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Article

Performance of Oak Seedlings Grown under Different Oust® XP Regimes

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Abstract: Herbaceous weed control (HWC) is prescribed for growing season control of vegetative competition in hardwood afforestation attempts on former agricultural areas. Without HWC, planted seedlings often exhibit poor growth and survival. While currently employed HWC methods are proven, there is a substantial void in research comparing HWC treatments spanning multiple years. A total of 4,320 bare-root seedlings of three oak species were planted on three Mississippi sites. All sites were of comparable soils and received above average precipitation for the majority of the three-year study. Eight combinations of HWC and mechanical site preparation were utilized at each site, with 480 seedlings planted in each of the nine blocks, and a total of 1,440 seedlings per species planted across all sites. Treatments were installed on 3.1 m centers, with mechanical treatments as follows: control, subsoiling, bedding, and combination plowing. HWC treatments included one and two-year applications of Oust® XP. Treatments were applied over seedlings post-planting in 1.5 m bands, at a rate of 140.1 g product/hectare. Excepting one species, HWC dependent height or groundline diameter differences were not detected among mechanical treatments, species, HWC regime, or combinations thereof. No survival differences were observed among site preparation treatments or species. However, analysis detected a growing season/HWC treatment interaction for seedling survival.

Keywords: herbaceous weed control; oak afforestation; hardwood plantations; silvicultural treatments; Oust XP treatment

1. Introduction

Cost share funding and recognition of important functions and values of bottomland ecosystems by public and private entities has driven efforts to afforest large sections of retired agricultural areas over the last 25 years [1,2]. During the 1990s, approximately 81,000 hectares of retired agricultural fields were afforested across the Lower Mississippi Alluvial Valley (LMAV) with the support of cost share funding [3]. In the period between the mid-1990s and 2004, approximately 150,000 hectares of retired agricultural fields underwent hardwood afforestation in the LMAV [4]. Continued afforestation is expected with an estimated 12 million hectares of retired agricultural field afforestation completed by the year 2040 [5]. As such, the importance of developing the appropriate methodology for establishing successful plantations in these areas cannot be understated. Much of this land base is expected to be regenerated in oak-dominate stands [6].

Inadequate growth and survival of seedlings planted on former agriculture fields is common. Resultant stands often retain low percentages of planted oaks [4,7–9]. The strong trend of failure observed in LMAV afforestation efforts indicates a need for greater understanding of hardwood plantation establishment in these settings. A multitude of factors can negatively impact seedling growth and survival including: soil conditions, planting techniques, seedling quality, and competing vegetation. These problems can be alleviated through proper planting of high quality seedlings, as well as through application of proper silvicultural practices designed to enhance survival and growth. Notably, seedling establishment on these areas can be improved through the use of herbaceous weed control (HWC).

Competing vegetation is often the driving causal factor in oak plantation failure. Both herbaceous and woody competition threaten survival of planted oak seedlings, with herbaceous competition posing the greatest risk during the first years of establishment [10,11]. Greater impact of herbaceous competition is likely the result of increased exploitation of soil moisture and nutrients due to the more extensive nature of herbaceous species root systems [12].

Improved growth and survival of hardwood seedlings treated with broad-spectrum pre-emergent herbicides has been documented. Woeste *et al.* [13] observed that three-year-old seedlings of ten northern hardwood species treated with a pre-emergent application of aminopyralid (Milestone®) displayed greater survival than seedlings grown under control conditions. Of these species, northern red oak (*Quercus rubra* L.) seedlings exhibited lower survival than black cherry (*Prunus serotina* Ehrh.), black walnut (*Juglans nigra* L.), white ash (*Fraxinus. americana* L.), or white oak (*Quercus alba* L.) seedlings. Greater incidences of top dieback were observed in the control plots, and seedlings in control plots exhibited less stem volume in seven of the ten species.

Groninger *et al.* [14] found that green ash (*Fraxinus pennsylvanica* Marsh.) treated with a 140.1 grams (g) /hectare application of Oust® exhibited 40 percent greater height growth after three years than untreated seedlings. Ezell *et al.* [15] observed that a 140.1 g/hectare pre-emergent application of

Oust® is an effective herbaceous competition control technique and improves survival of planted oaks. Seedlings in plots treated with Oust® exhibited between 21 to 44 percent greater survival compared to seedlings in untreated plots for three separate field studies. In a study involving cherrybark oak (*Quercus pagoda* Raf.), Nuttall oak (*Quercus texana* Buckley.), Shumard oak (*Quercus shumardii* Buckley), water oak (*Quercus nigra* L.), willow oak (*Quercus phellos* L.), and white oak, Ezell and Catchot [16] found that Oust®, when used as a pre-emergent application, caused no damage and resulted in an increase of approximately 20 percent in first-year survival across all species. Ezell and Hodges [17] reported that a pre-emergent application of Oust® resulted in higher second-year survival of planted Shumard oak with no observable phytotoxicity in seedlings.

2. Experimental Section

2.1. Study Site Description

This study was conducted on three publicly owned properties in Mississippi. Each site was selected for consistency of terrain, soil texture, and former agriculture production status. While some variation existed among sites, all were relatively homogeneous regarding selection criteria. Additionally, all were representative of sites currently undergoing afforestation in the LMAV.

The first site was located on the United States Army Corps of Engineers Arkabutla Lake Project approximately 8.5 kilometers (km) northwest of Coldwater, Mississippi (33.744° N, 90.079° W). The site was in soybean (*Glycine max* (L.) Merr.) production until September 2007. The soils are mapped as Memphis silt loam (Fine-silty, mixed, active, thermic Typic Hapludalfs) and Loring silt loam (Fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) [18]. These soils are well drained and soil tests indicated an average pH of 6.2 across the site. Average yearly and growing season (March–October) precipitation over the three-year course of this study was 153.8 cm and 111.4 cm, respectively. Average 40-year temperature was 15.7 °C, with temperature extremes ranging from −24.4 °C to 41.7 °C, 40-year average precipitation was 142.5 (cm), and 40-year average growing season precipitation was 90.1 cm [19]. Dominant herbaceous species present at study initiation were Brazil vervain (*Verbena brasiliensis* Vellozo.), poorjoe (*Diodia teres* Walt.), and thorny amaranth (*Amaranthus spinosus* L.). Twenty-one other herbaceous species occurred in small quantities. Total ground coverage of all species was approximately five percent.

The second site was located on the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP) Copiah County Wildlife Management Area (WMA), approximately 26 km northwest of Hazlehurst, Mississippi (31.819° N, 90.672° W). The site was retired from row crop production in the 1990s and was maintained as a wildlife opening through mowing and disking from the time of agricultural retirement until initiation of this study. The soil series is Oaklimeter silt loam (coarse-silty, mixed, thermic Fluvaquentic Dystrochrept) [20], which is moderately well drained, and soil tests indicated an average pH of 5.2. Average yearly and growing season precipitation over the three-year course of this study was 161.1 cm and 101.3 cm, respectively. Average 35-year temperature was 18.4 °C, with temperature extremes ranging from −12.8 °C to 38.3 °C, 35-year average precipitation was 150.3 cm, and 35-year average growing season precipitation was 95.1 cm [19]. Dominant herbaceous species included crimson clover (*Trifolium incarnatum* L.), ladino clover

(*Trifolium repens* L.), and ryegrass (*Lolium multiflorum* Lam.). Twenty-four other herbaceous species occurred in small quantities. Total ground coverage by all species was 100 percent.

The third site was located on the MDWFP Malmaison WMA, approximately 23 km northeast of Greenwood, Mississippi (33.688° N, 90.053° W). The site was retired from row crop production in 1998 and was maintained as an opening for wildlife through mowing and disking from the time of agricultural retirement until initiation of this study. The soil series is Collins silt loam (coarse-silty, mixed, acid, thermic Aquic Cumulic Haplorthent) with slopes between zero and three percent [21]. This soil is moderately well drained, and soil tests indicated that a pH of 6.3 across the site. Average yearly and growing season precipitation over the three-year course of this study was 148.5 cm and 110.7 cm, respectively. Average 40-year temperature was 17.9 °C, 40-year average precipitation was 136.8 cm, and 40-year average growing season precipitation was 87.2 cm [19]. Dominant herbaceous species were ryegrass, bermudagrass (*Cynodon dactylon* L.), Brazil vervain, and Carolina horsenettle *(Solanum carolinense* L.). Forty other herbaceous species occurred in small quantities. Total ground coverage of all herbaceous species was 100 percent.

2.2. Experimental Design

The study was completely replicated at all three sites. Each site had its own unique installment of randomized treatment combinations. The experiment utilized a split, split-plot design with whole plot factors in a randomized complete block design, sub-plot factors randomized within whole plot factors, and sub, sub-plot factors randomized within sub-plot factors. The whole plot factor was site preparation treatment, the sub-plot factor was species, and the sub, sub-plot factor was HWC regime. The experimental unit was a plot with its unique combination of site preparation treatment, species, and HWC regime. Response variables were height and groundline diameter (GLD). Three replications, each containing all possible site preparation/species/HWC treatment combinations, were established at each site.

2.3. Seedling Establishment

Seedlings were lifted from an Alabama nursery, and were germinated from acorns collected in the Delta region of Mississippi. Seedling specifications required 1–0 seedlings to be of overall vigorous appearance and have relatively intact root systems. Seedling parameters dictated that the stems be 45.7 cm to 61.0 cm tall and possess root systems that were 20.0 cm to 25.0 cm long, with a minimum of eight first-order lateral roots.

Across the three sites a total of 4320 seedlings were planted, with 1440 seedlings each of Nuttall oak, Shumard oak and swamp chestnut oak (*Quercus michauxii* Nutt.). At each site, the study had 480 seedlings of each oak species (480 total = 160 per block = 40 per mechanical treatment = 20 per HWC regime). Seedlings were planted at root collar depth using planting shovels during February 2008. A spacing of 3.1 m by 3.1 m was chosen to give a seedling density of 1075 seedlings per hectare.

2.4. Site Preparation and Herbaceous Weed Control Treatments

Four site preparation treatment options were used in this study: no site preparation (control), subsoiling treatment, bedding treatment, and combination plowing treatment. Site preparation treatments were applied on 3.1 m centers using an agricultural tractor. Site preparation treatments were applied during the first week of November 2007. Statistical differences were detected among seedlings grown under different mechanical site preparation regimes, but are outside the scope of this paper. Those results are reported elsewhere [22].

A pre-emergent Oust® XP application was applied during March, 2008 to each species/site preparation treatment combination. This treatment was applied in 1.5 m bands at a rate of 140.1 g of product/hectare, over the top of all seedlings after planting and prior to budbreak. Using the same band and rate specifications, a second application of Oust® XP was randomly allocated to one half of seedlings in all species/site preparation treatment combinations during March 2009. A Solo® backpack sprayer was used for herbicide application with a total spray volume of 93.5 liters per hectare (LPH).

2.5. Seedling Measurements and Precipitation

Initial height and GLD of seedlings were taken during February–March, 2008. Height of surviving seedlings was measured to the nearest centimeter using a meter stick. GLD was measured at ground level in 0.1 millimeter (mm) intervals using digital calipers. Ocular damage evaluations were performed monthly for all seedlings throughout the duration of the study. Damage was recorded by type, severity, and causal agent. End of growing season measurements (total height, GLD, and survival) were taken during October 2008, 2009, and 2010. Onsite precipitation totals were recorded for the duration of the study in 0.254 mm intervals using RainWise® Model 111 rain gauges and Hobo® Event Rainfall Loggers placed within planting boundaries.

2.6. Data Analysis

Initial seedling height and groundline diameter were analyzed using Statistical Analysis System (SAS) software version 9.1.3® (Cary, North Carolina). Analysis of Variance (ANOVA) was used to analyze height and groundline diameter for consistency both within and among species. Differences were not detected at the $\alpha = 0.05$ level of significance.

All subsequent statistical analyses were performed using Statistical Analysis System (SAS) software version 9.2® (Cary, North Carolina). PROC UNIVARIATE was used for univariate analysis of height and GLD responses. Analyses indicated skewness which was corrected by taking the log of height and GLD. Model fit included baseline measurements of initial height and initial GLD. Repeated Measures ANOVA was applied on log of height and log of GLD using the covariate of log of baseline measurements of respective responses in PROC MIXED and PROC GLIMMIX. The best covariance structure was 2-band Toeplitz for analysis on height and GLD. Full split, split-plot analysis of covariance model determined a significant species by year interaction for both height and GLD, which mandated further analysis of each species separately.

Height and GLD data were then analyzed for interactions among site preparation and pre-emergent herbaceous control treatments by species. PROC GLIMMIX was used to perform ANOVA to test for main effects and interactions, and to estimate least square means (LSMEANS). Differences were considered significant at the α = 0.05 level of significance.

Survival percentages were arcsine square root transformed for normalization purposes. Repeated Measures ANOVA was applied on transformed survival data using PROC MIXED and PROC GLIMMIX. The best covariance structure was 2-band Toeplitz for analysis of survival. Full split, split-plot analysis of covariance model detected a significant HWC regime by year interaction for survival.

Survival data were then analyzed for interactions among species, site preparation treatments, and year by HWC regime. PROC GLIMMIX was used to perform ANOVA in testing main effects and interactions, and to estimate least square means (LSMEANS). Differences were considered significant at the α = 0.05 level. While transformed survival data were used for analyses, untransformed means are presented for interpretive purposes.

3. Results and Discussion

3.1. Seedling Growth Response to HWC Treatment

No interaction effects were observed for seedling GLD or height among mechanical site preparation and HWC combinations. Additionally, HWC was not found to affect seedling GLD for any species, or seedling height for Nuttall oak or Shumard oak. The only statistical HWC influence detected was observed for height of swamp chestnut oak. Analysis detected a significant main effect height difference ($p = 0.0120$, $F = 6.53$) for swamp chestnut oak seedlings by HWC treatment. Seedlings in areas treated with one year of Oust® XP exhibited greater average height compared to seedlings in areas treated with the two-year Oust® XP treatment (90.4 cm and 83.1 cm, respectively) (Table 1).

Table 1. Average height of swamp chestnut oak by herbaceous weed control (HWC) regime planted on three Mississippi sites, 2008–2010.

HWC Treatment	Height (cm)
1-year Oust® XP	90.4 a [1]
2-year Oust® XP	83.1 b

[1] values within a column followed by same letter are not significantly different at α = 0.05.

While it appears that swamp chestnut oak seedlings grown in two-year Oust® XP areas failed to exhibit a positive response to HWC treatment, no phytotoxic symptoms were observed on any seedlings. This lack of phytotoxic effect has been substantiated by previous research efforts testing effects of Oust®/Oust® XP on hardwood seedlings [15–17]. However, the possibility of negative impacts to seedlings treated with Oust® XP cannot be summarily dismissed. It is possible that variability in susceptibility of oak species to Oust® XP could have played a role in the lower height growth observed in swamp chestnut oak seedlings in two-year Oust® XP application areas compared to one-year areas. Additionally, it is possible that microsite pH variance could have resulted in areas of the study wherein increased activity of Oust® XP produced negative impacts.

While the likelihood of resultant negative impact to seedlings is possible, a more plausible explanation for negative height response exists for swamp chestnut oak seedlings grown in two-year

Oust® XP application areas. Vegetation complexes differed among one-year and two-year Oust® XP application areas. The majority of herbaceous species were controlled for much of two growing seasons in two-year Oust® XP areas. The absence of the shading effect created by herbaceous vegetation could have negatively influenced survival through increased soil desiccation. Additionally, lack of shading resulted in leaf scorching observed on some swamp chestnut oak seedlings. Swamp chestnut oak is classed as shade intolerant [23], but scorches relatively easily when fully exposed to full sunlight such as that encountered in two-year Oust® XP areas. Combined with a period of droughty conditions during May and June of the 2010 growing season, the effects of increased light exposure could have resulted in a retarded cumulative growth effect in the two-year Oust® XP application areas. In these areas, it is possible that two years of increased light exposure resulted in a continuation of lower overall height of seedlings in two-year Oust® XP areas compared to one-year Oust® XP areas. It is probable starting in 2009, that seedlings in one-year Oust® XP areas were better positioned for vigorous growth due to above average first and second-year precipitation and shading by herbaceous species compared to those grown in two-year Oust® XP application areas.

3.2. Seedling Survival by Growing Season and HWC Treatment

Survival differences were not detected among interactions of HWC and mechanical site preparation or species. However, analysis detected a growing season/Oust® XP treatment interaction ($p = 0.0334$, $F = 3.43$) for seedling survival. A decrease in survival was noted each succeeding year in both Oust® XP treatments (Table 2). While the survival difference was significant in the interaction among growing season/HWC treatment combinations, overall seedling survival in the 2-year Oust® XP areas (92.5 percent) would be considered excellent in most afforestation efforts. No combination exhibited a survival level sufficiently low as to dictate a change in establishment techniques.

Table 2. Oak seedling survival by growing season and HWC treatment planted on three Mississippi sites, 2008–2010.

	HWC Treatment	
	1-year Oust® XP	2-year Oust® XP
	Survival (%)	
2008	98.93A [1] a [2]	98.86 Aa
2009	97.82 Ba	96.45 Bb
2010	95.71 Ca	92.50 Cb

[1] values within a column followed by same uppercase letters are not significantly different at α = 0.05; [2] values within a row followed by same lowercase letters are not significantly different at α = 0.05.

No survival differences were detected in seedlings between Oust® XP treatments for 2008 (Table 2). However, a difference was observed among treatments for 2009 and 2010. Seedlings in areas treated with two years of Oust® XP exhibited lower survival for both years. While possible, it is unlikely that Oust® XP applications had any direct negative influence on survival. Monthly seedling evaluations did not reveal visible phytotoxic effects of Oust® XP on any seedlings during the duration of the study. Again, probable causes were a combination of factors including increased leaf scorching, drought conditions during early summer of 2010, and the loss of two years of shading effect in areas receiving two years of HWC.

4. Conclusions

The afforestation of retired agricultural lands during the past three decades has resulted in the development of many different management techniques. Hardwood species are being regenerated on thousands of hectares across the LMAV each year using a variety of these techniques. Due to a variety of reasons, many of these efforts have not been successful. Low planted seedling retention indicates a need for greater understanding of proper plantation establishment techniques. Seedling establishment can be improved through usage of HWC.

Increased growth and survival of hardwood seedlings treated with various HWC applications have been well documented [13–17]. The results of this study corroborate the earlier positive trend afforded through HWC applications.

Significant height or GLD differences were not detected between HWC treatments with the exception of height of swamp chestnut oak seedlings. Swamp chestnut oak seedlings grown in areas treated with the two-year Oust® XP treatment exhibited less height growth compared to those grown in areas receiving the one-year treatment. It is probable that leaf scorching contributed to lower observed height in swamp chestnut oak in two-year Oust® XP areas.

As expected, survival decreased with each growing season. However, survival ranged from 95.71 percent in one-year Oust® XP treated areas to 92.5 percent in two-year Oust® XP treatment areas. This is considered excellent survival, and a change in establishment technique would not be warranted on biometric results alone.

First-year differences were not observed between HWC treatments. However, second and third-year differences were detected. Overall, lower seedling survival was observed in areas receiving the two-year Oust® XP treatment compared to the one-year Oust® XP treatment for the 2009 and 2010 growing seasons. It is improbable that HWC treatment resulted in directly detrimental effects to seedlings as no phytotoxic effects were detected in monthly evaluations of seedlings throughout the study. It is more likely that cumulative effects of leaf scorching, soil desiccation, and third-year droughty summer conditions contributed to lower seedling survival in areas that received the two-year Oust® XP treatment.

In conclusion, results of this study indicate that seedling survival is greater in areas receiving one year of Oust® XP compared to two years of Oust® XP. Of the HWC regime options used, under the same site and weather conditions, the one-year 140.1 g/hectare Oust® XP application would be the logical choice in establishment efforts. Lack of increased seedling growth and survival in two-year Oust® XP areas compared to those receiving only one Oust® XP application, combined with the cost of an additional year of herbicidal treatment, would promote selection of the one-year Oust® XP treatment in future efforts.

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Author Contributions

Andrew Ezell provided funding, technical advice and assistance, and editing for this project. Dennis Rowe aided in both analysis of collected data and the subsequent writing of the data analysis section of this manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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