RELATIONSHIP OF ABOVEGROUND BIOMASS PRODUCTION, SITE INDEX AND SOIL CHARACTERISTICS IN A LOBLOLLY PINE STAND

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Abstract—As a part of the continuing studies of the Cooperative Research in Sustainable Silviculture and Soil Productivity (CRiSSSP), 24 experimental plots in a loblolly pine (*Pinus taeda* L.) stand have recently been installed near Natchitoches, LA. The plots were uniformly assigned to 3 blocks based on topography (i.e., up slope, midslope, and down slope). Trees and understory vegetation were sampled to determine total biomass production and nutrient content. Soil carbon, macronutrients, and mineralizable nitrogen were also analyzed. Stem analysis indicated that up-slope and midslope blocks had similar site indexes, 19 m and 18 m at base 25 years, respectively, and both had significantly higher site indexes than that of down-slope block (15 m). Major soil nutrients (N, K, Ca, and Mg) covaried with overall biomass production in the stand but not with the site index. However, mineralizable N was significantly and positively correlated with the site index ($R^2 = 0.24$, $p < 0.02$). Our results suggest that overall, soil nutrients alone are not a strong indicator of site quality. Mineralizable N, in contrast, may be a better measurement of overall quality of the stand on this particular soil.

INTRODUCTION

Concerns over the sustainability of intensive forest management practices led to the establishment of a nationwide study of long-term soil productivity (LTSP) by the U.S. Department of Agriculture, Forest Service, in 1989 (Powers and others 1990). The concerns also drew the attention of forest industries and universities and eventually lead to the Cooperative Research in Sustainable Silviculture and Soil Productivity (CRiSSSP) that initiated studies along the gulf coast in 1993 (Carter and others 1995). One of the principal objectives of CRiSSSP is to link soil properties to site productivity.

It is generally agreed that productivity is associated with soil fertility. In forestry, we expect higher productivity with higher site index. Fisher and Binkley (2000) state, "Site index is extremely important in site quality analysis in North America because it forms the standard against which all other forms of site evaluation are measured." Despite the limitation of site index, its usefulness in assessing site quality is widely accepted. Acknowledging or understanding the relationships among aboveground biomass production, site index, and soil properties of a current generation of trees could help us understand the potential productivity of the next generation of trees. This would also provide some insights on the dynamics of soil properties associated with stand development. In addition, these efforts may help to identify factors that affect the productivity of the site. Therefore, the objective of this study is to examine the relationships among aboveground biomass production, site index, and soil physical and chemical properties in a mature loblolly pine stand.

STUDY AREA AND METHODS

Study Area

This study was conducted on a 45- to 55-year-old, naturally regenerated loblolly pine (*Pinus taeda* L.) stand located in Natchitoches Parish (lat. 31.8°N, long. 93.0°W), LA owned by Roy O. Martin Timber Company. The site is 59 m above sea level, has a mean temperature in January and July of 7.9 and 28.6 °C, respectively, and receives an average of 1395 mm precipitation annually. The soil is primarily a fine-silty, siliceous, semiactive, thermic Glossaquic Paleudalf. It is a deep, moderately well-drained, and very slowly permeable soil that formed in loamy over clayey sediment of Tertiary Age. The soil is primarily Keithville series and some Shatta series. Three blocks were installed on a topographical gradient. Up-slope and midslope blocks were established on the side of a gentle slope, and a down-slope block was established at the toe of the slope. General information of pine trees associated with each topographical position is given in table 1. There might have been cultivation on this site some time in the past.

Biomass Assessment

Within each slope position, aboveground biomass and soil properties were measured within eight 42-by 35-m plots. The biomass was determined by various components for each plot. Biomass of the overstory trees [> 5 cm in diameter at breast height (d.b.h., 1.37 m)] were determined with measurements of all d.b.h. and total height and then calculated with equations developed by Clark and others (1985) for hardwoods and Baldwin (1987) for pine trees. Understory and litter biomass were determined with 4 clipped-plots, each of which was 1 by 2 m in size and systematically placed in the middle of each quadrant within

Table 1—General information on pine trees for each topographical position of a loblolly pine stand near Natchitoches, LA

Slope position	Up-slope	Mid-slope	Down-slope
Number (*per ha*)	71	65	148
Relative frequency (*%*)	56	56	61
Basal area (*m^2 per ha*)	8.8	5.9	11.0

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a plot. All plant samples were dried at approximately 65 °C to a constant weight and ground to pass a 20-mesh stainless steel screen. Nutrient contents of the various biomass components were determined. Total nitrogen (N) and carbon (C) were measured with a Fison's Instrument Model EA 1108 CHN Analyzer. For other elements, samples were wet-ashed in nitric acid-hydrogen peroxide (Huang and Schulte 1985) and analyzed with an ICP emission spectrophotometer. Height development of the existing stand was reconstructed with ring counts on wood disks cut at fixed height intervals along the stem. Average total height at 25 years old for the dominant or codominant trees sampled in each slope position was taken as site index.

Soil Properties

Soil bulk density was determined for 3 depths at 5 locations in each plot using a volumetric probe with a 5.0-cm inside diameter. Soil samples were taken at depths of 0 to 5, 10 to 15, and 20 to 25 cm and dried at 105 °C to a constant weight.

Soil samples were collected at 4 random locations in each plot for nutrient analyses. These soil samples were taken to a depth of 30 cm from the soil surface. Soil samples were mixed, air-dried, and sieved to pass a 2-mm screen. For exchangeable cations, 2.5 g of soil were placed in 25 ml of 1.0 M NH_4OAc (pH 7.0), shaken for 15 minutes, filtered, and analyzed in ICP emission spectrophotometer. Soil nutrients were determined with methods similar to those used to measure nutrient concentration in the vegetation.

Soil N availability

An index of potentially mineralizable N was estimated using an anaerobic N mineralization technique described by Waring and Bremner (1964) and by Keeney (1982) with modifications. Soil samples were collected in July 2000 at a depth of 20 cm with a push-tube probe (2.0 cm inside diameter), sealed in plastic bags, and put on ice for storage and transport. Ten grams of soil were incubated in a 120-ml plastic bottle with 20 ml of deionized water. Oxygen in the bottle's head space was flushed with nitrogen gas for approximately 10 seconds and capped tight immediately. Samples were incubated at 40 °C for 7 days. Dry weight of the sample was determined with a 20-g subsample. Immediately after incubation, mineral N was extracted in a 100-ml solution of 2-N KCl shaken for 1 hour at 225 rpm. After settling, the mixture was vacuum filtered and the filtrate refrigerated until analysis. Ammonium concentration of the filtrate was determined with a precision conductivity cell (Timberline Instruments). Standard curves were developed with eight diammonium sulfate solutions. Available mineral N per ha was calculated with corresponding soil bulk density at a 0- to 30-cm depth.

Statistical Analysis

Data were summarized by plot and analyzed by slope position. Therefore, eight data points per slope position were used in the analysis of variance and regression analysis for biomass, site index, soil bulk density, and mineralizable N. Other soil nutrient contents were calculated by averages of nutrient concentration and soil bulk density of each slope position. Unless indicated otherwise, all significant difference refers to $\alpha = 0.10$.

RESULTS AND DISCUSSION

Standing biomass for the various components within each slope position is listed in table 2. Pine biomass in midslope block was lower than the pine biomass in up-slope and down-slope blocks, though not significantly lower. Hardwood biomass was three times or more higher in the down-slope block than in the up-slope and midslope blocks. Understory and litter biomass systematically declined from the up-slope to the down-slope block. Total aboveground biomass was highest in down-slope block and lowest in midslope block. The comparatively low total biomass in the midslope block was most likely due to low pine density, whereas the comparatively high total biomass in the down-slope block had the highest density of pine trees (table 1). These differences in biomass components clearly indicate that block to block variations exist within this study site.

The site indexes of the up-slope and midslope blocks were similar, 19 and 18 m, respectively. Site indexes from these topographic positions were about 23 percent higher than the down-slope position's site index of 15 m (fig. 1). This suggested a gradient in site quality from up-slope to down-slope blocks.

Table 2—Aboveground biomass (Mg/ha) of each topographical position from a loblolly pine stand near Natchitoches, LA[a]

Slope position	Up-slope	Mid-slope	Down-slope
Component			
Pine	67.2a	43.4a	62.9a
Hardwood	5.9b	9.3b	33.1a
Understory	14.3a	9.2ab	6.1b
Litter	18.8a	16.2b	14.7b
Total	106.2ab	78.1b	116.8a

Within each component, same letters indicate no significant difference among slope positions at $\alpha = 0.10$ level.

[a] Stand age was averaged at 50 years.

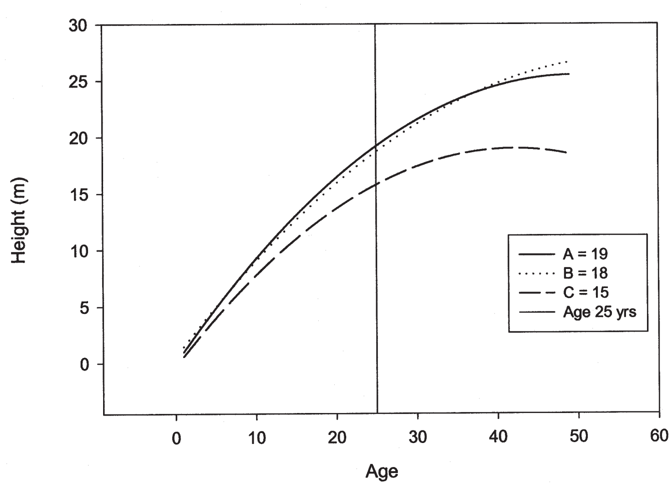

Figure 1—Growth curves reconstructed from stem analysis of dominant and codominant trees of each slope position in a loblolly pine stand near Natchitoches, LA. Site index is the height at age 25 years. A = up-slope, B = midslope, and C = down-slope blocks.

The soil bulk density in the up-slope and midslope blocks was similar, and the soil in the down-slope block was significantly lighter (table 3). The differences in soil bulk density among slope positions may be the result of different combinations of soil minerals, organic matter, and pore space. These differences produce variations in the availability of water, nutrients, and oxygen in the soils. Goncalves and others (1997) reported that lower bulk density was associated with greater stem volume in 4-year-old *Eucalyptus camaldulensis* in the savanna region of central Brazil. At the Louisiana site, the highest aboveground biomass was associated with the lowest bulk density in downslope; however, the higher biomass was due to higher tree density, not higher site index.

Differences in soil C content could not be distinguished between the slope positions (table 3), suggesting that organic matter content in the soils was similar throughout the study area. Total N and extractable P and K showed only slight differences between the blocks. Soil Ca and Mg, however, showed substantially higher levels in the down-slope block compared to the other two blocks. None of these nutrient contents were associated with site index. Some investigators have noticed that high Mg in the upper layer of soil may negatively impact tree growth (Personal communication. Richard F. Fisher. 2003. Operation Leader, Applied Research & Development, Temple-Inland Forest Products Coorperation, Diboll, TX 75941). It is uncertain, however, if the Mg level in the down-slope block had any such effect in this site. Mori and Kagawa (2000), from their culture experiments, found a negative effect on algal growth if the Ca-Mg ratio in culture media is less than 4. Another study revealed that a decrease in the Ca-Mg ratio was associated with the decrease of soil pH (Barton and Wallenstein 1997). This phenomenon seems to be true in our study site (table 3). However, there is not enough information for us to speculate if a Ca-Mg ratio of 2.0 observed in the down-slope block reduced site quality compared to the up-slope and midslope blocks where Ca-Mg ratios were 3.6 and 3.8, respectively.

The pattern in the mineralizable N with respect to slope position has a much different pattern from the other soil nutrient contents. Mineralizable N systematically decreased from up-slope to down-slope blocks (Table 3) and corresponded with the site index of each slope position. Regression analysis indicated that mineralizable N was significantly and positively correlated with site index ($R^2 = 0.24$, $p < 0.017$, $n = 23$) (fig. 2). This relationship suggested that available N might be a better measurement of the site quality. Other soil nutrients, although important, may not translate directly to site quality.

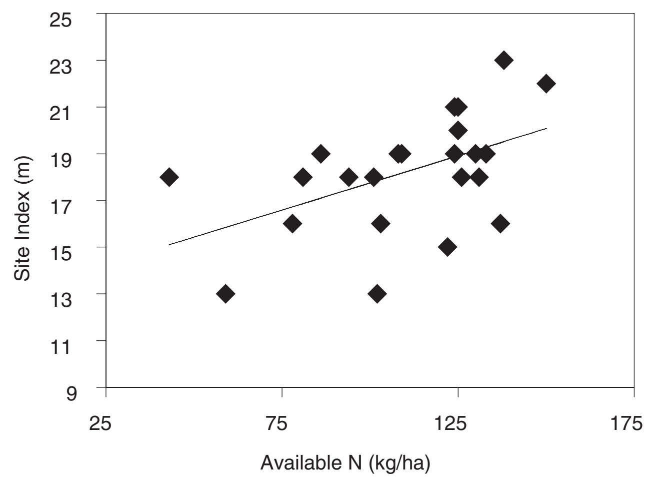

Figure 2—Scatter plot and regression line showing the relationship between site index and mineralizable N in a loblolly pine stand near Natchitoches, LA. The regression model is $Y = 13.06+0.046 X$ where Y = site index and X = mineral N ($R^2 = 0.24$, $p < 0.017$, $n = 23$).

Table 3—Soil bulk density (g per cm³), soil pH, soil carbon (C) and other soil nutrient contents by slope position in a loblolly pine stand near Natchitoches, LA

Slope position	Up-slope	Mid-slope	Down-slope
Bulk Density (*g per cm³*)			
0-5 cm	1.03a[a]	1.09a	0.84b
10-15 cm	1.47a	1.47a	1.36b
20-25 cm	1.52a	1.60a	1.39b
Soil pH at 0-30 cm	5.5	5.2	5.0
Soil C (*Mg/ha*)[b]	21.2	18.7	23.5
N (*kg/ha*)	1,037.4	794.7	994.4
P (*kg/ha*)	10.2	9.9	9.7
K (*kg/ha*)	115.6	84.3	151.1
Ca (*kg/ha*)	876.4	796.6	1,425.0
Mg (*kg/ha*)	243.9	211.4	696.6
Mineral N at 0-30 cm (*kg per ha*)	104.5a	95.7a	65.9b

[a] Within each row, same letters indicate no significant difference among slope positions at $\alpha = 0.10$ level.
[b] These values were calculated based on average nutrient concentration and average soil bulk density of each slope position at the depth of 0-30 cm from soil surface. Therefore, no statistical comparisons were made.

CONCLUSIONS

Delineation between site index and aboveground biomass production was difficult because of different stand densities. Since soil nutrient contents did not correspond to the site indexes of different topographical positions, we conclude that soil nutrient contents alone are not sufficient to account for site quality and productivity. In contrast, the significant and positive relationship between the mineralizable N and site index suggests that available N may be a better measurement of site quality and, perhaps, productivity in this soil.

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