BIOMASS REMOVAL AND ITS EFFECT ON PRODUCTIVITY OF AN ARTIFICIALLY REGENERATED FOREST STAND IN THE MISSOURI OZARKS

Felix Ponder, Jr.[1]

Abstract—Intensive harvesting, which removes a greater proportion of the forest biomass than conventional harvesting and the associated nutrients, may cause a decline in forest productivity. Planted seedling response to three biomass removal levels (1. removal of boles only=OM1, 2. all surface organic matter removed, forest floor not removed=OM2, and 3. removal of all surface vegetation plus forest floor = OM3) was examined in one of the Forest Service Long-Term Soil Productivity (LTSP) research studies located in the Missouri Ozarks. Before harvesting, the study area contained a mature upland oak-hickory (*Quercus*-*Carya* spp.) forest with some oak-pine (*Quercus* spp.-*Pinus echinata* Mill.) communities. Soil nutrient concentrations at one year and eight years later were compared with soil nutrient concentrations in uncut control plots. Survival of red oak, white oak, and shortleaf pine seedlings increased with increasing levels of surface organic matter removal. Mean height for red and white oaks was significantly ($p \leq 0.05$) greater for OM1 and OM2 plots than for OM3 plots. Mean diameter at breast height (dbh) was significantly less for OM1 plots than for OM3 plots. Mean height for shortleaf pine was not significantly affected by biomass removal treatments but dbh was. Overall, measurements of tree growth after nine growing seasons and soil and leaf chemistry indicated that site productivity has not been impaired by the removal of surface organic matter.

INTRODUCTION

Forested ecosystems contain large amounts of nutrients in woody biomass that may exist either as standing material, on the soil surface, or within the soil profile. Logs removed during timber harvesting removes considerable amounts of nutrients and the disturbance caused by the process may sometime later, if not immediately, affect the amount of nutrients left on the site due to increased soil erosion, mineralization, and leaching (Alban and others 1978, Boyle and others 1973, Hornbeck and Kropelin 1982).

Wells and Jorgensen (1979) concluded that because soil nutrient supply and productivity in forests change relatively slowly, biomass-harvesting practices could be selected from rotation to rotation without serious risk of decline in soil productivity. Increasing the amount of biomass removal reduces the quantity of organic residue that would ordinarily be subjected to decomposition and nutrient release. If forest floor temperature and moisture are increased by biomass removals, there could be a nutrient flush from accelerated forest floor decomposition.

Most attempts to predict the effects of organic matter removal on long-term forest productivity have been severely limited by lack of information. An alternative to prediction is to wait 40 to 100 years for the outcome after installing such studies (Wells and Jorgensen 1979). In this paper, data is presented on planted red oak (*Quercus rubra* L.), white oak (*Q. alba* L.) and shortleaf pine (P*inus echinata* Mill.) after nine growing season, which were planted in plots with different levels of surface organic matter removal. The objective of the study was to determine the effect of three levels of surface organic matter removal on the productivity of the site. The study is part of a network of studies in the USDA Forest Service's Long-Term Soil Productivity (LTSP) program that is based on the following rationale (Powers and others 1990):

- Management practices create soil disturbances
- Soil disturbances affect soil and site processes
- Soil and site processes control site productivity

[1] Research Soil Scientist, USDA Forest Service, North Central Research Station, Jefferson City, MO 65102.

The research focuses on the impact of soil compaction and organic matter removal on the growth, development, and long-term soil productivity (LTSP) of forested lands in the United States and similar studies established in parts of Canada. Installations are designed to be maintained for at least one rotation.

MATERIALS AND METHODS

Site Description

The site for this study is located in the Carr Creek State Forest in Shannon County, Missouri. The silt loam soils on the site are primarily of the Clarksville series (Loamy-skeletal, mixed mesic Typic Paledults). 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 (*Quercus* spp.) -hickory (*Carya* spp.) forest with a site index for 50-year-old black oak (*Q. velutina* Lam.) that ranges from 22.5 to 24.3 m (Hahn 1991). Mean annual precipitation and temperature is 112 cm and 13.3º C, respectively (Barnton 1993).

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 tree boles removed, crowns retained, felled understory, and forest floor not removed (OM1), (2) all aboveground living vegetation removed, forest floor retained (OM2), and (3) all surface organic matter removed, exposing mineral soil (OM3). Merchantable boles included trees with diameters at breast height (dbh) of 25 cm or larger. Total biomass dry weight was calculated for individual trees, then plotted against dbh for each tree species, and biomass at each 5-cm diameter class was extrapolated from an eye-fitted curve. Combined with the number of trees per acre, total dry weight of the overstory (> 4 cm) was estimated. Allometric regression equations in the literature in the form Y = a(DBH)**B were developed and compared to these estimates; for white oak and hickory (Clark and others 1985), for black, scarlet, and white oak and hickory (Wiant and others 1977), and black oak (King and Schnell 1972). The three levels of compaction included: (1) no compaction (C1), (2) moderate compaction (C2), and (3) severe compaction (C3). Soil compaction was accomplished by using heavy road construction equipment (Ponder and Mikkelson 1995). Mean bulk density increased to 1.8 g cm^3 compared to 1.3 g cm^3 for the noncompacted treatment. The 3 x 3 factorial arrangement of treatments was replicated 3 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. Following treatment installation, 1-0 seedlings of red oak, white oak, and shortleaf pine were planted in rows at a spacing of 3.66 m apart in and between rows at a ratio of 3 oaks of each oak species to one shortleaf pine. A complete description of the site and the LTSP installation are provided elsewhere (Ponder and Mikkelson 1995).

For this report, only the three levels of organic matter removal without compaction and the uncut control plots were used to compare soil nutrient changes and other measurements. For the first 2 years after planting, a 3-foot 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 survival, height, and diameter were measured after planting and annually thereafter. Diameter at 2.54 cm above the soil surface and diameter at breast height (dbh), when trees reached 1.4 m tall or taller, were measured. Red oak, white oak, current-year shortleaf pine leaves were collected in August of year 8 for nutrient analyses. Soil samples were collected at 10 cm increments from 0 to 30 cm deep both at pre-inventory and during the ninth growing season. To reduce cost for sampling and analyses, only leaves from the OM1 and OM3 treatments and soil from the OM1 and OM3 treatments plus uncut controls were sampled. For soil, data for all depths were combined for each plot, analyzed, and results presented as relative differences between treatments after one year and during the ninth growing season. Leaf samples for each plot were kept separate and analyzed.

Statistical Analyses

The experiment was analyzed as a randomized complete block design. Survival was analyzed using the PROC LIFETEST procedure (Allison 1995). Growth and leaf nutrient 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

Surface Organic Matter

Boles (OM1) made up approximately 37 percent of the organic matter removed in the OM3 treatment (table 1). Removing all living vegetation (OM2) increased organic matter removal by another 40 percent over removing only merchantable boles (OM1). Removing all living vegetation plus the forest floor (OM3) increased organic removal over OM2 by 23 percent. Considerably lesser amounts of nutrients were removed in the OM1 treatment than in OM2 and OM3 treatments (table 1). Removing boles and crowns more than doubled the amount of nutrients removed from the site, and for some nutrients, such as Ca and Al, the OM2 treatment was three times the OM1 treatment. The amount of Al removed in the OM3 treatment was 10 times higher than in the OM2 treatment. These results indicate that tree branches account for large amounts of the nutrients in a tree. In a study similar to this study, mixed conifers (*P. ponderosa, P. lambertianaover, Abies concolor, Pseudotsuga menziesii,* and *Sequoiadendron giganteum*, boles accounted 80 percent of the above ground organic matter but less than half of the N present above ground biomass (Powers and Fiddler 1997).

Table 1—Estimated biomass and nutrients removed in organic matter removal treatments

	Treatment		
Variable	OM1	OM2	OM3
	- - - - - - - - - - *Mg/ha* - - - - - - - - - -		
Biomass			
Biomass removed	85	176	228
	- - - - - - - - - - - *kg/ha* - - - - - - - - - - -		
Nutrients removed			
Nitrogen	195	540	811
Phosphorus	7	26	48
Potassium	109	256	285
Calcium	774	2303	2819
Magnesium	20	53	81
Manganese	7	18	49
Iron	1	3	18
Zinc	0.5	2	3
Aluminum	2	8	81
Sodium	0.5	1	2
Copper	0.1	0.3	0.6
Boron	0.4	1	1.5

OM1 = removal of boles only; OM2 = all surface organic matter removed, forest floor retained; OM3 = removal of all surface vegetation plus forest floor.
Values are the mean for 18 trees.

The impact of organic matter removal on major soil chemical properties during the first nine years is presented in table 2 as relative differences between chemical properties of the soil in OM1 and OM3 treatments and the uncut control treatment. Differences between treated plots and uncut control plots show few nutrient declines. Only K and Mg were less for treatments in 2002 than in 1995, nine years after treatment application. The percent soil carbon did not change. Data from seven Coastal plain sites indicated that organic matter removal had negligible impact on the concentration of soil C after 10 years (Powers and others 2004).

Although treating the plots removed large amounts of nutrients, considerable amounts of nutrients remained in the soil. It was estimated that 8,436 kg N/ha remained in the soil on this site following the most severe organic matter removal treatment (OM3). This amount is within the range of 7,561 to 23,286 kg N/ha reported for two other central hardwood sites with site indexes similar to the site index for the present study site (Kaczmarek and others 1995). Soil nitrogen pools on such sites can be large and variable. Nitrogen as well as other soil nutrients released from organic matter on the forest floor in the Missouri Ozarks may be cycled at a very slow rate in midsummer because decomposition is often limited by moisture during that time of the year (Meentenmeyer 1978, White and others 1988). Also contributing to the pool of nutrients that remains after harvesting or organic matter removal is the root biomass which has been estimated to be almost proportional to aboveground biomass (Harris and others 1977). Further, it has been estimated that precipitation, including dustfall, annually adds 7.9, 0.1, 4.0, 5.6, and 0.8 kg/ha of N, P, K, Ca, and Mg, respectively, to the landscape (Foster 1974).

Tree Survival, Height, and Growth

Survival for all seedlings declined with age but increased with increasing organic matter removal (table 3). After nine growing seasons, survival for red oak and white oak was 81, 86, and 94 percent and 79, 82 and 88 percent, respectively, for OM1, OM2, and OM3 treatments. For shortleaf pine, survival ranged from a low of 51 percent for the OM1 treatment to a high of nearly 60 percent for both OM2 and OM3. The better survival associate with increasing organic matter removal may be due to fewer mice and rabbits during the first few years of the study because of less cover for protection and forage in OM2 and OM3

Table 2—Relative differences in some soil chemical properties between treatments at the initiation (1995) of the study and during the ninth growing season (2002)

	Treatment difference from uncut control[a]			
	1995		2002	
Chemical property	OM1	OM3	OM1	OM3
pH	+0.3	+0.3	+0.1	0
Carbon (percent)	+0.9	+0.2	+0.8	+0.2
Nitrogen (percent)	+0.03	+0.03	—[b]	—[b]
Phosphorus (kg/mg)	+4.5	+8.9	+9.2	+2.6
Potassium (kg/mg)	+12.0	+10.6	-72.0	-21.9
Calcium (kg/mg)	+342.5	+363.2	+759.0	+270.0
Magnesium (kg/mg)	+10.6	+18.1	-33.7	-14.3

OM1 = removal of boles only; OM3 = removal of all surface vegetation plus forest floor.

[a] Uncut control plots are three plots that are adjacent to treated plots where soils and timber stand conditions are similar to treated plots before treated plots were harvested. Positive values are higher than values for uncut control and negative values are less than values for uncut control.

[b] Data not available.

Table 3—Percent survival of planted 1-0 red oak, white oak, and shortleaf pine after the second, fifth, and ninth growing season in three organic matter removal treatments

	Treatment		
Year	OM1	OM2	OM3
	- - - - - - - - - - - *percent*[a] - - - - - - - - - - -		
Red oak			
2	83a	89b	97c
5	81a	88b	95b
9	81a	86a	94b
White oak			
2	83a	88ab	93b
5	81a	86ab	92b
9	79a	82a	88b
Shortleaf pine			
2	62a	67b	70b
5	61a	62a	68b
9	51a	60b	61b

OM1 = removal of boles only; OM2 = all surface organic matter removed, forest floor retained; OM3 = removal of all surface vegetation plus forest floor.
Values followed by the same letter within the row for different treatments are not significantly different by the Tukey's multiple-range test ($p < 0.05$).
[a] Percent = number of live trees ÷ number of trees planted x 100.

treatments. Shoot damage, which is typically associated with these predators, was more apparent in OM1 plots. Plastic tree protectors were installed around seedlings soon after planting, but apparently not before a disproportioned number of seedlings in OM1 plots were killed. Also, part of the better survival of trees in OM3 plots may be associated with reduced vegetative competition created early on by forest floor removal that generated better root growth and water and nutrient uptake (Grossnickle and Heikurinen 1989).

Mean height of red oak and white oak declined with increasing organic matter removal level (table 4). After nine growing seasons, red oaks were 40 cm or more taller than white oaks for all treatments. Mean annual growth rates for oaks were similar (fig. 1). The decline in mean annual height growth increment for oaks that occurred in 1998 and in 2000, except for the OM2 treatment for red oak, did not occurred for shortleaf pine. The cause for the decline is not known, but may be related to precipitation. Rainfall data for 1999 and 2000 was 42 and 46 percent lower than from April through August. However, rainfall varied from 0.9 cm during April 2000 to 17 cm during June 2000. We speculate that the three species reacted differently to changes in precipitation, with shortleaf pine less tolerant of spring drought.

The dbh of red and white oaks also decreased with increased levels of organic matter removal (table 4). For red oak, trees in OM2 and OM3 treatments had significantly smaller dbh than trees in the OM1 treatment while white oaks trees with the smallest dbh were in the OM3 treatment. Shortleaf had the smallest mean dbh in the OM1 and OM3 treatments and the largest in the OM2, indicating they performed best in with an intermediate level of organic matter removal.

Table 4—Mean height and diameter at breast height of red oak, white oak, and shortleaf pine after the ninth growing season in three organic matter removal treatments

	Treatment		
Species	OM1	OM2	OM3
	- - - - - - - - - *cm* - - - - - - - - -		
Height			
Red oak	300.7 (115) a	291.8 (118) a	274.7 (117) b
White oak	256.9 (93) a	246.1 (97) a	233.1 (99) b
Shortleaf pine	470.5 (117) a	474.0 (101) a	455.1 (150) a
	- - - - - - - - - *mm* - - - - - - - - -		
Diameter (d.b.h.)			
Red oak	26.5 (20) a	24.6 (15) ab	22.4 (15) b
White oak	23.6 (17) a	23.3 (14) a	20.9 (14) b
Shortleaf pine	75.2 (37) a	88.3 (31) b	80.9 (31) ab

OM1 = removal of boles only; OM2 = all surface organic matter removed, forest floor retained; OM3 = removal of all surface vegetation plus forest floor; d.b.h. = diameter at breast height.
Values followed by the same letter within the row for different treatments are not significantly different by the Tukey's multiple-range test ($p < 0.05$).
Numbers in parentheses are standard deviations.

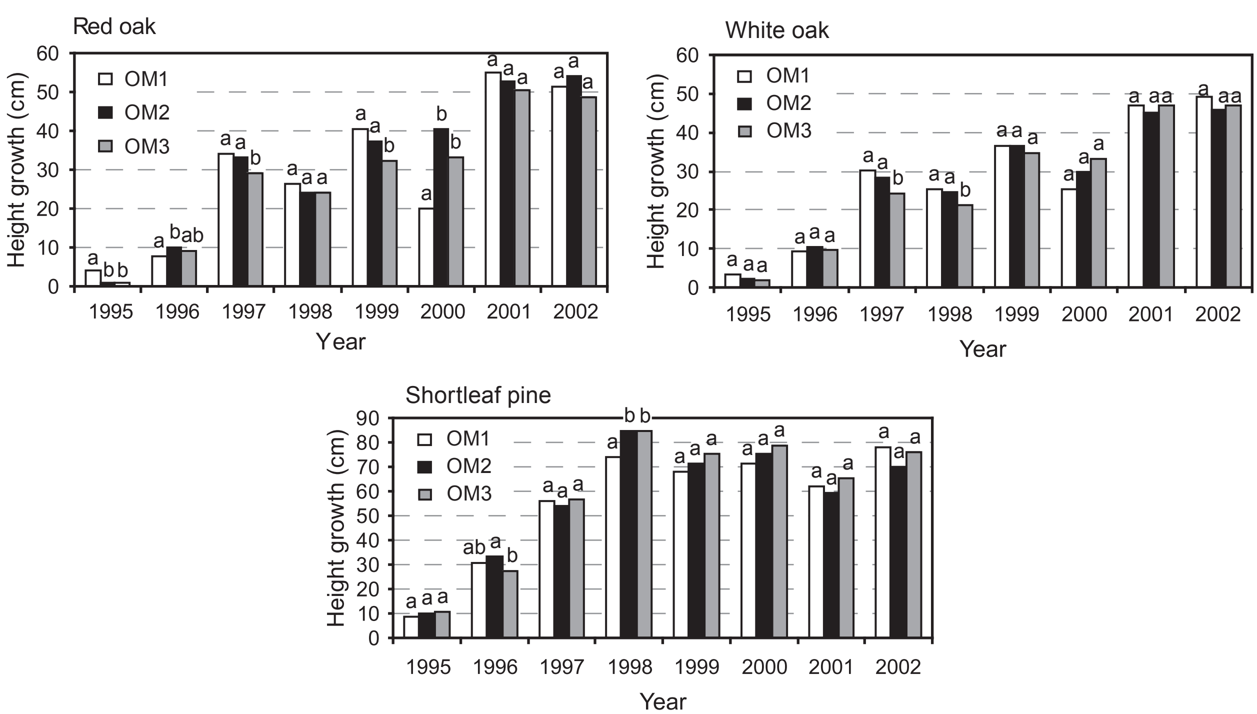

Figure 1—Annual height growth of planted red oak, white oak, and shortleaf pine on plots treated with three levels of organic matter removal including OM1 = all merchantable tree boles removed, OM2 = all aboveground vegetation removed except forest floor, and OM3 = all aboveground vegetation removed plus forest floor exposing mineral soil. Means with the same letters within a year are not significantly different based on Tukey's test at the p<0.05 level.

Much of the reason for species responding differently to organic matter removal levels is likely due to inherent differences in species. Responses by oaks and shortleaf pine in table 4 cannot be explained by leaf nutrient concentrations for 2001 (table 5). Except for differences in P and Mn concentrations for red oak between OM1 and OM3 treatments, differences between treatments for leaf nutrient concentrations were not significant. Neither leaf nutrient concentrations nor relative differences in soil chemical properties (table 2) indicate a decline in site productivity; although, growth of oaks would suggest there was. The overall mean height and dbh measurements after 9 growing seasons shown in table 4 indicate differences between organic matter removal treatments; however, the analysis of variance for the annual growth data graphically shown in figure 1 revealed that except for red oak in 2000, treatment differences for red and white oak growth were not significant after 1999 and were significant for shortleaf pine only in 1996 and 1998. Thus, mean differences in height and diameter after 9 growing seasons can be attributed to growth differences established by trees in the earlier years.

Recently, Powers and others (2004) showed that removing all surface organic matter prior to planting had no general impact on total vegetative production (standing trees plus understory vegetation) at 10 years for two species of conifers. These authors, with caution, also reported that the linear trend developed by the regression suggests that removing surface organic matter reduces productivity more on poorer sites than on better sites. The Missouri Ozarks is among the poorer sites in the Central Hardwood region for the tree species in this study; primarily because occasional summer droughts occur and soils are often cherty and/or shallow plus low in fertility. Despite being unable to compare the productivity of study trees on more productive sites, apparently, even on this site, any detrimental effect that might have existed earlier has disappeared. However, these are early results and caution must be exercised in making conclusions about a study that is planned to continue for 80 to 100 years. In the present study, tree growth rather than total vegetation was measured in response to organic matter removal. Total vegetation production better reflects site potential than just trees growth alone, particularly were tree stocking has not yet reached site carrying capacity.

CONCLUSIONS

Nine growing seasons are a short time period in the life of a forest stand. Results indicated that significant growth differences attributed to organic matter removal treatments were accomplished early in the life of the trees and these differences have been maintained through 9 growing seasons. Hence, later annual growth differences were not significantly different between treatments. Measurements of tree growth and soil and leaf chemistry indicate that site productivity has not been noticeably impaired by the removal of surface organic matter. The greatest impact of treatments on vegetation production can not be fully evaluated until crown closure. Although, the lack of site impairment due to organic matter removal agree with findings reported earlier for another group of LTSP studies (Powers and others 2004), results can not be generalized over the range of sites where other LTSP installations exist because of differences in climate, soils, and tree species. Generalized conclusions may not be possible until data from most of the more than 100 LTSP installations are analyzed.

Table 5—Leaf nutrient concentrations for red oak, white oak, and shortleaf pine during the eighth growing season in the low and high organic matter removal treatments

	Treatment					
	Red oak		White oak		Shortleaf pine	
Nutrient	OM1	OM3	OM1	OM3	OM1	OM3
	- g/kg -					
Nitrogen	20.8a	21.5a	19.1a	18.9a	15.0a	14.8a
Phosphorus	1.1a	1.3b	1.0a	1.1a	1.1a	1.1a
Potassium	6.3a	6.2a	5.7a	5.9a	5.3a	5.8a
Calcium	8.9a	8.2a	9.7a	10.0a	2.0a	1.9a
Magnesium	1.9a	1.9a	1.5a	1.3a	0.8a	0.9a
Sulfur	1.2a	1.2a	1.2a	1.2a	0.9a	0.8a
	- mg/kg -					
Sodium	37.5a	37.6a	36.7a	33.9a	36.3a	34.8a
Iron	93.2a	87.2a	65.6a	75.4a	68.5a	48.0a
Manganese	1200.3a	962.5b	742.5a	804.9a	305.3a	369.5a
Zinc	35.0a	35.1a	16.7a	16.6a	42.2a	39.9a
Copper	6.3a	6.5a	6.7a	6.6a	5.4a	5.3a
Boron	35.7a	32.6a	47.2a	47.3a	13.9a	14.3a

OM1 = removal of boles only; OM3 = removal of all surface vegetation plus forest floor.
Values followed by the same letter within the row for different treatments are not significantly different by the Tukey's multiple-range test ($p < 0.05$).
Each value is the mean of nine samples.

LITERATURE CITED

Alban, D.H.; Perla, D.A.; Schlaegel, B.E. 1978. Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota. Canadian Journal of Forest Research 8:290-299.

Allison, P.D. 1995. Survey analysis using the SAS system: a practical guide. Cary, NC: SAS Institute Inc. 292 p.

Barnton, A.G. 1993. Atlas of frequency distribution, auto-correlation of daily temperature and precipitation at stations in the U.S. Camp Springs, MD: U.S. Department of Commerce, National Oceanic & Atmospheric Administration, Atlas No. 11m. 440 p.

Boyle, J.R.; Phillips, J.J.; Ek, A.R. 1973. "Whole tree" harvesting: a nutrient budget evaluation. Journal of Forestry 71:760-763.

Clark, A., III; Phillips, D.R.; Frederick, D.J. 1985. Weight, volume, and physical properties of major hardwood species in the Gulf and Atlantic Coastal Plains. Res. Pap. SE-250. Asheville, NC: USDA, For. Serv. Southeastern Forest Experiment Station. 66 p.

Foster, N.W. 1974. Annual macroelement transfer from *Pinus banksiana* Lamb. forest to soil. Canadian Journal of Forestry Research 4:470-476.

Gott, J. 1975. Soil survey of the Mark Twain National Forest area. Missouri (Parts of Carter, Oregon, Ripley, and Shannon Counties). U.S. Department of Agriculture, Forest Service, Rolla, MO. 56 p.

Grossnickle, J.; Heikurinen, J. 1989. Site preparation: water relations and growth of newly planted jack pine and white spruce. New Forests 3:99-123.

Hahn, J.T. 1991. Timber resource of Missouri. Research Bulletin NC-119. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 123 p.

Harris, W.F.; Kinerson, R.S., Jr.; Edwards, N.T. 1977. Comparison of belowground biomass of natural deciduous forest and loblolly pine plantations. Pedobiologia 17:369-381.

Hornbeck, J.W.; Kropelin, W. 1982. Nutrient removal and leaching from a whole-tree harvest of northern hardwoods. Journal of Environmental Quality 11:309-316.

Kaczmarek, D.J.; Rodkey, K.S.; Reber, R.T. [and others]. 1995. Carbon and nitrogen pools in oak-hickory forests of varying productivity. In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings of the tenth central hardwood forest conference. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 79-93.

King, W.W.; Schnell, R.L. 1972. Biomass estimates of black oak tree components. Tech. Note-B1. Division of Forestry, Fish, and Wildlife Development, Tennessee Valley Authority, Norris TN. 24 p.

Meentenmeyer, V. 1978. Macroclimate and ligin control of litter decomposition rates. Ecology 59:465-472.

Ponder, F., Jr.; Fumin, L.; Jordan, D. [and others]. 2000. Assessing the impact of *Diplocartia ornate* on physical and chemical properties of compacted forest soil in microcosms. Biology and Fertility of Soils 32:166-172.

Ponder, F., Jr.; Mikkelson, N.K. 1995. Characteristics of a long-term forest soil productivity research site in Missouri. In: Gottschalk, K.W.; Fosbroke, S.L.C., eds. Proceedings of the tenth central hardwood forest conference. Gen. Tech. Rep. NE-197. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 272-281.

Powers, R.F.; Alban, D.H.; Miller, R.E. [and others]. 1990. Sustaining site productivity in North American forests: problems and prospectives. In: Gessel, S.P.; Lacate, D.S.; Weetman, G.F.; Powers, R.F., eds. Sustained productivity of forest soils. Proceedings of the seventh North American forest soils conference. Vancouver, B.C., University of B.C., Faculty for Forestry Publication: 49-79.

Powers, R.F.; Fiddler, G.O. 1997. The North American long-term soil productivity study: progress through the first 5 years. In: Proceedings of the eighteenth annual forest vegetation conference. Sacremento, CA. and Redding, CA: Forest Vegetation Management Conference. 88-102.

Powers, R.F.; Sanchez, F.G.; Scott, D.A. [and others]. 2004. The North American long-term soil productivity experiment: coast-to-coast findings from the first decade. In: Shepperd, W.D.; Eskew, L.G., comp. Proceedings of the national silviculture workshop. Gen. Tech. Rep. RMRS-P-34. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 191-206.

Wells, C.G.; Jorgensen, J.R. 1979. Effects of intensive harvesting on nutrient supply and sustained productivity. In: Proceedings impact of intensive harvesting on forest nutrient cycling. Syracuse, NY, State University of New York, College of Environmental Science and Forestry: 212-230.

White, D.L.; Haines, B.L.; Boring, L.R. 1988. Litter decomposition in Southern Appalachian black locust and pine-hardwood stands: litter quality and nitrogen dynamics. Canadian Journal of Forest Research 18:54-63.

Wiant, H.V., Jr.; Sheetz, C.E.; Colaninno, A. [and others]. 1977. Tables and procedures for estimating weights of some Appalachian hardwoods. Bulletin-659T. West Virginia University Agriculture & Forest Experiment Station, Morgantown, WV. 36 p.