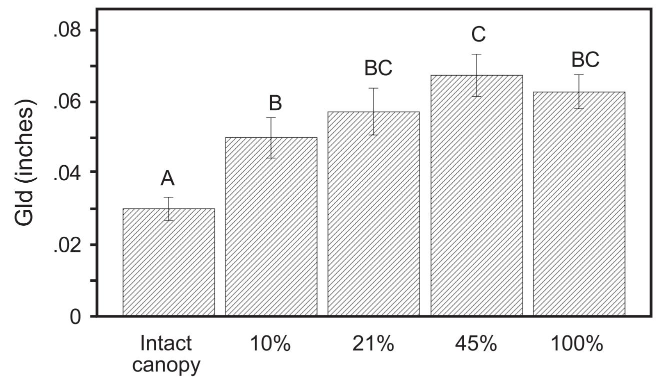

Figure 2—Ground line diameter (gld) growth of white oak advance regeneration by treatment. Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

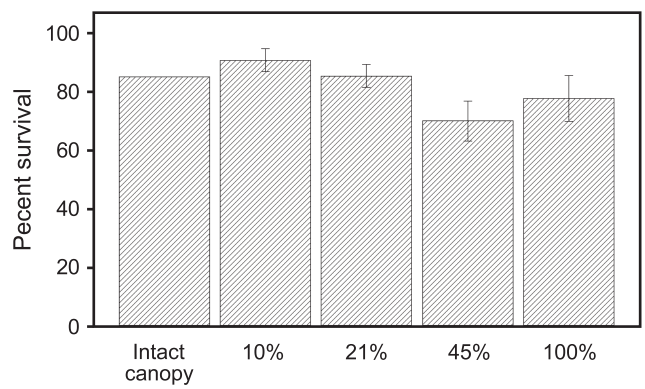

Figure 3—Survival of bare-root 1-0 white oak seedlings by treatment.

There was a general negative relationship between height growth and light with the intact canopy treatment resulting in significantly greater height growth than all other treatments ($p<0.0001$). In the artificially shaded treatments, the 21 percent light treatment resulted in significantly greater height growth than the 10 percent, 45 percent and the 100 percent treatments ($p=0.0022$) (fig. 4).

There was no significant difference among treatments with respect to ground line diameter ($p=0.0713$) with the exception of the 10 percent treatment which grew significantly less than the control and 100 percent treatments ($p=0.0448$) (fig. 5).

DISCUSSION

While artificial shading, provided by shade cloth, does not simulate the entire suite of environmental variables associated with naturally shaded conditions it is a reasonable means of investigating light requirements. It is suggested from other shading studies that light is not the only abiotic factor affecting growth and development. Soil moisture, humidity, temperature, and overall microclimate are all extremely important variables to consider in the development of tree seedlings. While no other abiotic factors were measured other than PAR in our study, it was apparent from observation that soil moisture in the more heavily shaded treatments was higher and remained longer after a precipitation event. The effect of silvicultural treatments on available soil moisture is a reasonable area of study and should be assessed further.

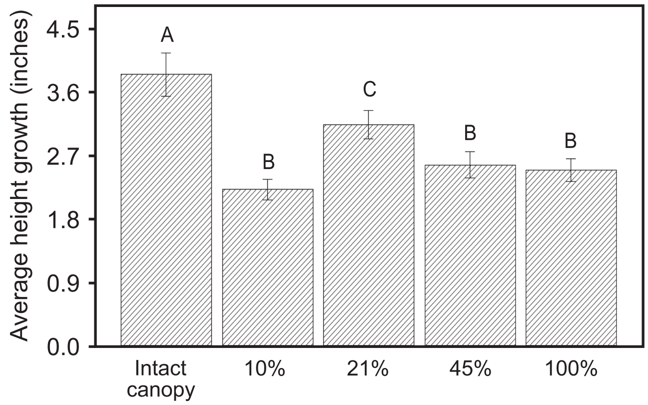

Figure 4—Height growth of bare-root 1-0 white oak seedlings by treatment. Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

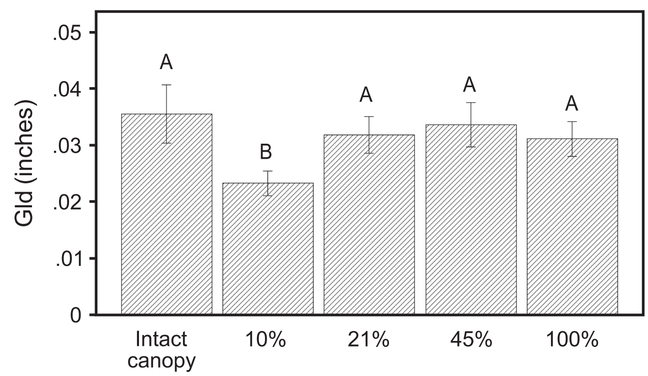

Figure 5—Ground line diameter growth of bare-root 1-0 white oak seedlings by treatment. Letters represent significant differences detected using ANOVA and LSD at the p<0.05 level.

White oak being one of the more shade tolerant oaks will most likely be able to maintain height growth at lower light levels compared to less tolerant oaks such as northern red oak and cherrybark oak. These initial insights suggest that while northern red oak and cherrybark oak may grow best at around 50 percent of full sunlight, white oak advance regeneration seems to prefer slightly lower irradiance levels around 20 percent. This difference in light requirements indicates that species specific treatments should be applied and tested to successfully increase the vigor of advance oak regeneration.

Bare root seedlings performed best initially under an intact canopy. Although we did not measure the diameter of the new growth, from observation the initial growth put on by these seedlings in an intact canopy was extremely etiolated. As time progresses we do expect that this initial trend will be reversed. Subsequent growing seasons will reveal the light preferences of bare root seedlings once they are fully established and have no confounding effects of transplant.

CONCLUSIONS

Results of this study indicate that 20 percent full sunlight is a reasonable target for mid-story removal treatments to increase the height growth of white oak advance regeneration. Results also show the potential for long-term vigor increases as indicated by increases in gld at this light level as compared to the intact canopy treatment. This response in height and gld of the white oak advance regeneration in this study occurred at lower light levels than have been found for other oaks adapted to mesic sites. The results indicate that the oak shelterwood system initially developed for northern red oak and cherrybark oak has potential for implementation in white oak stands but needs further study.

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