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Article

Effects of Mechanical Site Preparation on Growth of Oaks Planted on Former Agricultural Fields

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Abstract: Mechanical site preparation is frequently proposed to alleviate problematic soil conditions when afforesting retired agricultural fields. Without management of soil problems, any seedlings planted in these areas may exhibit poor growth and survival. While mechanical site preparation methods currently employed in hardwood afforestation are proven, there is a substantial void in research comparing subsoiling, bedding, and combination plowing treatments. A total of 4,320 bare-root Nuttall oak (*Quercus texana* Buckley), Shumard oak (*Quercus shumardii* Buckley), and swamp chestnut oak (*Quercus michauxii* Nutt.) seedlings were planted in February 2008 on three Mississippi sites. All sites were of comparable soils and received above average precipitation throughout the three-year duration of the study. Four site preparation treatments were replicated at each site, with 480 seedlings planted in each of nine replications, and a total of 1,440 seedlings per species planted across all sites. Mechanical treatments were installed using 3.1 m row centers, with treatments as follows: control, subsoiling, bedding, and combination plowing. Treatment effects on seedling height, groundline diameter (GLD), and survival were analyzed. Seedlings exhibited greater height in bedded and combination plowed areas (79.7 cm to 102.7 cm and 82.6 cm to 100.1 cm, respectively) compared to subsoiled or control areas (70.4 cm to 84.6 cm and 71.4 cm to 86.9 cm, respectively). Greater GLD was observed in bedded and combination plowed areas (11.9 mm to 18.4 mm and 12.2 mm to

18.3 mm, respectively) compared to subsoiled or control areas (10.2 mm to 14.6 mm and 10.5 mm to 15.6 mm, respectively). Survival was high for this study (94.%), and no differences were detected among treatments.

Keywords: mechanical site preparation; retired agricultural fields; oak afforestation

1. Introduction

With the advent of cost share funding and recognition of important functions and values of bottomland ecosystems by federal, state, and private entities, interest in afforestation of retired agricultural areas has increased dramatically over the past two decades [1]. Approximately 80,972 hectares of retired agricultural fields were afforested during the 1990s [2]. Estimates show approximately 149,798 hectares of retired agricultural fields were afforested between the mid 1990s and 2004 in the Lower Mississippi Alluvial Valley (LMAV) [3]. With an estimated 12,145,749 hectares of retired agricultural fields expected to be reforested by the year 2040 [4], the importance of formulating successful methods for establishing plantations on former agricultural areas can not be understated. Oak-dominated stands are expected to be regenerated on much of this land base [5].

Often, growth and survival of planted seedlings on former agriculture fields has not been satisfactory; resulting in a low percentage of oaks in established stands [3]. The preponderance of these failed afforestation attempts on former agriculture fields indicates a need for greater understanding of proper plantation establishment techniques. Several factors can decrease 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 applying proper silvicultural practices to enhance survival and growth.

Seedling establishment on these areas can be improved through the use of mechanical site preparation. Many retired fields have soils with substantial levels of compaction due to past land use practices [6]. Subsoiling, bedding, and combination plowing are mechanical site preparation treatments that may be beneficial for ameliorating surface soil compaction. Subsoiling, also known as ripping, is typically performed by pulling an 8.0 cm to 15.0 cm wide shank through the soil behind a tractor. The typical cutting depths range from 41.0 cm to 61.0 cm using traditional straight or parabolic shanks with or without winged tips. If winged tips are used in traditional subsoiling, planting should not occur for up to one year to allow air pockets to close [3]. The Case International ecolo-til™ 2500 no-till and conservation tillage system is designed to lift, twist, and then roll the compaction layer. The system is designed to prevent surface disturbance and subsequent creation of large peds in heavy clay soils. Unlike using traditional subsoiling equipment, planting can proceed as quickly as one month post treatment [7].

Subsoiling fractures restrictive layers often found in retired agricultural fields and can increase tree growth by ameliorating problems with drainage, root penetration, and nutrient availability often encountered in compacted soils [8]. This practice can be a valuable tool in afforesting compacted areas, as it may increase seedling survival and enhance root and stem growth. It is thought to improve seedling growth as a result of increased moisture availability, more uniform planting depths, better deep root development, and soil exploitation [9]. Increased growth and survival of seedlings in oak plantings undergoing subsoiling treatments has been documented [10]. In a study evaluating the effects of subsoiling, researchers found that subsoiling significantly increased seedling height and groundline diameter growth during the first growing season for Shumard oak (*Quercus shumardii* Buckley), water oak (*Quercus nigra* L.), willow oak (*Quercus phellos* L.), and green ash (*Fraxinus pennsylvanica* Marsh.) seedlings [5]. Research has also shown that subsoiling improves rooting depth in the first growing season for northern red oak (*Quercus rubra* L.) [11]. Improvement in root growth would be especially helpful in low moisture and low fertility conditions by allowing seedlings to absorb nutrients and water more readily and efficiently.

Bedding, also known as hipping or mounding, is typically performed utilizing a moldboard plow, offset disk, levee plow, or furrow plow [12]. Soil is turned inward creating a planting site 1.0 to 1.8 m wide and between 15.0 cm and 61.0 cm high above the soil surface [13]. The practice is typically used in the establishment of seedlings on poorly drained soils [12], and increased pine survival has been documented in bedded areas that were inundated and/or saturated regularly [14]. Greater survival is likely the result of raising the elevation of the rooting zone in beds. Many oak species are not tolerant of poorly drained soils and could benefit even from slightly higher elevations [15]. While most bedding research has been related to pines, the benefits should not vary regarding planting many hardwood species.

Bedding can increase early growth of hardwood seedlings through improved soil aeration and drainage, concentrated organic matter and nutrients, and short-term competition control [12]. Research showed five-year-old Nuttall oak height growth and survival to be greater on bedded sites compared to unbedded sites [16]. Nuttall oak height and diameter growth in bedded areas were as much as 35 percent greater in these areas. However, some research efforts have not noted any effects of bedding on growth or survival in oak plantings. An absence of a bedding effect was noted on growth or survival differences in pin oak (*Quercus palustris* L) and swamp white oak (*Quercus bicolor* Willd.) seedlings planted in the Missouri River floodplain [12]. Additionally, a lack of any bedding effect was observed for swamp chestnut oak (*Quercus michauxii* Nutt.) planted on a poorly drained upland flat site in southeastern Indiana [17].

Combination plowing is accomplished by combining subsoiling and bedding treatments into one mechanical treatment. Typically, a subsoil shank or coulter is pulled in front of a bedding plow. Problems with soil compaction, poor drainage, and vegetative competition are improved with growth and survival of planted seedlings being enhanced. This technique has been used in pine plantation management and has provided satisfactory results, but has not been researched in hardwood plantings. The objective of this study was to determine effects of different mechanical site preparation treatments on growth of oak seedlings in afforestation of retired agricultural areas.

2. Experimental Section

2.1. Study Site Description

This study was located on three publicly owned properties in Mississippi. Each site was selected for uniformity of terrain, soil texture, and former agriculture production status. 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 is 15.7 °C, with temperature extremes ranging from −24.4 °C to 41.7 °C, 40-year average precipitation is 142.5 cm, and 40-year average growing season precipitation is 90.1 cm [19]. Dominant herbaceous species present at study's 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 an opening for wildlife 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 is 18.4 °C, with temperature extremes ranging from −12.8 °C to 38.3 °C, 35-year average precipitation is 150.3 cm, and 35-year average growing season is 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]. These soils are 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 is 17.9 °C, 40-year average precipitation is 136.8 cm, and 40-year average growing season is 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%.

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 herbaceous weed control (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. 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 3.0 m centers using an agricultural tractor. Subsoiling was performed to a depth of 38.0 cm using the Case International ecolo-til™ 2500 subsoiler system. Bedding was performed using a furrow plow with the blades set to pull a soil bed approximately 1.0 m wide and between 20.0 cm and 25.0 cm deep. Combination plowing involved pulling a 1.0 m wide and 20.0 cm to 25.0 cm deep soil bed over the top of subsoiled trenches. Site preparation treatments were applied during the first week of November 2007.

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 seedlings after planting and prior to budbreak. Using the same rate, a second application of Oust XP® was performed during March, 2009 on one half of planted seedlings. However, due to absence of significant statistical differences between Oust XP® treatments, growth differences of seedlings planted in the different Oust XP® treatments are not discussed. A Solo® backpack sprayer was used for herbicide application with a total spray volume of 93.5 liters per hectare (LPH).

2.4. Seedling Establishment

Seedlings were purchased from Joshua Timberlands Elberta Nursery in Elberta, Alabama. 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 4,320 seedlings were planted, with 1,440 seedlings each of Nuttall oak, Shumard oak and swamp chestnut oak. At each site, the study had 480 seedlings of each oak species (480 total = 160 per block = 40 per mechanical treatment). 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 1,075 seedlings per hectare.

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 mm intervals using digital calipers. End of growing season measurements (total height and GLD) 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

All statistical analyses were performed using Statistical Analysis System (SAS) software version 9.2® (Cary, NC). 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 Analysis of Variance (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 each species separately.

Height and GLD data were 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 $\alpha = 0.05$ level of significance.

3. Results and Discussion

3.1. Variation in Survival by Site Preparation Treatment

Third-year survival was high for this study (94.1%). No detectable differences were observed among site preparation treatments. This is likely a resultant of a combination of excellent environmental conditions, proper planting, proper herbaceous weed control, and quality seedlings.

3.2. Height Variation by Site Preparation Treatment

Analysis detected site preparation main effect differences in height for all three oak species (Nuttall oak, $p \leq 0.0001$, F = 7.95, Shumard oak, $p = 0.0394$, F = 3.03, swamp chestnut oak, $p = 0.0017$, F = 5.90). Seedlings of all three oak species exhibited a similar pattern of statistical ranking with greater seedling heights observed in bedded and combination plowed areas (79.7 cm to 102.7 cm and 82.6 cm to 100.1 cm, respectively) compared to subsoiled or control areas (70.4 cm to 84.6 cm and 71.4 cm to 86.9 cm, respectively) (Table 1). However, in Shumard oak, height of seedlings in bedded and control areas did not differ.

Table 1. Repeated measures analysis of average height of oak seedlings by species and site preparation treatment planted on three Mississippi sites, 2008–2010.

Mechanical treatment	Height (cm)		
	Nuttall oak	**Shumard oak**	**Swamp chestnut oak**
Combination Plowed	100.1 a *	81.6 a	95.9 a
Bedded	102.7 a	79.7 ab	91.7 a
Subsoiled	84.6 b	70.4 c	80.5 b
Control	86.9 b	71.4 bc	79.9 b

* Values within a column followed by same letter are not significantly different at $\alpha = 0.05$.

Greater oak seedling height in bedded areas compared to control areas corroborates the findings of an earlier study [16]. The authors of this study found that fifth-year Nuttall oak height was greater on bedded sites compared to control sites. Detecting no difference between oak seedling height in subsoiled and control areas was unexpected. Previous research found that subsoiling increased seedling height of hardwood species during the first growing season compared to seedlings in untreated areas [5,22]. Historical experience suggests that the benefits of subsoiling would prove beneficial beyond the first growing season. It is possible that the lack of statistical differentiation in seedling height between the control and subsoiled areas was due to the absence of the moisture stresses during the first two years of the study, proper herbaceous weed control, and high site quality.

The lack of differentiation between Shumard oak seedlings planted in bedded and control areas was unexpected and not readily explained. It is possible that Shumard oak was not as well-suited to site conditions as Nuttall oak and swamp chestnut oak. All three sites received some periodic short-term flooding, and Shumard oak is more susceptible to soil saturation than the other two species [23]. Although species were analyzed separately, Shumard oak height and GLD were appreciably less than Nuttall oak and swamp chestnut oak grown under comparable site preparation treatments. This might indicate genetic differences in growth potential among the species or an environment less favorable for Shumard oak growth.

Very little information exists regarding height growth of swamp chestnut oak grown under different mechanical site preparation regimes. However, as discussed above, greater seedling height was expected in areas receiving bedding or combination plowing compared to those receiving subsoiling or left untreated. Finding that seedling height in subsoiled areas did not differ from that of seedlings in control areas is not typical [5].

Greater overall height of Nuttall oak, Shumard oak, and swamp chestnut oak seedlings in the two more intensive treatments might be partially explained by the lowering of soil resistance through the use of mechanical site preparation. Decreased soil resistance within these two treatments probably promoted root system exploitation, thereby increasing nutrient and water availability allowing for greater growth of oak seedlings in bedded and combination plowed areas compared to seedlings in control or subsoiled areas. Onsite evaluations with a soil resistance meter indicated that soil resistance in all three mechanical treatment areas was lower compared to soil resistance in control areas. Soil profile pits indicated restrictive layers were present at all three sites. Consequently, it is anticipated that seedlings in the subsoiled areas will statistically separate from seedlings in control areas sometime in the near future.

3.3. GLD Variation by Site Preparation Treatment

Analysis detected main effect differences among site preparation treatments for GLD in all three oak species (Nuttall oak, $p \leq 0.0001$, F = 12.70, Shumard oak, $p = 0.0059$, F = 34.79, swamp chestnut oak, $p \leq 0.0001$, F = 9.31). The same pattern of significance observed in seedling height analyses was present in the ranking pattern for seedling GLD. Greater GLD was observed for seedlings grown in bedded and combination plowed areas (11.9 mm to 18.4 mm and 12.2 mm to 18.3 mm, respectively) compared to subsoiled or control areas (10.2 mm to 14.6 mm and 10.5 mm to 15.6 mm, respectively) for all three species (Table 2). Similar statistical ranking of mechanical treatments for both overall height and overall GLD serves to substantiate discussion in the height variation by site preparation section above.

Table 2. Repeated measures analysis of average GLD of oak seedlings by species and site preparation treatment planted on three Mississippi sites, 2008–2010.

Mechanical treatment	GLD (mm)		
	Nuttall oak	**Shumard oak**	**Swamp chestnut oak**
Combination Plowed	18.3 a *	12.2 a	15.2 a
Bedded	18.4 a	11.9 a	15.1 a
Subsoiled	14.6 b	10.2 b	12.3 b
Control	15.6 b	10.5 b	12.4 b

* Values within a column followed by same letter are not significantly different at $\alpha = 0.05$.

4. Conclusions

Given the increased interest in afforesting retired agriculture fields with oak species during the past three decades, many different management techniques have been developed. Plantations are being established on thousands of hectares across the LMAV each year using a variety of these techniques. In many of these plantings, retired agricultural fields are being utilized [5]. Due to a variety of reasons, many of these plantings have failed [3]. The preponderance of these failed afforestation attempts on former agriculture fields indicates a need for greater understanding of proper plantation establishment techniques.

Growth and survival of seedlings could potentially be improved through the use of mechanical site preparation. Many retired fields have soils that have substantial levels of compaction due to past land use practices [6]. Subsoiling, bedding, and combination plowing are mechanical site preparation treatments with possible beneficial effects regarding compaction commonly found in these areas.

Overall, height and GLD of Nuttall oak, Shumard oak, and swamp chestnut oak seedlings were greater in areas treated with bedding or combination plowing compared to control or subsoiled areas. The only observance where seedling height or GLD was not greatest in bedded and combination plowed areas was found in Shumard oak seedling height. While Shumard oak seedlings in combination plowed areas exhibited greater height compared to seedlings in control or subsoiled areas, there was no statistical difference between bedded or control treatments. It is possible that the lack of statistical differentiation in seedling height and GLD growth between control and subsoiled areas is due to a combination of excellent precipitation during the first two years of the study, quality seedlings, proper planting, proper herbaceous weed control, and high site quality.

In conclusion, mechanical site preparation has significant beneficial effects on height and GLD of oak seedlings in retired agricultural fields. Treatment areas that received bedding or combination plowing treatment exhibited greater levels of height and GLD compared to areas that received no mechanical treatment or subsoiling as a form of site preparation. While no growth differences were detected between bedding and combination plowing treatments, seedling roots in bedded areas were nearing the restrictive layer present in soils at the Malmaison WMA site. All sites had restrictive layers at varying depths and seedling roots will probably benefit from the deeper soil fracturing of combination plowing at some point in the future. Pricing of mechanical treatments varies locally due to contractor and equipment availability [24]. Typically combination plowing is more expensive than bedding. However, if restrictive soil layers were present, managers would be inclined to use combination plowing as it might have greater long-term benefits. If restrictive layers were not a concern, and costs were lower, bedding might be a more appropriate treatment under conditions similar to those of this research study.

Conflict of Interest

The authors declare no conflict of interest.

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