GROWTH RESPONSE OF DOMINANT AND CO-DOMINANT LOBLOLLY PINES TO ORGANIC MATTER REMOVAL, SOIL COMPACTION, AND COMPETITION CONTROL

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Abstract—The Long Term Soil Productivity (LTSP) experiment is a U.S. Forest Service led effort to test the effects that organic matter removal, soil compaction, and competition control have forest soil productivity, as measured by tree growth. A replicated experiment was installed on the Croatan National Forest, NC, in winter 1991 and loblolly pine (*Pinus taeda* L.) seedlings were planted there in early spring 1992. Experimental treatments included three levels of organic matter removal: stem-only; whole tree; and whole tree plus all forest floor, in combination with three levels of compaction: none; moderate; and severe. Plots were split for competition control treatments. Previous analyses, using all live trees in the measurements plots, indicated that competition control was the sole significant treatment effect on tree height for the first 14 years of this study. In this analysis we used height growth for the 10 trees in each plot identified as dominant or co-dominant. Both organic matter removal and soil compaction treatments have had a significant effect on height growth of dominant and co-dominant trees, suggesting that site preparation may affect merchantable timber production.

INTRODUCTION

Forests are subject to large-scale disturbance by harvesting and site preparation. An important question raised by forest soil scientists is whether soils can sustain the long-term needs of forest stands under the conditions of intensive site preparation, shortened rotations, and higher utilization standards (Powers and others 1990). Evaluating the fundamental relationships between soil type, drainage class, long-term productivity, and forest management practices, is integral to deepening our understanding of the lasting effects of modern silvicultural techniques. The effects that harvest intensity and site preparation have on soil properties and stand productivity, for a variety of forested ecosystems, are being analyzed as part of the U.S. Forest Service Long Term Soil Productivity (LTSP) network (Fleming and others 2006, Powers and others 2005, Sanchez and others 2006).

Previous analyses of the NC LTSP installations indicated a significant positive effect of competition control on height growth, but no effect of organic matter removal or soil compaction (Powers and others 2005, Sanchez and others 2006). However, these analyses included all live trees in the measurement plots and do not provide any information on the merchantable wood on the plots. Site index curves reflect expected tree height growth during a rotation, and are commonly used to compare productivity of specific tree species at different locations or on different soil types. Site index curves usually are generated based on heights of dominant and co-dominant trees on the site. By including only dominant and co-dominant trees in this analysis, we were able to gain an operational view of treatment effects. Additionally, comparisons of stem size distributions between treatment plots allowed us to examine treatment impacts on site productivity, as shifts in stem size distribution can indicate changes in merchantability of woody biomass (Hennessey and others 2004).

METHODS

An LTSP installation followed the clearcutting of a 60-year-old natural pine-hardwood stand on the Lower Coastal Plain, near New Bern, NC (34°53'58"N, 76°48'30"W) in 1991. Nine treatment plots (0.4-ha each) were established and assigned a 3 by 3 factorial combination of organic matter removal [stem-only (OM_0), whole-tree (OM_1), and whole-tree plus forest floor (OM_2)] and soil compaction [none (C_0), medium (C_1), and severe (C_2)] treatments (Eaton and others 2004). The treatment combinations were randomly assigned on each of three blocks. Treatment plots were then split to include total-competition control and no-competition control treatments. One block was located on a Goldsboro series soil (fine loamy, siliceous, thermic aquic Paleudults) and two blocks were located on a Lynchburg series soil (fine loamy, siliceous, thermic aeric Paleaquults). Site index at 50 years was 27.4 m for the Goldsboro block, and 26.2 m for the Lynchburg blocks (Goodwin 1989). Each split plot contained one 0.07 ha measurement plot where 80 loblolly pine trees were planted at a 3 by 3 m spacing.

To prepare the site, all trees were directionally felled into their respective plots. The OM_0 treatment was implemented by de-limbing trees in the plot and removing the bole, either by skidder in the C_1 and C_2 treatment plots, or by crane positioned adjacent to the plot in the C_0 plots. The OM_1 treatment was implemented in the same way except the entire tree was removed from the plot. The OM_2 treatment included the same procedures as the OM_1 treatment and the additional removal of the entire forest floor, either by bulldozer or hand-raked, depending on the compaction level. No machinery was allowed on the C_0 treatment plots, while the C_1 plots were compacted using a smooth drum vibratory roller passing once over the entire plot with no vibration. Compaction on the C_2 treatment was accomplished by passing the drum roller, on full vibration, twice over the entire

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plot. Vegetation control was carried out using brush saws and herbicide, as needed, to remove all non-planted vegetation.

Height measurements of all trees in the measurement plots were recorded annually for the first 10 years of the study. Heights were measured using height poles or a hypsometer. On each plot, ten trees, consistently identified as dominant or co-dominant, were re-measured at year 14. Analysis of variance (SAS 2003) was used to test for treatment effects on tree height.

RESULTS

Statistical analyses, using only the 10 dominant/co-dominant tree height values, indicate significant ($p \leq 0.05$) organic matter removal, soil compaction, and competition control effects at multiple ages during stand development (table 1). Organic matter removal treatments significantly ($p \leq 0.05$) impacted tree height for the first 5 years after planting (table 2). Mean tree heights in the OM_1 treatment were greater in all years. Tree heights on the C_0 plots were greater than on compacted plots (C_1 and C_2) from ages one through age three, but mean heights in the C_2 treatments were consistently higher after age four (table 2). Tree heights in the total competition control treatment plots were always higher than in the no competition control plots (table 2). Previous analyses, utilizing all live trees, indicated no significant main treatment effects but a significant competition control effect on tree height in nearly every year (Powers and others 1990, Sanchez and others 2006).

Histograms were produced to depict the stem volume frequency distribution by soil compaction treatment (fig. 1). Stem volume distribution showed two peaks for each soil compaction treatment and illustrate the strong competition control effect. Shifts in the mean within the two competition peaks for each of the three soil compaction levels confirm the stronger effect of competition control than soil compaction. There was a shift in the mode value, toward increasing volume, with increasing soil compaction in the competition controlled plots. Additionally, there were different distribution patterns by treatment, suggesting that soil compaction may impact harvest schedules by changing the number of harvests necessary to collect merchantable timber (C_2) or by changing the rotation length (C_1).

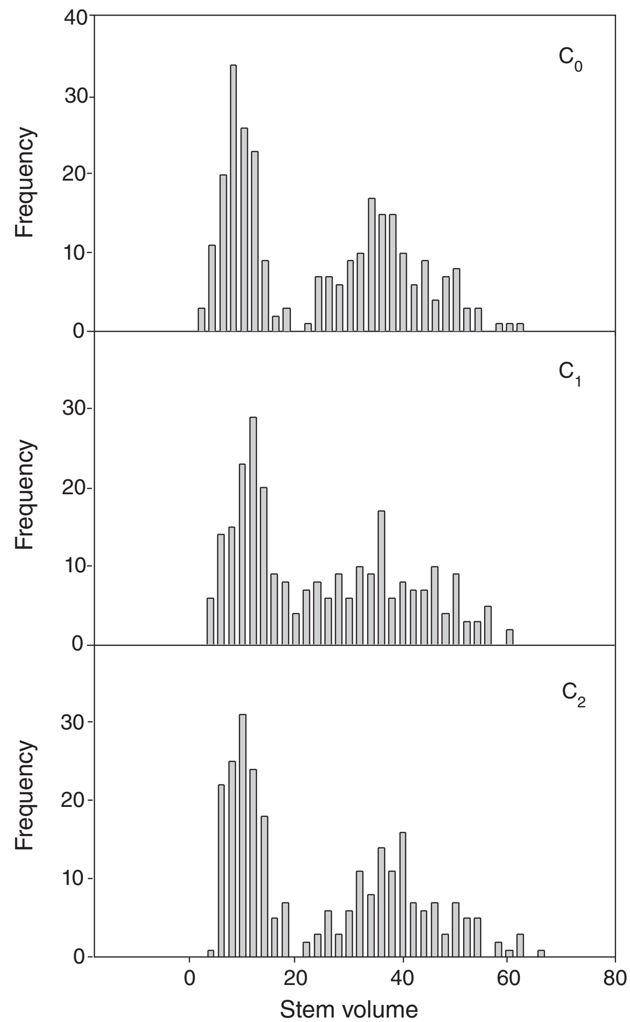

Figure 1—Histogram of loblolly pine stem volume distribution.

Table 1—Probability values (P > f) for treatment effects on the height of the 10 dominant or co-dominant loblolly pine trees per plots, at the Croatan LTSP study

Year	Organic matter removal	Soil compaction	Competition control
1	0.020	0.012	0.579
2	0.030	0.897	<0.0001
3	0.017	0.929	<0.0001
4	0.016	0.735	<0.0001
5	0.042	0.169	<0.0001
6	0.096	0.087	<0.0001
7	0.180	0.081	<0.0001
8	0.191	0.044	<0.0001
9	0.391	0.035	<0.0001
10	0.250	0.075	<0.0001
14	0.355	0.182	<0.0001

DISCUSSION

Previous analyses focused on detecting differences in mean heights for all surviving trees and found that only the competition control treatment was significant. Alternatively, when examining only the dominant and co-dominant trees, indices of merchantable timber, significant treatment effects were also detected for the organic matter removal and compaction treatments. The significant effect that organic matter removal had on height in years 1 through 6 and the consistently greater heights in the OM_1 treatment are likely

Table 2—Loblolly pine mean height (m) using the 10 dominant and co-dominant trees per measurement plot, at the Croatan LTSP study. Means were generated for individual main effect and split-plot treatments. Numbers in parentheses represent the treatment levels; letters represent results for Tukey's means separation test. Within a column, for a given year, means with the different letters are significantly different at $\alpha \leq 0.05$ level.

Year	Organic matter removal	Compaction	Competition control
1	(0) 0.55ab	(0) 0.56	(0) 0.55
	(1) 0.57a	(1) 0.55	(1) 0.56
	(2) 0.52b	(2) 0.55	
2	(0) 1.39ab	(0) 1.40	(0) 1.24a
	(1) 1.49a	(1) 1.37	(1) 1.53b
	(2) 1.28b	(2) 1.39	
3	(0) 2.59ab	(0) 2.61	(0) 2.24a
	(1) 2.74a	(1) 2.58	(1) 2.96b
	(2) 2.46b	(2) 2.60	
4	(0) 4.09ab	(0) 4.08	(0) 3.50a
	(1) 4.28a	(1) 4.11	(1) 4.73b
	(2) 3.97b	(2) 4.15	
5	(0) 5.34ab	(0) 5.27	(0) 4.55a
	(1) 5.59a	(1) 5.41	(1) 6.24b
	(2) 5.27b	(2) 5.51	
6	(0) 6.46	(0) 6.40	(0) 5.55a
	(1) 6.74	(1) 6.58	(1) 7.58b
	(2) 6.49	(2) 6.71	
7	(0) 7.84	(0) 7.76	(0) 6.70a
	(1) 8.11	(1) 8.00	(1) 9.20b
	(2) 7.90	(2) 8.10	
8	(0) 9.00	(0) 8.89a	(0) 7.73a
	(1) 9.31	(1) 9.17ab	(1) 10.53b
	(2) 9.09	(2) 9.34b	
9	(0) 10.08	(0) 9.85a	(0) 8.66a
	(1) 10.31	(1) 10.23ab	(1) 11.65b
	(2) 10.07	(2) 10.38b	
10	(0) 11.36	(0) 11.21	(0) 9.83a
	(1) 11.74	(1) 11.51	(1) 13.18b
	(2) 11.41	(2) 11.79	
14	(0) 15.53	(0) 15.35	(0) 13.77a
	(1) 15.81	(1) 15.47	(1) 17.38b
	(2) 15.38	(2) 15.90	

a result of several factors. The bole-only removal treatment (OM_0) left the most biomass on-site, but also allowed the highest amount of competition due to the low site disturbance. Additionally, the OM_0 plots had generally cooler summertime soil temperatures (Eaton and others 2004) which may decrease growth due to reduced mineralization rates (Powers 1990). Higher amounts of biomass, in the form of branches, provided a higher quantity of nutrients, but those may not be readily accessible. Conversely, on the most severe organic matter removal treatments (OM_2), reduced nutrient levels due to the removal of the forest floor may have reduced height growth, especially in the first 6 years (Sanchez and others 2006).

CONCLUSION

Previous analysis of LTSP data focused on the yearly height measurements of all living trees in the measurement plot to determine if there were significant differences due to treatments. Other than the drastic differences due to competition control, no treatment effects were found. Comparison of trees that would normally be measured for site index curves (dominant and co-dominant) indicate that both the compaction and organic matter treatments have had a significant effect on the height growth; a trend that continued through year 14, and could have important operational impacts. Additional data collection and further study is recommended to resolve the differences between the two methods of analysis. Because site index generally is used as a field tool to evaluate productivity, these differing results indicate that the target audience should be considered when future analysis and reporting is done.

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