IMPACTS OF HARVEST INTENSITY AND SOIL DISTURBANCE ON EARLY TREE GROWTH AND EARTHWORM POPULATIONS IN A MISSOURI OZARK FOREST

Felix Ponder, Jr., Darrell E. Alley, Diann Jordan, Mary E. Swartz, and Victoria C. Hubbard[1]

Abstract—The long-term impact of increased removal of forest biomass and nutrients with increased harvest intensity on soil productivity is a general concern. In 1994, a long-term study was initiated in the Missouri Ozarks as part of the National Long-Term Soil Productivity (LTSP) study to study the effects of biomass removal and compaction on soil productivity. The study has three levels each of organic matter removal (boles only, whole tree, and whole tree plus forest floor) and soil compaction (none, moderate, and severe). This report presents 3-year preliminary results from the low and high organic matter removal and soil compaction treatments with and without weed control on survival and growth of planted northern red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), and shortleaf pine (*Pinus echinata* Mill.) seedlings. Differences in seedling survival were affected by organic matter removal and soil compaction treatments. Trees with weed control were larger in diameter, taller, and had more diameter and height growth than trees without weed control. Organic matter removal and soil compaction treatments significantly affected the height and diameter growth of trees differently. Analysis of spring and fall samplings of earthworm populations showed that soil compaction and time of sampling significantly influenced the number and biomass of earthworms.

INTRODUCTION

Forest harvesting obviously removes nutrients from the ecosystem. Conventional harvesting removes about 5 to 30 percent of the total nutrients in the aboveground stand, but the average for most forests rarely exceeds 10 percent (McColl and Grigal 1979). Intensive harvesting, which removes a greater proportion of the forest biomass than has traditionally been removed in sawtimber harvests, is contemplated as a means to provide more biomass for fiber, fuel, and chemicals. There is worldwide concern, however, that increased removal of biomass and the associated nutrients may cause a decline in forest productivity. Also, the use of heavy equipment may adversely affect physical properties of the soil causing compaction, loss of porosity, and erosion.

These concerns led to the development of a joint National Forest System/Forest Service Research study (Powers and others 1989) on long-term site productivity (LTSP). The national study has two major objectives. The first is to determine how changes in soil porosity and organic matter affect fundamental soil processes controlling forest productivity and sustainability. The second objective is to compare results from similar replicated studies among major forest types and soil groups across the United States and Canada. This report presents some early results in the Missouri LTSP study of effects of organic matter removal, soil compaction and weed control on the survival and growth of planted trees and earthworm numbers and their biomass.

METHODS AND MATERIALS

Study Site

The oak-hickory (*Quercus* L. - *Carya* Nutt.) forest type is the major timber type in the Central Hardwood Region occurring over a variety of soils, relief, and stand conditions. The Missouri LTSP study is located at the Carr Creek State Forest in Shannon County. Shannon County is located in the southeastern Missouri Ozarks. Mean annual precipitation in the area is 112 cm and mean annual temperature is 13.3°C. The study site is located on the upper northeastern-facing side slopes of two parallel ridges. Both convex and concave landforms occur on the sloping (20 to 28 percent slopes) topography. The weathering of the Ordovician and Cambrian dolomite has resulted in a deep mantle of cherty residuum (Gott 1975). Soils derived from this residuum are primarily of the Clarksville series (loamy-skeletal, mixed, mesic, Typic Paleudults). Prior to harvest, the site had a well-stocked, mature, second-growth oak-hickory forest. The site index for 50 year-old black oak (*Quercus velutina* Lam.) ranged from 74 to 80 feet (Hahn 1991).

Experimental Design

The LTSP study includes nine treatments derived from combinations of three levels each of organic matter removal and soil compaction. The three levels of organic matter removal included (1) merchantable boles removed (boles only, **BO**), (2) All living vegetation removed (whole tree, **WT**), and (3) all living vegetation plus forest floor removed, exposing mineral soil (whole tree + forest floor, **WTFF**). Merchantable boles included trees with diameters at breast height (dbh) of 25 cm or larger. The three levels of compaction included (1) no compaction ($\mathbf{C_0}$),

[1] Research Soil Scientist, Forestry Technician, and Biological Science Technician, USDA Forest Service, North Central Forest Experiment Station, Lincoln University, Jefferson City, MO 65102; Associate Professor and Research Analyst, Department of Soil and Atmospheric Sciences, The School of Natural Resources, University of Missouri, Columbia, MO 65211, respectively.

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(2) moderate compaction (**C_1**), and (3) severe compaction (**C_2**). The targeted bulk density of severe compaction treatment was an increase of 30 percent more than the bulk density of the no compaction treatment. The moderate soil compaction treatment was intermediate between the severe compaction and no compaction treatments. Each of the nine treatment combinations was replicated three times. Physical and chemical plot variables were also measured in three uncut (unharvested) plots adjacent to treatment plots in the study. For this report, two levels of organic matter removal and two levels of soil compaction, each with and without weed control, were used (Table 1).

Pre-Harvest Measurements, Site Preparation, Treatment Application, and Sampling

After determining that the key soil properties did not vary significantly across the areas, preliminary plot boundaries were established. Contiguous plots, approximately 0.4 hectare (1 acre) in size, were assigned treatments randomly in the summer of 1993. Five-meter-wide buffer strips were included around all plots. A clearcut area with all vegetation removed, whose width approximated or exceeded the height of bordering trees, separated all treatment plots from residual forest. The pre-harvest inventory of the overstory, understory, herbaceous layer and dead and downed woody material was completed in the summer of 1993 by the Missouri Forest Ecosystem Project forester and botany crew of the Missouri Department of Conservation (Ponder and Mikkelson 1995). Other collections before the harvest were biomass samples from overstory canopy trees, understory saplings, ground vegetation, and leaf litter/humus layer. In addition to 2.5 meter deep soil pits being dug and soil profiles described, soil samples were collected for nutrient and bulk density analyses (Ponder and Mikkelson 1995).

Trees were harvested from February thru May 1994. On plots designated as no compaction, all trees with a dbh of 25 centimeters or larger (merchantable trees) on BO, WT,

Table 1—Treatment combinations for two levels each of organic matter, compaction, and weed control in a Missouri forest

Treatment	Organic matter removal	Soil compaction	Weed[a] control
BOC_0	BO	C_0	With
BOC_0	BO	C_0	Without
BOC_2	BO	C_2	With
BOC_2	BO	C_2	Without
$WTFFC_0$	WTFF	C_0	With
$WTFFC_0$	WTFF	C_0	Without
$WTFFC_2$	WTFF	C_2	With
$WTFFC_2$	WTFF	C_2	Without

[a] Each treatment plot split on weed control treatment.

and WTFF plots were directionally felled and removed with a skyline cable logging system. Merchantable trees on plots where the soil was to be compacted, plot borders, and the area within the study boundary were directionally felled and removed with a skidder that traveled only on designated paths within the plots and in plot borders. After the removal of merchantable trees in BO plots, the remaining trees were felled. This standing biomass included trees with dbh less than 25 centimeters (unmerchantable trees), crowns from merchantable trees, standing dead and live snags, and trees in the herbaceous layer with basal diameters greater than 2 centimeters or at least 25 centimeters tall. Trees were cut into lengths that permitted material to be hand carried, lay on or near the ground, and form a layer of uniform height over the plot. Except for crowns, which were retained on the BO plots but not on WT plots, the remaining biomass on WT plots was treated the same as biomass on BO plots. On WTFF harvested plots, all biomass remaining after harvest was removed. This included all understory vegetation plus the forest floor was raked away to the mineral soil. For BO and WT plots requiring compaction, it was necessary to remove and replace these materials (except the leaf/litter layer) after compaction was completed. Skidders and tractors were permitted on compacted plots, but not on plots that were not to be compacted. A 14-ton vibrating sheep-foot roller was used to compact soil. The roller made passes over the severe compaction treatment until there was no change in bulk density after roller passes. For bulk density measurements, soil cores (30 centimeters in length x 9.2 centimeters in diameter) were extracted from each plot using a soil-coring device (Ponder and Alley 1997). The cores were divided into 10-centimeter depth increments, oven dried at 105°C, and weighed. Bulk density for each sample was calculated according to the method of the Soil Survey Staff (1984). Soil bulk density measurements were taken after the roller made one, three, five, and eight passes over plots that received the severe compaction treatment. Changes in bulk density usually ceased after five passes.

In late spring of 1994, all plots were planted with 1-0 red oak, white oak, and shortleaf pine in a 3:3:1 ratio, (3 red oak seedling plus 3 white oak seedlings to 1 shortleaf pine seedling), using hoedads. Seedlings were planted in rows at a spacing of 2.5 meters by 2.5 meters. A 3-foot radius area around each seedling was sprayed with a glyphosate and simazine mixture to control weeds. Beginning in the 3rd growing season (1996), half of each plot was kept weed-free to permit planted trees to grow freely. The other half of the plot was allowed to develop naturally. Net primary productivity in these two plant communities will provide direct measures of productivity as influenced by study treatments.

Seedling heights and diameters at 2.5 centimeters above the ground were measured immediately after planting, and annually thereafter. Twelve 900-centimeters^2 subplots of herbaceous or ground flora samples were collected from each plot annually in the fall for dry weight and nutrient element concentration. Samples were clipped, placed in paper bags, air-dried before oven drying, weighed, ground in a Wiley mill and sent to the Ohio Research Analytical Laboratory for elemental analyses.

Earthworm Sampling

Plots were sampled for earthworms in the spring and fall of 1995, the second year after completing the installation of the study. Ten earthworm-sampling units were taken randomly at approximately the same distance apart across each plot: 5 from the upper 1/3 of the plot (top) and 5 from lower 1/3 of the plot (bottom). Each sampling unit measured 30.5 centimeters (length) x 30.5 centimeters (width) x 15 centimeters (depth). Earthworms were also collected from three uncut plots. Earthworms in top and bottom samples were combined for statistical analysis.

Earthworms were hand-sorted, counted, and placed in specimen cups containing about one-third volume of soil and stored in ice chest immediately. Earthworms were later recounted and preserved in formalin before being identified using the internal characteristic identification method of James (1990). Earthworms were dried in an oven at 60°C for 48 hours and dry weights were recorded. The oven-dried earthworms were ashed in a muffle furnace at 500°C for 4 hours and the ash weights recorded. Earthworm biomass was calculated by subtracting the ash weight from the dry weight (Parmelee and others 1990).

Statistical Analyses

The experiment was analyzed as a split-plot design with three replications, with organic matter removal and compaction treatments as the main plots and the weed control treatments as the subplots. Analysis of variance procedures were conducted with the PROC GLM procedures in SAS (SAS Institute, 1987). Survival data were analyzed using SAS (Allison 1995). Prior to analysis, the data were transformed to equalize variance using log10 transformation. Data were analyzed using analysis of variance and comparisons were made using the Least Significance Difference (LSD) test. Unless otherwise noted, all statistical tests were performed at the (α = 0.05 level of significance.

RESULTS AND DISCUSSION

Bulk Density

The severe soil compaction treatment effectively increased the bulk density over the no compaction treatment (Table 2). Bulk density generally increased with depth. The percent change in bulk density between the no compaction treatment (0 passes) and the severe compaction treatment (5 or more passes) was 22, 29, and 26 percent for the 10, 20 and 30 centimeter depth increments, respectively. Although soil compaction levels for the severe soil compaction treatment were not at the targeted level of 30 percent greater than the levels for the no soil compaction treatment, the differences were significant at the 0.05 level.

Table 2—Mean soil bulk density measurements for no compaction and severe compaction treatments. Soil compaction was done with a 14-ton vibrating sheep-foot roller

	Bulk density	
Depth	No compaction	Severe compaction[a]
Cm	------------------ *G/cm*^{3}	-------------------
0 - 10	1.26(±0.2)[b]	1.61(±0.09)
11 - 20	1.33(±0.23)	1.88(±0.08)
21 - 30	1.56(±0.27)	2.12(±0.37)

[a] Five or more passes.
[b] Numbers in parenthesis are standard deviation of mean based on 12 samples.

Survival

After three years, weed control had no significant effect on survival of the planted seedlings (Table 3). However, there were survival differences associated with organic matter removal and soil compaction for each species. Survival for all species was significantly lower in the BO treatments compared to the WTFF treatments. Also, survival was better for all species in the severe soil compaction treatment than in the no compaction treatment. Most of the mortality occurred during the first year (1994) after planting (Table 4). Some of the mortality was undoubtedly caused by the late planting period of May thru June.

Table 3—Survival of planted northern red oak, white oak, and shortleaf pine with two levels each of organic matter removal (removal), compaction, and weed control three years after site preparation and treatment application in the Missouri LTSP study

Treatment	Red oak	White oak	Shortleaf pine
	-------------------	*Percent*	-------------------
Removal[a]			
BO	76.1a[b]	77.3a	64.0a
WTFF	90.5b	87.4b	68.5b
Compaction			
C_0	79.4a	79.3a	60.4a
C_2	87.0b	85.8b	70.3b
Weed control			
With	80.2a	80.3a	60.1a
Without	78.2a	73.3a	57.6a

[a]BO means boles only and WTFF, whole tree plus forest floor removal.
[b]Values in a column for a tree species and for a parameter are not significantly different (α=0.05) when followed by the same letters.

Table 4—Survival of planted northern red oak, white oak, and shortleaf pine after one two and three years following site preparation and treatment application in a harvested Missouri forest stand

	With weed control			Without weed control		
Treatment[a]	1995	1996	1997	1995[b]	1996	1997
	Percent					
Northern red oak						
BOC_0	77	72	68a[c]	69	66	62a
BOC_2	95	93	84b	89	86	77b
$WTFFC_0$	97	96	91b	97	97	93b
$WTFFC_2$	94	93	90b	94	94	92b
White oak						
BOC_0	78	73	72a	72	71	63a
BOC_2	86	86	82ab	80	80	79a
$WTFFC_0$	93	93	86b	95	95	78a
$WTFFC_2$	96	95	88b	93	93	84b
Shortleaf pine						
BOC_0	47	47	46a	50	47	46a
BOC_2	82	82	82b	90	90	90b
$WTFFC_0$	78	78	75b	63	60	50a
$WTFFC_2$	58	58	58a	71	71	70ab

[a]BO means boles only and WTFF, whole tree plus forest floor removal.
[b]All trees had weed control in 1995.
[c]Values in a column for a tree species are not significantly different (α=0.05) when followed by the same letters.

The lack of survival differences between weed control treatments is not a surprise. All plots received weed control treatments for the first two years after planting. Without weed control during the first several years after planting, seedlings planted in harvested stands using conventional procedures usually have very poor survival. Much better survival has been known to occur when large diameter seedlings are planted beneath shelterwood systems (Johnson and others 1986). It appears that part of the reason for the relative low survival of trees in BOC_0 treatment where only boles were removed and there was no soil compaction treatment may be due to the somewhat better growth of invading herbaceous vegetation. Although the weight of herbaceous vegetation did not differ significantly between treatments, they ranked in the order of BOC_0 > $WTFFC_0$ > BOC_2 > $WTFFC_2$. Also, the uncompacted plots tended to have more surviving natural trees and sprouts. Many existing small trees and shrubs were killed or severely damaged during the soil compacting process. Also, damaged stumps in the severe compaction treatment produced few sprouts. Removing the forest floor also eliminated seeds from the plots and exposed others that might have been eaten by birds and rodents.

Growth

Both diameter and total diameter growth of trees three years after planting were significantly affected by treatments (Table 5). Treatments affected species differently. Organic matter removal affected both the diameter and the total diameter growth of both red and white oak, but not shortleaf pine. Diameter growth was more than two times and nearly two times greater for red oak and white oak, respectively, in the Bo treatment compared to the WTFF treatment. Neither was diameter or total diameter growth of any of the trees tested significantly affected by compaction treatments, but weed control did. Trees with weed control were larger in diameter and had more diameter growth than trees without weed control. There were significant interactions between organic matter removal and weed control, and organic matter removal and compaction for diameter, and between organic matter removal and weed control for total diameter growth for white oak. Both diameter and total diameter growth followed the order of BO with weed control > WTFF with weed control > BO without weed control > WTFF without weed control. The diameters of white oak trees for the significant interaction between organic matter removal and compaction were BOC_2 > BOC_0 > $WTFFC_2$ > $WTFFC_0$.

Except for shortleaf pine, trees with weed control were significantly taller than trees without weed control (Table 6). Total height growth of northern red oak was also significantly better with weed control than without it. Organic matter removal did not affect total height growth of of any of the species tested, but it did significantly affect the height of white oak. White oak in the BO treatment was taller than

Table 5—Diameter and total diameter growth of planted northern red oak, white oak, and shortleaf pine with two levels each of organic matter removal (removal), compaction, and weed control three years after site preparation and treatment application in the Missouri LTSP study

	Diameter			Total diameter growth		
Treatment	Red oak	White oak	Shortleaf pine	Red oak	White oak	Shortleaf pine
	mm					
Removal[a]						
BO	19.8a[b]	11.5a	22.8a	15.2a	7.0a	20.0a
WTFF	11.4b	8.5b	20.5a	6.7b	3.8b	17.7a
Compaction						
C_0	17.8a	10.3a	20.6a	13.2a	5.9a	17.9a
C_2	11.7a	9.7a	20.6a	6.9a	5.0a	17.7a
Weed control						
With	21.2a	11.5a	25.3a	16.6a	7.1a	22.6a
Without	9.5b	8.3b	17.9b	4.8b	3.8b	15.1b

[a]BO means boles only and WTFF, whole tree plus forest floor removal.
[b]Values in a column for a tree species and for a parameter are not significantly different (α=0.05) when followed by the same letters.

Table 6—Height and total height growth of planted northern red oak, white oak, and shortleaf pine with two levels each of organic matter removal (removal), compaction, weed control three years after site preparation and treatment application in the Missouri LTSP study

	Height			Total height growth		
Treatment	Red oak	White oak	Shortleaf pine	Red oak	White oak	Shortleaf pine
	Cm					
Removal[a]						
BO	76.9a[b]	57.6a	105.5a	41.7a	41.0a	90.0a
WTFF	73.8a	51.3b	106.3a	40.9a	35.0a	92.0a
Compaction						
C_0	77.2a	54.5a	98.5a	43.3a	38.2a	83.2a
C_2	72.2b	54.1a	115.7b	37.6a	37.4a	101.3a
Weed control						
With	83.7a	60.5a	106.8a	49.5a	43.8a	92.0a
Without	66.6b	47.8b	105.0a	32.5b	31.5a	89.9a

[a]BO means boles only and WTFF, whole tree plus forest floor removal.
[b]Values in a column for a tree species and for a parameter are not significantly different (α=0.05) when followed by the same letters.

white oak in the WTFF treatment. Soil compaction affected the height of northern red oak and shortleaf pine differently. Northern red oaks in the no soil compaction treatment were taller than red oak in plots that were in the severe soil compaction treatment, but the opposite was true for shortleaf pine. There was a significant interaction between soil compaction and organic matter removal for both height and total height growth for white oak. Treatments for height followed the order $BOC_0 > WTFFC_2 > BOC_2 > WTFFC_0$. The order of treatments for total diameter growth followed the order $BOC_2 > BOC_0 > WTFFC_2 > WTFFC_0$.

Earthworms

Soil compaction significantly affected the number of earthworms in both spring and fall samples, but it affected their biomass only in the fall samples (Figures 1 and 2). The number of earthworms found in the spring was 50, 42, and 15 per meter^2, respectively, for uncut, no compaction, and severe compaction treatments. The number of earthworms was considerably higher in soils sampled in the fall than in soils sampled in the spring. They were 132, 89, and 48 per meter^2, respectively, for no compaction, uncut, and severe compaction treatments. Earthworm biomass for fall samples was 5.1, 3.0 and 2.1 grams/meter^2, respectively, for no compaction, uncut, and severe compaction plots. Neither the number of earthworms nor their biomass was significantly affected by organic matter removal treatments in spring or fall samples.

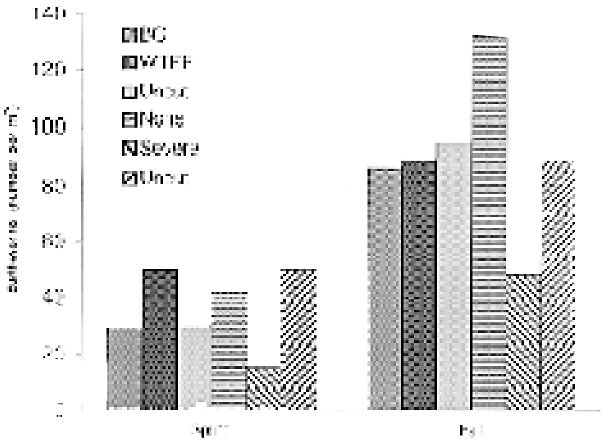

Figure 1—Response of earthworms to organic matter removal (BO, WTFF, and Uncut) and soil compaction (None, Severe, and Uncut) in a Missouri forest.

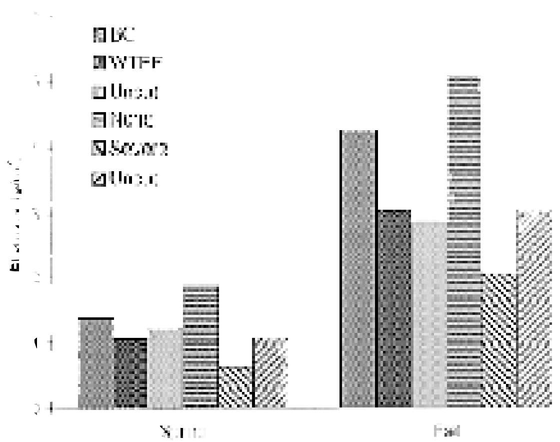

Figure 2—Earthworm biomass affected by organic matter removal (BO, WTFF, and Uncut) and soil compaction (None, Severe, and Uncut) in a Missouri forest.

These observations suggest that soil compaction has, perhaps, been more influential than organic matter removal on tree growth and earthworm activity. Nutrient analyses of the herbaceous vegetation collected in year three of the study showed that except for P, differences between treatments were not significant. The leaf P concentration for herbaceous vegetation from the BOC_0 treatment was significantly higher than the P concentration in herbaceous vegetation from the $WTFFC_0$ and the $WTFFC_2$ treatments. Phosphorus concentration for all four treatments were in the order of $BOC_0 > BOC_2 > WTFFC_2 > WTFFC_0$. Herbaceous samples collected in year two showed N to be significantly different between the BOC_0 treatment and other treatments (Ponder 1997). But the difference was not present in year three. Apparently, nutrient differences caused by biomass removal treatments (Ponder and Mikkelson 1995), which may eventually affect soil nutrient supply, are not currently different enough to be detected consistently in herbaceous samples.

The increase in soil bulk density associated with soil compaction can, depending on the soil moisture content affect the soil strength. Soil strength affects the ability of roots, and perhaps earthworms, to penetrate or move through the soil. Soil compaction also reduces soil porosity. Decreased soil porosity can reduce soil water, cause poor aeration, and affect the distribution and growth of earthworms (Edwards and Bohlen 1966). We do not report soil strength or soil porosity measurements for this study. However, researchers investigating other LTSP sites have reported that after five years, soil strength in compacted plots was significantly higher and soil porosity was significantly lower than for soil in no compaction plots, (Powers and Fiddler 1997; Stone and Elioff 1998).

Because of the cherty, well-drained, soils in the study area, we had expected earthworm numbers to be higher in the spring when soil moisture was believed to be greater. The larger number of earthworms in the fall compared to the spring may be due to, in addition to the effects of soil compaction, the results of a number of soil environmental factors acting alone or interacting with each other. These may include soil temperature, soil moisture, organic matter, and perhaps, the species reproduction patterns.

SUMMARY

Early tree survival was significantly higher in $WTFFC_2$ treatments. Both organic matter removal and soil compaction treatments affected diameter, diameter growth, height, and height growth of tree species differently. Tree growth was also significantly better with weed control than without weed control.

These results are preliminary. The earthworm study along with some more recently initiated monitoring of soil and leaf nutrient analyses, soil moisture, and soil temperature is continuing. Also of interest, will be the long-term effects of weed control on tree biomass production, soil moisture, and soil temperature, and interactions of weed control with organic matter removal and compaction to influence vegetation growth (Powers and Fiddler 1997). Analyses of these data should help to better define the below-ground effects of organic matter removal and soil compaction on tree growth and how earthworms respond to these disturbances. Survival and growth differences among treatments should become more pronounced as the stand continues to develop.

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