

EARLY UNDERSTORY BIOMASS RESPONSE TO ORGANIC MATTER REMOVAL AND SOIL COMPACTION

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Abstract.—In the Missouri Ozarks, 6 and 8 years after treatment, understory biomass differences between bole only harvesting (BO) and whole-tree plus forest floor harvesting were not different; neither were there understory biomass differences between no compaction and severe compaction. Separation of the biomass into broad species categories (trees, shrubs, annuals, perennials, grasses, woody vines, and annual vines) showed some categories to be different between treatments. Some differences in species abundance over time were also noteworthy. Understory vegetation is important to the survival and growth of the developing stand and has significant implications for wildlife populations, fuel loads, and nutrient cycling, all of which can be considered part of site productivity.

INTRODUCTION

The disturbance caused by forest management can alter physical, chemical, and biological soil properties in ways that could intensely affect soil productivity. Soil compaction (SC) and organic matter removal (OMR) have been identified as key factors influenced by forest management activities (Powers and others 1990). In 1989, the U.S. Forest Service initiated the world's largest coordinated effort to understand how soil disturbance affects long-term forest productivity and in 1990 the first Long-Term Soil Productivity Study (LTSP) sites were established (Powers and others 1989). This nationwide study, which also includes sites in Canada, focused on the impacts of OMR associated with harvesting, and site preparation for regeneration, as well as SC associated with equipment traffic during timber harvesting and site preparation (Stagg and Scott 2006). In a coordinated way, the study investigates how OMR and SC affect a site's ability to capture carbon and process it into dry matter.

The removal of organic matter removes biomass that would ordinarily be subjected to decomposition, potentially reducing site productivity by altering nutrient cycles, biological functions, and other soil processes. Soil compaction diminishes soil productivity by increasing soil bulk density and reducing soil porosity. These dual effects combine to reduce the exchange of water and air, thereby reducing root growth and nutrient uptake (Greacan and Sands 1980), and growth of crop (Fleming and others 2006) and noncrop vegetation (Stagg and Scott 2006).

The effects of SC and OMR (leaf litter) were demonstrated in a greenhouse study (Jordan and others 1999) that reported decreased plant height, dry weight, and N uptake of red oak (*Quercus rubra* L.) and scarlet oak (*Q. coccinea* Muencch.) after 6 months of growth under high SC. However, the presence or absence of forest litter did not affect any of the response variables. An increase in harvesting intensity would be expected to increase soluble nutrient losses and increase transport of particulate matter, ultimately decreasing site productivity. However, because soil nutrient supply and productivity in forests change relatively slowly, Wells and Jorgensen (1979) speculated that biomass-harvesting practices could likely be selected from rotation to rotation without serious risk of decline in soil productivity. While this hypothesis may be true, site productivity includes a measure of total aboveground biomass, of which

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competing vegetation or understory, noncrop vegetation may constitute most of the standing biomass in an artificially regenerating forest stand. Over the short term, substantial quantities of nutrient elements can be temporarily conserved in the regrowth of woody and herbaceous vegetation invading the site following harvesting and during the years of the regenerating process, making nutrients unavailable to the trees and possibly affecting their growth (Marks and Borman 1972).

OBJECTIVE

This paper explores how OMR and SC have affected understory biomass during the early years of tree growth in a regenerating forest stand in Missouri.

MATERIALS AND METHODS

Site Description

The study site is in the Missouri installation of the LTSP, which was established in 1994. This site is located in the Carr Creek State Forest in Shannon County, MO. The silt loam soils on the site are primarily of the Clarksville series (loamy-skeletal, mixed mesic Typic Paleults). Initial soil chemical properties of the 0-30 cm depth were: pH (1:1 water) 5.7; total C, 3.3 percent; total N, 0.11 percent; P, 16.9 mg/kg; Ca, 789 mg/kg; and Mg, 61 mg/kg (Ponder and others 2000). Prior to harvest, the site had a well stocked, mature, second-growth oak-hickory (*Carya* spp.) forest with a site index for 50-year-old black oak (*Q. velutina* Lam.) that ranged from 22.5 to 24.3 meters (Hahn 1991). Mean annual precipitation and temperature are 112 cm and 13.3 °C, respectively (Barnton 1993).

Experimental Design

The LTSP study involves nine treatments derived from combinations of three levels each of organic matter removal and soil compaction. The three levels of organic matter removal were as follows: 1) merchantable tree boles removed, crowns retained, understory felled, and forest floor not removed (BO); 2) whole tree and all aboveground living vegetation removed, forest floor retained (WT); and 3) all surface organic matter removed, including whole tree, dead and living vegetation plus forest floor, exposing mineral soil (WT+FF). Merchantable boles were trees with diameters at breast height (d.b.h.) of 25 cm or larger. The three levels of compaction were: 1) no compaction (NSC); 2) moderate compaction (MSC); and 3) severe compaction (SSC). Soil compaction was accomplished by using heavy road construction equipment (Ponder and Mikkelsen 1995). Mean bulk density increased to 1.8 g cm⁻³ in SSC treatment compared to 1.3 g cm⁻³ for the NSC treatment.

The 3 x 3 factorial arrangement of treatments was replicated three times. Three uncut control plots, which were similar in stand history, species composition, and topography to harvested plots, were established as reference plots. Prior to tree harvesting and treatment installation, pre-harvest inventories of the overstory, understory, herbaceous layer, and dead and downed woody material, plus biomass and soil sampling were completed. After treatment installation, 1-0 seedlings of red oak, white oak (*Q. alba* L.), and shortleaf pine (*Pinus echinata* Mill.) were planted in rows at 3.66 m intervals at a ratio of three oaks of each oak species to one shortleaf pine. A complete description of the site and the LTSP installation are provided elsewhere (Ponder and Mikkelsen 1995).

For this report, only the high and low treatments of OMR and SC were used to compare aboveground biomass and nutrient measurements. Organic matter removal treatments removed 84.6 and 228.2 Mg ha⁻¹ of biomass respectively, for BO and WT+FF. For the first 2 years after planting, a 0.9-m radius area around

seedlings was sprayed annually in the spring with a mixture of glyphosate and simazine to control weeds. Growth responses to weed control are not part of this report.

Seedling height and diameter were measured after planting and annually thereafter. Diameter at 2.54 cm above the soil surface and when trees reached 1.4 m tall or taller, were measured. Beginning in 1999, year 6 of the study, and continuing annually, understory plants were inventoried in 7.9-m² permanent circular subplots where weeds were not controlled. Three subplots were established in each of the three replicates for the nine treatments for a total of 81 subplots. Plants were inventoried by species and counted and their heights measured. All subsamples were oven-dried for 48 hours, and weighed. Data were collected between early July and mid-August. Vegetation samples were later quantified into groups of woody plants (trees, shrubs, and woody vines) and herbaceous plants (annuals, perennials, and grasses). Plots were sampled randomly by blocks during each measurement period. For nutrient analyses, vegetation was clipped in three 0.30-m² sample areas located adjacent to each inventory subplot. Samples were oven-dried, and separated into leaves and stems; the stems were discarded before leaves were ground in a Wiley mill to pass through a 2-mm sieve. Samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) at the University of Arkansas Agricultural Diagnostic Laboratory in Fayetteville, AR. Total N was determined by combustion using a LECO CN 200 (LECO Corp., St. Joseph, MI) and P, K, Ca, and Mg was determined in HNO₃ digest on ICP.

Statistical Analyses

The experiment was analyzed as a randomized complete block design. Data were analyzed using analysis of variance with the PROC GLM procedures in SAS Version 8.2 (SAS Institute, Cary, NC). All statistical tests were performed at the $\alpha = 0.05$ level of significance.

RESULTS AND DISCUSSION

Biomass

Treatment differences for OMR and SC between understory biomass separated into groups of woody and nonwoody plants were not different for either measurement period (Table 1). Understory biomass followed the order of severe soil compaction > bole only > whole tree+forest floor removal > no soil compaction. The biomass for planted trees in year 8 averaged 38.2 and 36.7 Mg ha⁻¹, for bole only and whole tree+forest floor removal, respectively, and 36.0 and 37.7 Mg ha⁻¹, for no compaction and severe compaction, respectively (data on file at 208 Foster Hall, Lincoln University, Jefferson City, MO 65102). These values indicate that no adverse effect of OMR and SC on planted tree biomass was present. Similarly, Stagg and Scott (2006) reported that the biomass for planted loblolly pine was not significantly affected by soil compaction at age 5 yr or at age 10 yr. They did, however, report differences in the production of understory biomass between compaction treatments, indicating that the understory vegetation was much more susceptible to soil compaction than were the planted trees.

Height

Trees in the bole-only treatment were taller than trees in the whole tree+forest floor removal treatment for both measurement periods (Table 2). Both trees and woody vines were taller in the no soil compaction treatment than trees in the severe soil compaction treatment in year 6, but differences were not significant for year 8. Woody vines tended to be comparatively longer in no soil compaction plots than in severe soil compaction plots. The length of woody vines was likely associated with the taller shortleaf pines on these plots (Ponder, in press). Vines in trees were not actually measured, but their lengths were estimated.

Table 1—Mean understory of woody and non-woody biomass (Mg/ha) in response to two levels of organic matter removal (OMR) and soil compaction (SC) at 6 and 8 years of stand development.

Treatment ¹	Year 6			Year 8		
	Mean	S.Dev.	P>F	Mean	S. Dev.	P>F
Nonwoody						
BO	1.6	1.0	0.36	3.9	3.0	0.68
WT+FF	1.3	0.7		3.5	2.1	
NSC	1.5	0.8	0.83	2.6	1.8	0.67
SSC	1.6	0.6		4.1	2.2	
Woody						
BO	1.5	1.1	0.83	2.2	1.1	0.39
WT+FF	2.3	1.5		2.1	1.4	
NSC	2.1	0.8	0.40	2.9	1.2	0.75
NSC	0.8	0.5		2.1	1.4	
Combined						
BO	1.5	1.1	0.91	3.1	2.6	0.78
WT+FF	1.6	0.7		2.8	2.2	
NSC	1.5	0.9	0.93	3.0	2.4	0.92
NSC	1.5	0.8		3.1	1.6	

¹BO=bole only removed, WT+FF=whole tree+forest floor removed, NSC=no soil compaction, and SSC=severe soil compaction

Number of Plants

With few exceptions, the overall number of plants declined from year 6 to year 8 in most species groups (Table 2). The number of trees was higher for whole tree+forest floor removal than for bole only for year 6 and for no soil compaction than for severe soil compaction in years 6 and 8. Shrub and grass count also tended to be higher for severe soil compaction treatments than for the no soil compaction treatment. The implication is that soil disturbance can initially increase the number of plants, but competition for aboveground and belowground resources will likely affect their survivorship in later years.

The total number of plants declined from year 6 to year 8 (Table 2). With some exceptions, trees and shrubs that were in the highest number in year 6 continued to be high in year 8. Differences in the number of trees and shrubs between the no compaction treatment and the severe compaction treatments declined from 27 percent in year 6 to 14 percent in year 8. Overall, as the number of trees increased, grasses decreased by 60 percent from year 6 to year 8. Additionally, trees and shrubs responded differently to soil compaction. Both sassafras (*Sassafras albidum* (Nutt.) Nees) and dogwood (*Cornus* spp.) were in higher numbers in the no compaction treatment than in the severe compaction. On the other hand, the number of shortleaf pine tended to be higher in the severe compaction treatment compared to their number in the no compaction treatment while the opposite was the case for hickory. But the difference in numbers between treatments for hickory in year 8 suggests that the trend may be short lived.

Corns (1988) speculated that negative effects of compaction continue for a time, but as soils gradually revert to its precompaction levels, the physiological effect of soil compaction on plants may subside. By year 8 of this study, surface soil (0 to 10 cm) bulk density had recovered to precompaction level, while

Table 2.—Mean height and vegetation density (counts/plot) for trees, shrubs, annuals, perennials, grasses, woody vines, and annual vines in hardwood understory in response to two levels of organic matter removal (OMR) and soil compaction (SC) after 6 and 8 years of stand development

Species group	OMR ¹				SC ²			
	BO	WT+FF	BO	WT+FF	None	Severe	None	Severe
	Height		Density ³		Height		Density	
	---- cm ----		Counts/plot		---- cm ----		Counts/plot	
Year 6								
Trees	5.6a ⁴	4.7b	301a	415b	5.5a	4.9b	594a	300b
Shrubs	2.9	3.4	176	168	3.6	3.1	149a	209b
Annuals	2.7	2.6	222	183	5.0	6.2	114	165
Perennials	1.9	1.8	79	56	1.4	1.9	25	98
Grasses	1.8	1.7	196	241	1.5a	1.9b	151a	363b
Woody vines	3.5	3.1	246a	168b	3.7a	2.9b	241a	157b
Annual vines	1.1	1.3	21	59	1.1	1.3	45	49
Total	---	---	1241	1290	---	---	1319	1341
Year 8								
Trees	23.4a	18.9b	195	261	21.0	18.9	315a	184b
Shrubs	10.1	11.2	123	147	10.7	11.2	109	175
Annuals	7.0	6.1	142	134	5.0	6.2	114	165
Perennials	4.2	4.0	56	64	2.9	4.0	61	80
Grasses	3.7	3.4	66a	128b	3.0a	3.8b	66a	112b
Woody vines	10.8	7.8	144	127	10.6	8.2	161	92
Annual vines	2.2	3.2	6	10	2.3	2.2	12	5
Total	----	----	732	871	----	----	838	813

¹BO=bole only removed, WT+FF=whole tree+forest floor removed.

²None=no soil compaction, Severe=severe soil compaction.

³Counts/per plot is the number of individuals recorded in 27, 7.9-m² subplots.

⁴Means in a row for OMR or SC treatments within a year followed by different letters are significantly different at the 0.05 level based on Tukey's test.

bulk density differences between no compaction and severe compaction were still present for the 10- to 20-cm depth (data on file at 208 Foster Hall, Lincoln University, Jefferson City, MO 65102). Based on comparison with a number of these LTSP sites, Page-Dumroese and others (2006) concluded that the levels of compaction achieved, as measured by bulk density, were often of a similar magnitude to those reported for a variety of skid-trail studies, mimicking small-scale changes on large-scale plots. As vegetation develops on LTSP sites in response to SC treatments, investigators will be able to determine how applicable skid-trail studies are to larger areas and how recovery time is affected.

Disturbances such as OMR and SC play an important role in determining forest structure and species composition. Additionally, the development of plant communities will influence the type of wildlife using the site.

Disturbance that removes the overstory changes the amount of light that reaches the forest floor and increases the amount of nutrients available for new plants to utilize. In the present study, by year 8, mean nutrient concentrations in the understory vegetation on the site in this study did not differ among OMR and SC treatments (data not presented).

Soil disturbance typified by OMR and SC can decisively alter the seasonal soil moisture regime and plant-available water, but 5-year growth responses for western conifers growing in soils compacted to different levels were inconclusive (Gomez and others 2002). However, a significant increase in soil bulk density may not affect soil water (Froehlich and McNabb 1984). During compaction, micropores may be unaffected and soil porosity changes could be confined to the mesopore space (Startsev and McNabb 2001), resulting in little change in soil moisture content. In the present study, severe compaction generally resulted in increased moisture at 20 cm throughout the growing season during the first 5 years of the study (Page-Dumroese and others 2006). Machado and others (2003) reported that increased availability of soil resources (supply- demand) can affect understory vegetation growth, but the magnitude may depend on how tolerant plants are to shade.

CONCLUSIONS

Differences in understory dry weight for OMR and SC treatments were not detectable after 6 and 8 years of the study. Total understory biomass followed the order of SSC>BO>WT+FF>NSC. The total number of plants declined from year 6 to year 8, but the number of trees increased while grasses decreased by 60 percent from year 6 to year 8. Overall, while small differences within treatment categories (OMR and SC) were present, there does not appear to be any general adverse effect of OMR and SC on this regenerating stand. The adverse effects of soil compaction on the growth of forest vegetation are well documented, but some results show that some sites and tree species respond positively to compaction. No comparisons were made between the vegetative composition of other regenerating forests and the present site, but the lack of difference between BO and WT+FF in the present study suggest that the overall plant population would likely be similar to other regional regenerating forests following conventional harvesting. Studying understory biomass response to organic matter removal and soil compaction provides another opportunity to evaluate short- and long-term impacts of soil disturbance on forest stand development.

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