RESIDUAL EFFECTS OF MECHANICAL SITE PREPARATION ON SOIL COMPACTION IN OAK (*QUERCUS* SPP.) PLANTINGS

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Abstract—Mechanical site preparation is often used to aid with amelioration of compacted soil conditions typically found on former agricultural areas. While immediate reduction in soil compaction through use of cultural treatments is well studied, less research is available regarding longer term mechanical treatment residual effects. Four mechanical site preparation treatments were employed across three Mississippi sites during the winter of 2007. Treatments were installed using 10-foot centers as follows: control, subsoiling, bedding, and combination plowing. Two years post-treatment, 216 paired reading locations were randomly selected within each mechanical treatment area to sample soil resistance difference between treatment and non-treatment areas. Mechanical soil resistance was measured to a depth of 18 inches with readings taken at 3-inch depth intervals. Analysis determined significant site interactions. Consequently, sites were analyzed independently for main effects and interactions. Soil resistance differences varied by treatment with more intensive treatments exhibiting greater residual differences compared to those observed in less intensive treatment areas.

INTRODUCTION

Afforestation in the Delta region of Mississippi has resulted in the establishment of approximately 477,000 acres of hardwood plantations.[1] Successful establishment of these plantations is the result of research and operational efforts over the past several decades. Continued Federal and State cost share funding is expected to sustain interest in planting additional acreage into the foreseeable future.

Mechanical site preparation is often prescribed to aid in amelioration of the compaction problems sometimes associated with former agricultural fields (Allen and others 2001, Russell and others 1997, Self and others 2012, Stanturf and others 2004). Many former fields have substantial levels of compaction due to past land use practices (Allen and others 2001, Gardiner and others 2002, Stanturf and others 2004). Treatment with various forms of mechanical site preparation treatments can have beneficial effects regarding compaction commonly found in these areas. Potential increases in growth and survival from mechanical site preparation can come from improvements in moisture and nutrient uptake, organic matter concentration, enhanced root formation, and better planting quality (Ezell and Shankle 2004, Fisher and Binkley 2000, Kabrick and others 2005, Patterson and Adams 2003, Rathfon and others 1995, Russell and others 1997, Stanturf and others 2004). Multiple treatment options exist; however, subsoiling, bedding, and combination plowing are the most commonly prescribed forest site preparation practices. These treatments are designed to disturb surface layers of the soil profile and fracture restrictive layers often found in retired agricultural fields. These efforts can lead to increased planted seedling growth and survival (Ezell and Shankle 2004, Gardiner and others 2002, Russell and others 1997, Stanturf and others 2000, Stanturf and others 2004). Measurement of soil resistance in mechanical site preparation treatments can be very informative regarding the impact of individual treatments on physical soil characteristics. While the immediate benefits of mechanical site preparation in reducing soil compaction are well known, the longer term effect on soil compaction is a relatively unexplored topic in hardwood afforestation.

[1] Personal communication. Dan Prevost. 2017. Forester/Wildlife Biologist, Delta Wildlife, 433 Stoneville Road, Stoneville, MS 38776.

MATERIALS AND METHODS

Site Description

This study was located on three sites. Two sites were owned by the Mississippi Department of Wildlife, Fisheries, and Parks (MDWFP). One site was located on Copiah County Wildlife Management Area (WMA), and the other was located on Malmaison WMA. The third site was located near Arkabutla Lake on land owned by the U.S. Army Corps of Engineers.

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Malmaison WMA site - The Malmaison WMA study area was located approximately 14 miles northeast of Greenwood, MS in Grenada County. The site was formerly used in row-crop production and retired from agricultural production in the late 1990s. It was maintained as an opening for wildlife using mowing and disking from agricultural retirement until the initiation of this study. Soils were silt loams, and 40-year average yearly precipitation was 53.8 inches (NOAA 2011c). Soil tests indicated onsite pH ranged from 6.3 to 7.0.

Copiah County WMA site - The Copiah County WMA study area was located approximately 16 miles northwest of Hazlehurst, MS in Copiah County and was retired from row crop production in the 1980s. It was maintained as an opening for wildlife using mowing and disking from agricultural retirement until the initiation of this study. Soils were silt loams, and 35-year average yearly precipitation was 59.2 inches (NOAA 2011a). Soil tests indicated that onsite pH is 5.2.

Arkabutla Lake site - The Arkabutla Lake study area was located approximately 5 miles northwest of Coldwater, MS in Desoto County. The site was in soybean [*Glycine max* (L.) Merr.] production until September 2007. Soil series were silt loams, and 40-year average precipitation was 56.1 inches (NOAA 2011b). Soil tests indicate that the site had an average pH of 6.2.

Experimental Design

The study was completely replicated at all three sites. Each site had its own unique installment of randomized mechanical site preparation treatments. A split-plot design was utilized with site preparation treatments in a randomized complete block. Three blocks were established with each block receiving four different mechanical site preparation treatments randomly applied as a group.

Mechanical Site Preparation Treatments

Four mechanical site preparation treatments were used in this study: control (no mechanical treatment), subsoiling, bedding, and combination plowing. All site preparation treatments were applied on 10-foot centers. Subsoiling was performed to a depth of 15 inches 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 3 feet wide and between 8 and 10 inches deep. Combination plowing involved pulling a soil bed over the top of subsoiled trenches. Mechanical site preparation treatments were applied during the first week of November, 2007.

Soil Resistance Readings

Mechanical soil resistance was determined using a Field Scout SC900 Soil Compaction Meter. Paired-measurement readings were taken on each plot to a depth of 18 inches with resistance measured in pounds per square inch (PSI). Two hundred eighty-eight locations were randomly selected for soil resistance readings at each site, totaling 864 reading locations across all three sites (288 total per site = 72 per mechanical treatment = 24 per mechanical treatment per block). Readings were recorded at depths of 3, 6, 9, 12, 15, and 18 inches at each measurement location. Readings were performed approximately 22 months post-mechanical treatment when soil moisture conditions were slightly below field capacity during September, 2009.

Data Analysis

All statistical analyses were performed using Statistical Analysis System version 9.2 (SAS 9.2). Soil resistance readings were analyzed by taking the difference between readings within mechanical treatments and readings outside of mechanical treatments. General Linear Modeling (GLM) and analysis of variance (ANOVA) were used to test null hypotheses. Full model was significant and a significant site interaction was found. Analyses were then conducted for each site separately.

Proc GLM was used to test for main effects and interactions, and to estimate least square means (LSMEANS). Separate analyses were used to identify a treatment effect if a significant interaction occurred. The LSMEANS LINES option was used to identify differences among pairwise comparisons if a significant interaction occurred. Differences were considered significant at the $\alpha = 0.05$ level of significance.

RESULTS AND DISCUSSION

Analyses of soil resistance readings were performed on the difference between readings within the mechanical treatment and immediately adjacent to the mechanical treatment. Consequently, positive PSI values indicate that soil within the treatment exhibited less resistance compared to the area immediately out of the treatment area. Negative PSI values indicate that the soil within the treatment exhibited more resistance compared to the area immediately outside of the treatment area.

During analysis, a general trend was observed for 18-inch resistance readings at the Arkabutla Lake site. Readings in subsoiled and combination plowed areas showed substantially greater soil resistance at a depth of 18 inches compared to control areas. This anomaly was not observed at the Copiah County WMA or Malmaison WMA sites. The Arkabutla Lake site had a band of clay soil that was observed in soil profile pits at around 16 to 17 inches depth. Down pressure from the subsoil plow foot being pulled at a depth of 15 inches is thought to have served to create an artificial compaction layer. This band of clay was not present at the Copiah County WMA or Malmaison WMA sites and increased soil resistance was not encountered at the 18-inch depth. Due to these artificially increased readings at 18 inches at the Arkabutla Lake site and the similarity of resistance readings of the other mechanical treatment/site combinations at the 18-inch depth, readings at this depth were not used for further analysis.

Soil Resistance Differences by Site and Mechanical Treatment

A significant main effect difference was detected among mechanical site preparation treatments for soil resistance difference at the Arkabutla Lake site (p = <0.0001, F = 272.52). Overall, difference in soil resistance for the subsoiling and combination plowing treatments (247.5 PSI and 222.9 PSI, respectively) did not differ at the Arkabutla Lake site (table 1). Both were greater than average difference in bedded areas (119.0 PSI) and all three were greater than the difference in control areas (7.9 PSI). This indicates that all three mechanical treatments were successful in reducing soil resistance compared to areas where no mechanical site preparation was performed.

Analysis detected a significant main effect difference among mechanical site preparation treatments for soil resistance difference at the Copiah County WMA site (p = <0.0001, F = 176.86). Statistical ranking for overall differences of soil resistance readings by mechanical site preparation treatment at the Copiah County WMA site was identical to that of the Arkabutla Lake site (table 1). Overall, soil resistance measures for the subsoiling and combination plowing treatments (104.5 PSI and 105.9 PSI, respectively) did not differ significantly. Both were greater than average difference in bedded areas (15.9 PSI) and all three were greater than the difference in control areas (-1.3 PSI). This indicates that all three mechanical treatments were successful in reducing soil resistance compared to areas where no mechanical site preparation was performed. Overall, the Copiah County WMA site exhibited observably lower levels of soil resistance compared to either of the other two sites. An explanation for this occurrence might be that the Copiah County WMA site was in intensive deep cultivation immediately prior to the establishment of the study. It is possible that disturbance of this nature could require a significant amount of time to return to a state similar to soil conditions found in more traditionally cultivated areas. Neither of the other sites received this type of cultivation.

Another dissimilarity was observed between the Copiah County WMA and other sites. Soil resistance was appreciably lower to a depth of 15 inches in subsoiled and combination plowed areas compared to control areas for all three sites (table 2). Readings in bedded areas indicated that a substantial reduction in resistance existed to a depth of 9 inches at the Arkabutla Lake and Malmaison WMA sites. However, bedded areas at the Copiah County WMA site exhibited lower PSI readings only at the 3-inch depth. This divergence of the Copiah County WMA site from the other two sites is probably a result of the deep cultivation. It is thought that loose soil created by the bedding treatment filled in fissures created by deep cultivation. This siltation effect of loose soil could have negated the positive effects of bedding observed at the other two sites.

Analysis detected a significant main effect difference among mechanical site preparation treatments for soil resistance difference at the Malmaison WMA site (p = <0.0001, F = 290.73). Ranking for mechanical treatments was similar to ranking observed at the Arkabutla Lake and Copiah County WMA sites. Overall, difference in soil resistance for the subsoiling and combination plowing treatments (269.8 PSI and 252.5 PSI, respectively) did not differ at the Malmaison WMA site (table 1). Both were greater than average

Table 1—Overall soil resistance differences by site and mechanical treatment at two years post-treatment

	Arkabutla Lake	Copiah County WMA	Malmaison WMA
Mechanical treatment		*soil resistance difference (PSI)*[a]	
Subsoiling	247.5a	104.5a	268.8a
Combination plowing	229.9a	105.9a	252.5a
Bedding	119.0b	15.4b	88.6b
Control	7.9c	-1.3c	1.1c

[a] Values followed by different letters within a column are significantly different at α = 0.05.

Table 2—Two-year post-treatment soil resistance differences by site and mechanical treatment and depth interaction

Mechanical treatment	Depth of reading	Arkabutla Lake	Copiah County WMA	Malmaison WMA
	inches		*soil resistance difference (PSI)*[a]	
Control	3	-0.6a	-4.9a	-5.0c
	6	8.1a	4.2a	17.9a
	9	7.5a	-3.1a	7.6b
	12	9.9a	0.7a	-9.6c
	15	14.8a	-3.1a	-5.2c
Subsoiled	3	15.1d	39.8c	26.3d
	6	234.8c	105.7b	252.0c
	9	371.5a	169.7a	383.8a
	12	310.6b	186.7a	372.0a
	15	305.5b	20.7c	310.1b
Bedded	3	72.0c	55.9a	55.1c
	6	302.5a	13.6b	287.4a
	9	246.7b	-1.1b	111.5b
	12	-32.3e	-38.7c	-22.8d
	15	6.0d	47.5a	11.9d
Combination plowed	3	59.5c	54.2c	52.1c
	6	290.6a	65.9c	284.7b
	9	248.9b	159.5a	374.7a
	12	232.3b	153.6a	349.0a
	15	318.1a	96.5b	302.1b

[a] Values followed by different letters within a column are significantly different at $\alpha = 0.05$.

difference in bedded areas (88.6 PSI), and all three were greater than soil resistance difference in control areas (1.1 PSI). This indicates all three mechanical treatments were successful in reducing soil resistance compared to control areas.

Soil Resistance Differences by Site, Mechanical Treatment, and Depth

Analysis detected a significant interaction between mechanical treatment and depth for difference in soil resistance at the Arkabutla Lake site (p = <0.0001, F = 98.89). No difference in soil resistance was observed at any level in control areas (table 2). Resistance in subsoiled areas differed by depth with the greatest difference at a depth of 9 inches (371.5 PSI). Resistance at the 12- and 15-inch depths did not differ (310.6 PSI and 305.5 PSI, respectively), but resistance at both depths was greater than at the 6- or 3-inch depths (234.8 PSI and 15.1 PSI, respectively). Greater differences in soil resistance at deeper locations in the soil were expected due to the deep fracturing qualities associated with subsoiling.

The greatest difference in soil resistance observed in bedded areas was at a depth of 6 inches (302.5 PSI), followed by a depth of 9 inches (246.7 PSI), then 3 inches (72.0 PSI) (table 2). As expected, the least differences in soil resistance were observed at the 12- and 15-inch depths (-32.3 PSI and 6.0 PSI, respectively) with the 12-inch depth exhibiting increased resistance within the treatment. The bedding treatment did not extend below 10 inches in depth and should not have had substantial influence on readings below that depth. A greater resistance of -32.3 PSI at the 12-inch depth within the bedding treatment was minor. Statistical ranking of soil resistance differences in combination plowed areas was similar to that observed in subsoiled areas. Resistance differences at levels deeper than 3 inches were all significantly greater than resistance difference at 3 inches (59.5 PSI). Resistance differences at 6 and 15 inches (290.6 PSI and 318.1 PSI, respectively) did not differ, but were greater than those observed for the 9- and 12-inch depths (248.8 PSI and 232.3 PSI, respectively). Due to combination plowing including a subsoiling treatment, the similarity between the two treatments was expected.

Analysis detected a significant interaction between mechanical treatment and depth for difference in soil resistance at the Copiah County WMA site (p = <0.0001, F = 27.77). No difference in soil resistance was observed at any level in control areas (table 2). Similar soil resistance differences were observed at depths of 9 and 12 inches (169.7 PSI and 186.7 PSI, respectively) in subsoiled areas. Significantly less difference in soil resistance was noted at the 6-inch depth (105.7 PSI). Analysis detected the least soil resistance difference at the 3- and 15-inch depths (39.8 cm and 20.7 cm, respectively). No difference in soil resistance difference was noted at these two depths. As discussed earlier, greater differences in soil resistance readings were expected in the lower depths. It is possible that lower resistance levels observed at the 15-inch depth were influenced by the deep cultivation mentioned earlier.

The greatest differences in soil resistance observed in bedded areas were at depths of 3 and 15 inches (55.9 PSI and 47.5 PSI, respectively) (table 2). Resistance differences at these two depths were not significantly different. However, both were greater than differences observed at the 6- and 9-inch depths (13.6 PSI and -1.1 PSI, respectively). Soil resistance within treatment was found to be significantly higher at the 12-inch depth (-38.7 PSI). Readings at this depth indicated that there was a substantial increase in soil resistance with bedding compared to all other treatments. It is possible that siltation issues discussed earlier resulted in increased compaction at the 12-inch depth. While not statistically differentiated, soil resistance difference at the 9- and 12-inch depths (159.5 PSI and 153.6 PSI, respectively) was greater than resistance difference at the 15-inch depth (96.5 PSI). The least difference in soil resistance readings was observed in the 3- and 6-inch depths (54.2 PSI and 65.9 PSI, respectively).

Analysis detected a significant interaction between mechanical treatment and depth for difference in soil resistance at the Malmaison WMA site (p = <0.0001, F = 39.31). Unlike in Arkabutla Lake and Copiah County WMA site observations for difference in soil resistance differences, differences were noted in control areas (table 2). The greatest difference in soil resistance in control areas was observed at the 3-inch depth (17.9 PSI). Less difference in soil resistance was detected at the 9-inch depth (7.6 PSI). Analysis detected similar ranking in soil resistance difference at the 3-, 12-, and 15-inch depths (-5.0 PSI, -9.6 PSI, and -5.2 PSI, respectively). Difference between readings was negative at these three depths indicating that there were slight increases in soil resistance within the treatment. It is improbable that the slightly increased soil resistance observed in control areas would have any negative influence on planted seedling growth or survival. While statistically different, resistance differences at varying depths throughout the soil column are very small, ranging from -9.6 PSI to 17.9 PSI. It is highly unlikely that changes of this level would have any significant real world impacts on growth or survival of any seedlings planted.

Soil resistance difference rankings and the overall numeric scale of differences were very similar to the Arkabutla Lake site in bedded areas. Resistance in subsoiled areas differed by depth with the greatest observed difference at depths of 9 and 12 inches (383.8 PSI and 372.0 PSI, respectively) (table 2). Resistance at these depths did not differ, but resistance at both depths was greater than observed at the 15-inch depth (310.1 PSI). Less resistance difference was found at the 6-inch depth (252.0 PSI), and the lowest overall difference was noted at the 3-inch depth (26.3 PSI). Again, greater differences in soil resistance at deeper locations in the soil were expected.

Overall, bedded area resistance differences and the numeric scale of those differences were similar to those observed for the Arkabutla Lake site. The greatest difference in soil resistance observed in bedded areas was at a depth of 6 inches (287.4 PSI), followed by readings at the 9-inch depth (111.5 PSI), then resistance difference at the 3-inch depth (55.1 PSI) (table 2). The least differences in soil resistance were found at the 12- and 15-inch depths (-22.3 PSI and 11.9 PSI, respectively) with the 12-inch depth exhibiting increased resistance within the treatment. Again, the bedding treatment did not extend below 10 inches in depth and should not have had substantial influence on readings below that depth. The small increase in soil resistance observed within the bedding treatment is minor.

Statistical ranking of soil resistance differences in combination plowed areas was similar to those observed at the Arkabutla Lake and Copiah County WMA sites. Resistance differences at levels deeper than 3 inches were all significantly greater than resistance difference at the 3-inch depth (52.1 PSI) (table 2). Resistance differences at 9 and 12 inches (374.7 PSI and 349.0 PSI, respectively) did not differ, but were greater than those observed for the 6- and 15-inch depths (284.7 PSI and 302.1 PSI, respectively).

CONCLUSIONS

As expected, two years after treatment, areas receiving deep ripping treatments (subsoiling and combination plowing) possessed reduced levels of soil compaction compared to those that did not receive similar treatment (bedding and control areas). Decreased soil compaction is likely beneficial in every hardwood planting, but becomes of paramount importance in former agricultural fields. Often these areas possess artificially increased compaction which may require mechanical treatment for successful plantation establishment to occur.

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