CHARACTERISTICS OF A LONG-TERM FOREST SOIL PRODUCTIVITY RESEARCH SITE IN MISSOURI

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Abstract: Problems with soil quality and maintenance of soil productivity occur when management activities are improperly planned and carried out. To ensure that Forest Service management practices do not reduce long-term soil productivity (LTSP), a network of coordinated long-term experiments is being established across the United States. The first LTSP study in the Central Hardwood Region is being established in the Ozark Region of southeastern Missouri, in Shannon County. The study area contained mature upland oak-hickory forest with some oak-pine communities. Within the 17.4-ha (43- acre) study area are 27 plots that are approximately 0.4 ha (1 acre) each. The national study plan calls for three levels of organic matter removal (stem only, whole tree, and whole tree plus litter layer) and three levels of compaction (none, moderate, and severe). Logs were lifted from the uncompacted treatment (9 plots) using a skyline yarder system instead of entering plots with a skidder. The remaining plots were harvested conventionally. Pre-treatment data collected include census, height, diameter, and nutrient measurements of overstory, understory, and herbaceous plants; litter and forest floor weights as well as chemical composition; and chemical and physical (porosity and bulk density) soil properties. These data will be used to investigate the effects of treatments on growth, composition, and spatial distribution of woody and herbaceous vegetation, physical and chemical soil properties, and nutrient cycling.

INTRODUCTION

Developing forest management practices to ensure the long-term sustainability of forests is becoming a research and management priority. Interest in sustaining productivity of forest lands has steadily increased since the use of heavy equipment (Woodbury 1930) and whole tree harvesting (Hornbeck and Kropelin 1982). Public concern about the impacts of forest management activities has resulted in legislation (USDA Forest Service 1983) and policies (U.S. Code of Federal Regulations 1985) that mandate research and monitoring (USDA Forest Service 1987) of management systems to protect the productivity of the land.

Before these policies and legislation, there was the National Forest Management Act (NFMA) of 1976, which requires the research and monitoring of federal lands to safeguard the productivity of forest soils (Powers and others 1990). This requirement has led to a nationwide research and monitoring program to define the effects of management practices on long-term soil productivity through the establishment of coordinated, long-term experiments on major timber species, soils, and regions across the United States (Powers and others 1989). The objectives of the program are to: (1) quantify the effects of soil disturbance from management activities on long-term productivity; (2) validate soil monitoring standards developed in compliance with the NFMA of 1976; (3) learn more about the fundamental relationships between soil properties, long-term productivity, and forest management practices; and (4) evaluate the potential for mitigating the adverse effects of disturbance.

The soil properties believed to be primarily responsible in controlling forest productivity are soil porosity and soil organic matter content. These are also the soil properties greatly impacted by forest management activities. The experimental design used creates an artificially imposed factorial gradient in soil porosity and organic matter content to generate a productivity response as a function of these two soil properties rather than the impact of operational practices. The response relating changes in growth potential to changes in site organic matter and soil porosity will

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allow us to estimate the magnitude of damage to forest productivity that has been generated by disturbance. Except for treatments producing minimal soil disturbance, the remaining treatments sometimes greatly exceed the degree of disturbance caused by normal logging operations.

The national long-term soil productivity (LTSP) study plan calls for three levels of compaction (none, moderate, and severe) and three levels of organic matter removal (stem only, whole tree, and whole tree and litter layer). Most harvesting operations currently being conducted in the Central Hardwood Region fall into the lowest levels of compaction and biomass removal. The long rotation length (approximately 80 years), high installation cost, and commitment to maintain, measure, and report on study progress are not small matters. The present study (LTSP in Missouri) is being led by Forest Service Research, with cooperation from the Mark Twain National Forest, Missouri's Department of Conservation and Department of Natural Resources, Natural Resource Conservation Service, and the University of Missouri.

This paper describes pretreatment data collection and treatment installation; and it presents pretreatment data to characterize the first LTSP in the Central Hardwood Region.

METHODS

The Study Site

Site selection, plot criteria, experimental design, and treatments for the Missouri LTSP are based on information in the national LTSP study plan (Powers and others 1989). The study is located on the Carr Creek State Forest (Missouri Department of Conservation) in Shannon County. Mean annual precipitation there is 112 cm (44 inches), and mean annual temperature is 13.3°C (56°F). The site occupies the upper sideslopes of two northeastern ridges that extend from north to south in the southeastern Missouri Ozarks. It contained a well-stocked, mature, second-growth oak-hickory forest. Site index ranges from 74 to 80 based on black oak (*Quercus velutina* Lam.) at 50 years (Hahn 1991). The oak-hickory timber type is the major timber type in the Central Hardwood Region occurring over a variety of soils, relief, and stand conditions.

The sloping topography (20-28% slopes) has small shallow streams that contain exposed cobbles and stones. The area is underlain mainly by Ordovician dolomite, and areas of Cambrian dolomite and Precambrian igneous rocks are also present (Missouri Geological Survey 1979).

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). Water drains freely through the soils into subsurface channels.

Treatments

A preliminary soil survey was made to locate the study area on relatively uniform soil. Soil pits were dug and soils were described and analyzed with cooperation from the Missouri Department of Natural Resources, the Natural Resources Conservation Service, the Mark Twain National Forest, and the University of Missouri. Field examination included estimation of depth to restrictive layer, horizon thickness, texture, and gravel content. After estimating that the key soil properties did not vary significantly across the areas, we established boundaries for plots. Three replicates of nine treatment plots approximately 0.4 ha (1 ac.) in size were laid out in the summer of 1993. Four-meter-wide buffer strips were laid out around all plots. Treatments include a nine-plot factorial of three levels each of organic matter removal and soil compaction. Organic matter removal consists of: (1) stem only, (2) whole tree, and (3) whole aboveground biomass including the forest floor. Soil compaction levels are none, moderate, and severe. Severe compaction is defined as 80% of the difference between the hypothetical growth-limiting bulk density (Daddow and Warrington 1983) and the bulk density of the uncompacted soil. Moderate is midway between the extremes.

Inventory

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 (MOFEP) botany crew of the Missouri Department of Conservation. Overstory measurements were made on 0.2-ha (0.49-ac.) circular plots. All trees living and dead standing 11.5 cm (4.5 in.) dbh and greater were identified, and dbh was measured. All live saplings between 3.8 cm (1.5 in.) and 11.2 cm (4.4 in.) dbh were identified and measured on four circular 0.02-ha (0.05-ac.) plots located 17.25 m (56.4 ft.) from the center point in each cardinal direction (N, S, E, and W). Understory woody vegetation 1.3 cm but less than 3.8 cm dbh and greater than 1 m tall was measured on 0.004- ha (0.01-ac.) plots that were located within sapling plots. Dead and downed woody material greater than 5 cm dbh and 0.6 m long was inventoried (species, maximum diameter, length, and decomposition class) along each of four line intercepts 17.25 m (56.4 ft.) in length. Herbaceous vegetation was identified and counted on four 1-m^2 plots that were located 6.1 m from the sapling plot center along NE, SE, SW, and NW transects; a total of 16 herbaceous plots were sampled within each 0.2-ha plot.

Biomass and Nutrient Sampling

Biomass samples were collected for overstory canopy trees, understory saplings, ground vegetation, and leaf litter/humus layer. All samples were dried at 105°C for 72 hr or until a constant weight was achieved. Each sample was then ground to a fine powder in a Wiley Mill and analyzed for macronutrient and micronutrient content.

Leaf litter/humus samples were collected from eight 0.125-m^2 plots that were located 5 and 15 m from each plot center along N, S, E, and W transects. Leaf litter was separated from humus material, and all eight samples were combined for biomass and nutrient analysis. Woody and herbaceous ground cover was clipped separately on four 2.5-m^2 plots located at 5 m from plot center along the same cardinal transects. Plot centers for these samples correspond to each of the 27 treatment plots but not necessarily with all MOFEP inventory plot centers. Samples were collected before leaf drop in the fall of 1993.

A total of 54 trees were selected, felled, and weighed in the field during the spring of 1994. Twenty-six saplings (dbh < 10 cm) and 28 midstory and overstory trees (dbh > 10 cm) were selected for measuring total tree biomass. Individual trees were selected based on the following criteria: 1) one of the major species present in the overstory; i.e., black oak, scarlet oak, hickory spp., white oak, and shortleaf pine, 2) sapling with a dbh between 2.5 and 10 cm, at least one for each 2.5-cm size class, 3) midstory and overstory trees with a dbh between 10 and 50 cm, when possible, one for each 5-cm size class, and 4) trees that appeared vigorous and healthy with no outward signs of rot or limb damage. The dbh of trees sampled covered the range from 5 cm to 50 cm. Total height, dbh, basal diameter, and specific crown dimensions were measured on each tree. Trees with merchantable logs were sectioned in appropriate lengths: others were cut to 2-m lengths. Sawdust samples and wood disks were collected from the end of each log section up to the 10-cm diameter. Tree crowns were sectioned into <2 cm, 2 to 10 cm, and 10+ cm size classes. Fresh weights of all tree logs and crown portions were measured in the field. Some merchantable logs were too large to be weighed in the field (scale limit = 500 lbs). Thus, detailed log dimensions were taken to estimate volume: weight was later predicted from laboratory samples. Samples were also collected from each crown size class for further analysis. Fresh weights of all sawdust samples, wood disks, and crown subsamples were measured separately.

Soil Sampling

In addition to soil pits, soil samples were collected with a two-person power-driven coring device in a systematic design. Four intact cores (7.6 cm diam. x 40 cm long) of soil per plot were collected and partitioned according to soil horizon before determination of bulk density, pH, organic matter content, hydraulic conductivity, and macronutrient content (Soil Survey Staff 1984, Page and others 1982, Black 1965).

Timber Harvesting

Trees and biomass were removed according to protocols in the national LTSP study plan (Powers and others 1989) by means that minimize soil disturbance. Trees were harvested over a 4-month period in 1994, beginning in February and ending in May. On plots designated as uncompacted, merchantable trees were directionally felled and removed with a skyline cable logging system. Merchantable trees on remaining plots, 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. Remaining crowns, unmerchantable trees, dead and live snags, dead and down, leaf litter layer, and other debris were removed manually according to protocols. Depending on treatment, it was necessary to replace these materials (except the leaf/litter layer) after compaction was completed in some plots.

Tree crowns were retained on the stem only plots. On plots where the whole tree and leaf/litter layer were removed, the total aboveground biomass was removed. All understory vegetation was clipped and removed, and the forest floor was raked away to the mineral soil. The raking of the forest floor began in August and was completed by mid-November. Skidders and tractors were not permitted on uncompacted plots, but they were permitted on compacted plots.

After plots are compacted with a 14-ton vibrating sheep-foot roller, each 0.4-ha treatment plot will be regenerated with the appropriate timber species. Half of each plot will be kept weed free to permit target trees to grow freely. The other half will be allowed to develop naturally into a more complex community of trees and other vegetation. Net primary productivity in these two plant communities will provide direct measures of productivity as influenced by the degree of soil disturbance.

RESULTS AND DISCUSSION

The values for chemical properties, bulk density, and percent organic matter in Table 1 are typical for soils in the Clarksville series (Gott 1975). There is concern that the high gravel content in the soil could reduce the depth to which the soil can be effectively compacted. However, principal investigators of some LTSP studies have had problems in achieving a distinct difference between the moderate and severe levels of compaction in soils with low gravel content (Personal communication).

Table 1. Mean chemical properties and bulk density of soil in the Missouri LTSP study*.

Depth	Extractable bases				Extr.	Organic	pH	Bulk
	Ca	Mg	K	Na	Al	C	H_2O	density
cm	------- meq/100g --------					%		g/cm^3
0-10	4.6	0.8	0.3	Tr	0.8	5.4	5.5	1.54
10-20	0.5	0.4	0.2	Tr	1.1	0.5	5.3	1.58
20-30	0.6	0.5	0.1	Tr	1.2	0.1	4.8	1.70
30-40	1.1	2.3	0.2	Tr	3.1	0.1	4.9	1.71

*N and P analyses are not complete and are not presented.

Census Data

Overstory species composition by diameter class is shown in Figure 1. The red oak group consists primarily of black and scarlet (*Quercus coccinea* Muenchh.); the white oaks include white (*Quercus alba* L.) and post (*Quercus stellata* Wangenh.); the hickory group includes black (*Carya texana* Buckl.), mockernut (*Carya tomentosa* Nutt.) and pignut

(*Carya glabra* Mill.); the other category is composed of black walnut (*Juglans nigra* L.), blackgum (*Nyssa sylvatica* Marsh.) and dogwood (*Cornus stolonifera* L); and the predominant native pine species is shortleaf pine (*Pinus echinata* Mill.). Average height of co-dominants for each class were: 25.9 m for red oaks, 23.2 m for white oaks and hickory, and 23.8 m for pine. Red oaks, white oaks, hickory and pine made up 47.5, 26.1, 17.3 and 4.2 percent, respectively, of the overstory. Species composition of the sapling understory is shown in Figure 2. Hickory, white oaks, and dogwood accounted for 80 percent of all stems; the red oaks represented less than 3 percent. Seedling composition (less than 3.8 cm dbh) is shown in Figure 3. Total number of stems per hectare in this group was 1,905.

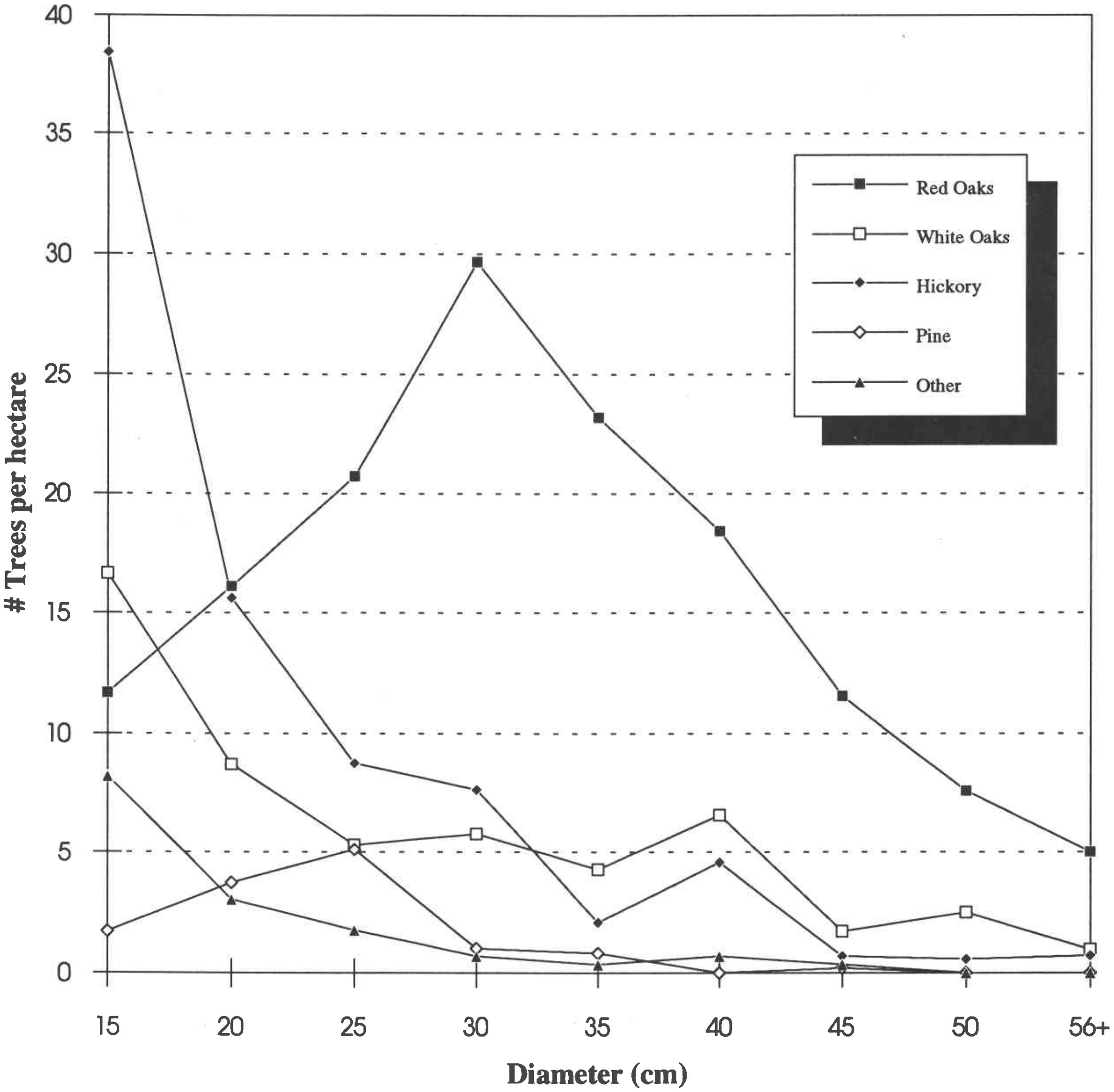

Figure 1. Overstory diameter frequency distribution by species for LTSP study site.

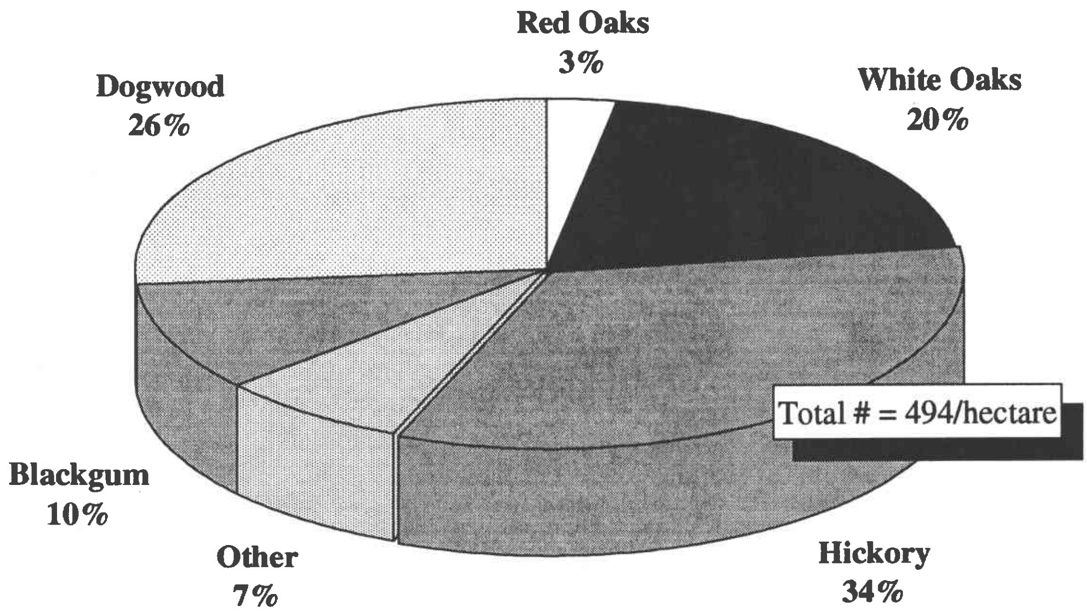

Figure 2. Sapling understory (3.8 to 12.5 cm dbh) species compostion.

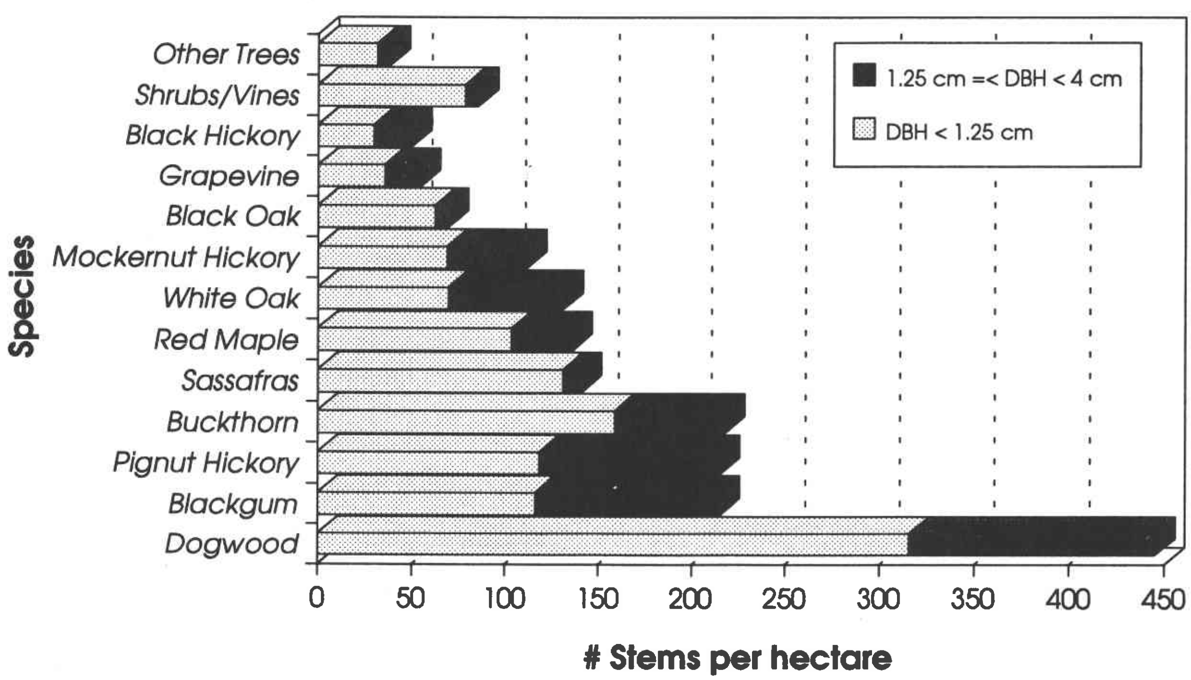

Figure 3. Number of stems per hectare of understory woody species at least 1 m tall.

The total number of dead standing trees is shown in Figure 4. The average number per hectare was 30. Most of the dead stems (74%) were either black or scarlet oak. Decay stage was recorded but is not presented here. The stages range from recently dead to highly decomposed but still standing.

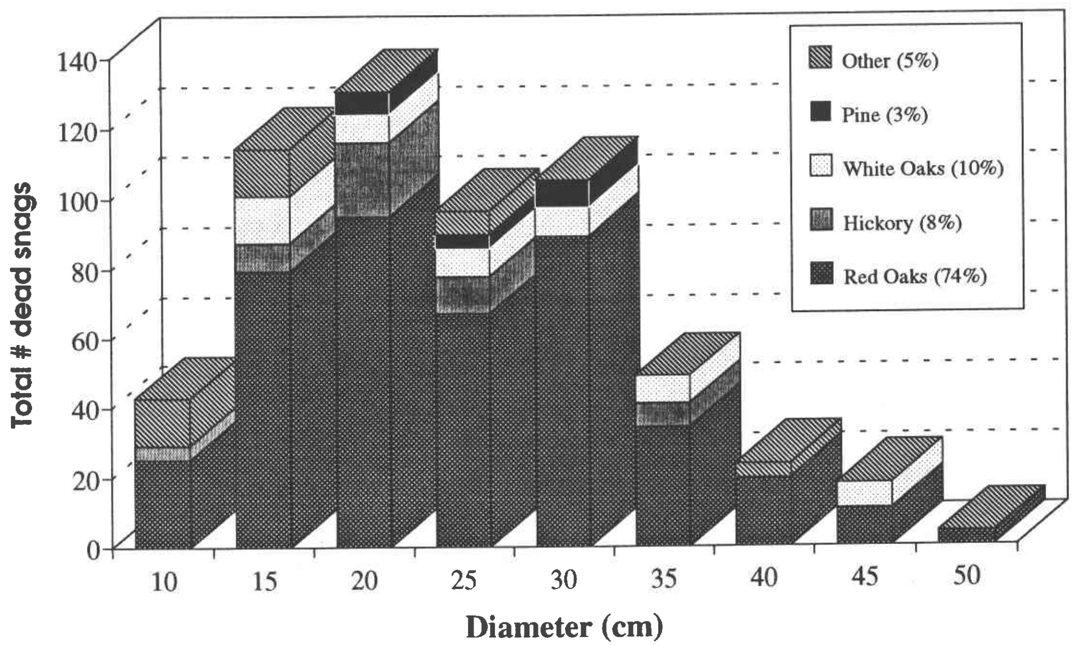

Figure 4. Total number and percent composition of dead standing trees on LTSP study site.

Biomass and Nutrient Data

Total dry weight biomass was calculated for all individual trees that were sampled. Dry weight was then plotted against dbh for each 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 to be 175.5 tons per hectare (1,016 kg/ton). Figure 5 depicts the total amount of biomass estimated to be removed by each of the three organic matter treatments. Of the 175.5 tons of woody dry matter, red oaks comprised 63%, white oaks 15%, hickory 16.5%, pine 2%, and other species 3.5%.

Allometric regression equations of the form Y = a(DBH)**b were also developed and compared to these estimates. Additionally, the literature on biomass equations for the species found on our site was reviewed and used for comparison. Dry weight estimates for white oak and hickory by Clark and others (1985): black, scarlet and white oak and hickory equations by Wiant and others (1977); and black oak sawlog biomass equations by King and Schnell (1972) were compared to the dry weight estimates from our regression.

In general, estimates for dry matter for all species compared fell within one standard deviation of our estimates for size classes below 25 cm dbh, but estimates of dry matter above 25 cm ranged from 1.3 to 9.5 standard deviations from our data. One exception was the white oak estimates from Wiant and others (1977), in which all size classes were within 1.1 standard deviations of our data.

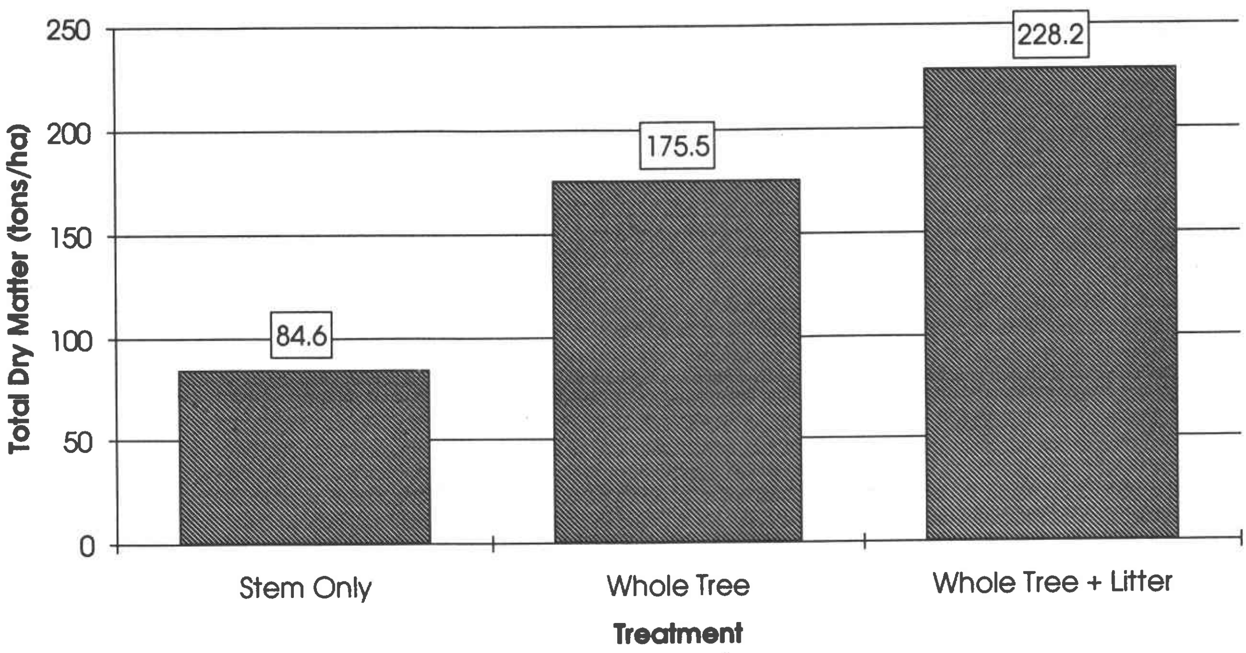

Figure 5. Total dry matter removed from plots relative to treatment.

Nutrient analysis was completed for all subsamples of ten individual trees, two of each dominant overstory species and dogwood. Crown, wood, and bark components were analyzed separately and multiplied by the proportion of the biomass they represented. Total macronutrient and micronutrient content is summarized in Table 2. The amount of nutrients removed in the biomass increased considerably when the leaf/litter layer was included.

The whole tree plus leaf/litter layer treatment removed 33% more N, 46% more P, 10% more K, 18% more Ca, and 35% more Mg than the whole tree treatmentl. Among micro-nutrients, considerably more Mn, Fe, and Al were removed in the whole tree plus leaf/litter treatment than in the whole tree treatment. Branches and unmerchantable tree parts also have large amounts of nutrients as shown when the whole tree treatment is compared to the merchantable stem only treatment. Removing the whole tree removed 3 times more N and P, 2 times more K, 3 times more Ca, and 2.6 times more Mg than did removing only the stem. Similar trends were apparent in micronutrients between whole tree and stem only treatments.

Table 2. Macronutrient and micronutrients removed from the site relative to organic matter treatment.

Nutrient	Stem only	Whole tree	Whole tree + litter*
	TREATMENTS		
	------------------ kg/hectare------------------		
Macro			
N	195.26	540.04	810.80
P	7.41	25.96	48.30
Ca	108.65	255.61	284.90
Mg	774.24	2303.11	2819.22
	19.97	52.59	81.20
Micro			
Mn	7.08	18.00	49.37
Fe	1.01	2.56	17.48
Zn	0.53	1.55	2.61
Al	2.10	7.61	81.12
Na	0.48	1.08	1.63
Cu	0.11	0.32	0.58
B	0.38	1.13	1.50

*Excluding snags and dead woody debris.

SUMMARY

This is a long term study that is in the latter part of the installation phase. It will be several years before answers about the relationships between management practices and long-term soil productivity are available. Data from this study will provide information for evaluating the effects of soil disturbance on long-term productivity of several Central Hardwood tree species and their associated flora and fauna communities. The results will help us better understand the joint role of soil porosity and site organic matter in their effect on site processes that control productivity. Combining information from the network of LTSP studies with other ecological information is expected to provide managers with more complete information with which to manipulate soil properties to either increase productivity or prevent reductions.

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