SWEETGUM RESPONSE TO NITROGEN FERTILIZATION ON SITES OF DIFFERENT QUALITY AND LAND USE HISTORY

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Abstract—Nitrogen (N) fertilizer management in young hardwood plantations is difficult due to our lack of understanding of the site-specific mechanisms that control tree response. Differences in landuse history and soil characteristics can alter the plant response to added N considerably. Foliage biomass, N content, N concentration, resorption, and soil N supply characteristics were measured on two 4 year-old sweetgum (*Liquidambar styraciflua* L.) plantations in South Carolina that represent different landuse histories and soil types. Fertilizer responses were much greater overall on a poorly drained pine cutover site compared to a well-drained ag field. Vector analysis and analysis of variance indicated that fertilization increased foliage biomass, N content, N concentration, and leaf area on the cutover site, but only increased foliar N content on the ag site. Foliar responses were negatively related to actual soil N supply, but not potentially mineralizable or total N. N fertilizer recommendations must be site-specific, and an accurate estimate of soil N supply is essential for increasing fertilization efficiency.

INTRODUCTION

Sweetgum and other hardwood plantations have the potential to be an important source of hardwood fiber throughout the South, but the success of hardwood plantations depends heavily on management intensity. Relative to loblolly pine plantations, sweetgum plantations require more intensive site selection and preparation, herbaceous and woody competition control, and nutrient management for plantation success.

Abandoned or marginal agricultural fields have historically been the primary lands planted to hardwood plantations throughout the South, but the demand and value of hardwood fiber coupled with the relative paucity of agricultural lands in certain local areas has increased the area of cutover pine lands planted to hardwood plantations. Within these two groupings of potential hardwood plantation lands, wide differences exist in soil types, which makes our understanding of site-specific plantation responses to various treatments difficult.

Specifically, accurate, site-specific hardwood nitrogen (N) fertilizer recommendations are not yet available for hardwood plantations because of our lack of understanding of the site-specific influences on soil N supply, plant N demand, and plant response to various fertilizer rates. Several studies have shown the impressive response of young hardwood stands to N fertilizer, but variations in soil types, fertilizer rates, and management differences have hindered our ability to make accurate N fertilizer recommendations.

In most studies, N fertilization has resulted in growth responses. A few studies have linked N fertilization response to soil type or previous management (Torreano and Frederick, 1988), illustrating that the soil N supply can control the response to added N. For example, Wittwer and others (1980) applied N fertilizer each year to sycamore (*Platanus occidentalis* L.) on a bottomland site and on a terrace site. They observed a 45 percent growth response on the bottomland site and a 205 percent growth response on the terrace site at age 5, and attributed the relative response to soil N. Torreano and Frederick (1988) and Blackmon (1977) showed that hardwoods may respond quite differently on pine cutover sites than on abandoned agricultural sites.

Most recently, studies have focused on determining fertilization effects on specific plant responses other than height or volume growth. Since approximately 50 percent of aboveground plant N uptake is met by resorption of foliar N prior to senescence (Aerts and Chapin, 2000), factors which affect the resorption efficiency may dramatically change fertilizer needs. Nelson and others (1995) reported resorption efficiencies of 50-74 percent for sweetgum and attributed differences to environmental conditions, i.e., moisture availability, but not N fertilization. Kuers and Steinbeck (1998a) found similar efficiencies of 43-62 percent for sweetgum, but reported significant increases in resorption efficiency in the fertilized treatment.

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To better understand the processes controlling sweetgum response to added N, the objectives of this study were to quantify the foliar response to N fertilizer treatments on two contrasting site types and relate potential differences in foliar responses to soil N supply parameters.

METHODS

Site Descriptions and Characterization

The pine cutover site is on Westvaco Corporation land, located in Colleton County, South Carolina (32° 8' N 80° 7' W) on the lower Atlantic coastal plain, and was established in February 1995. The soil is a somewhat poorly to poorly drained Argent sandy loam (clayey, mixed, active, Typic Endoaqualfs) developed from marine deposits. The site undergoes wide fluctuations in soil water contents, from saturated soils with standing water in the bed furrows in the late fall until spring to dry soils during the growing season. Nine 0.2 ha sweetgum plots were established following loblolly pine harvest and site preparation, which consisted of bedding, fertilization and non-crop vegetation control. All plots received 280 kg/ha diammonium phosphate (DAP) in March 1995. Non-crop vegetation control consisted of pre-emergent herbicide applications in February and March of 1995, 1996, and 1997. Herbicides were also applied by directed spray in 1995 and 1996 during the growing season.

The agricultural field study site is located on International Paper's Trice Research Forest in Sumter County, South Carolina (33° 58' N 80° 12' W) on the middle Atlantic coastal plain. The soil is a well-drained Norfolk sandy loam (loamy, kaolinitic, thermic Typic Kandiudult. Nine 0.2 ha sweetgum plots were established in 1996. The sites had been regularly managed for dryland crops (corn, soybeans, etc.) for more than 20 years, and soybeans (*Glycine max.* (L.) Merr) were the primary crop for the 5 years previous to woody crop plantation conversion. All plots were treated with an initial fertilizer program of 280 kg/ha diammonium phosphate (DAP) in November 1995 and 101 kg/ha urea in August 1996.

Experimental Design

At each site, three biannual N fertilizer treatments were initiated at age 1 and replicated three times. Every two years, ammonium nitrate (NH^4NO^3) was applied at the following rates: 0 kg/ha, 168 kg/ha, and 336 kg/ha, which provide 0, 56, and 112 kg/ha N, respectively. The error control design at the cutover site was a Completely Randomized Design, while the design at the agricultural site was a Randomized Complete Block Design. The blocking factor was depth to mottling.

Table 1—Proportion of total foliage dry mass in each of three crown positions by fertilizer treatment, after Kuers and Steinbeck, 1998b

Crown	Control	Low N	High N
Upper	0.35	0.35	0.35
Middle	0.38	0.41	0.44
Crown	0.27	0.24	0.21

Foliage Measurements

In September 1998 (pine cutover site) and 1999 (ag field), which corresponded to age 4 in both plantations, 3 foliage samples were taken from the southern portion of the canopy from five trees in each plot. Upper, middle, and lower crown samples comprised of leaves of all stages of development were collected from single branches within the respective crown position (Kuers and Steinbeck, 1998b). The leaves were refrigerated until leaf area determinations were made with a Li-Cor Leaf Area Meter (Li-Cor, Lincoln, NE). The leaves were then oven dried at 65 °C for at least 72 hours and weighed to determine specific leaf area (cm^2/g). Foliar N concentration was determined on each sample with a N analyzer (LECO FP-528, St. Joseph, MI) and converted to total nutrient content with estimates of foliage mass obtained from litterfall measurements. Litterfall was collected from 5 randomly located litter traps (approximately 1 m^2 per trap) per plot.

Kuers and Steinbeck (1998b) showed that fertilization increases sweetgum leaf area disproportionately between the leader, upper, middle, and lower crown positions. If the leader is included with the upper crown, they found 35, 37, and 27 percent of the total dry mass in the upper, middle, and lower crowns positions, respectively. However, in plots fertilized at a higher rate of N than the highest rate in this proposed study, they found 36, 44, and 21 percent of total dry mass in the upper, middle, and lower crown positions, respectively. We calculated total foliar nutrient demand as the summation of the products of foliar nutrient concentration and estimated foliage mass for each crown position (table 1). Foliar N resorption was calculated as the difference between foliar N content at midseason and in the litterfall (Nelson and others, 1995).

Soil Nitrogen Supply

Total nitrogen—Total N was determined on a 5 g soil sample using the macro-Kjeldahl digestion method (Bremner and Mulvaney, 1982) followed by colorimetric analysis (Bran+Luebbe TRAACS 2000, Oak Park, IL).

Potentially mineralizable nitrogen—Nitrogen mineralization potential was determined by measuring NH^{4+} and NO^{3-} produced in biweekly extractions of aerobically incubated soil samples for 24 weeks (Stanford and Smith, 1972; Burger and Pritchett, 1984). Briefly, approximately 70 g field-moist soil from each site was mixed with approximately 150 g washed silica sand and lightly packed into a 5 cm i.d. and 15 cm long PVC tube. The samples were incubated at 35 °C. Every two weeks, the samples were leached with 250 mL of 0.01 M CaCl2, which was analyzed for NH^{4+} and NO^{3-} concentration via automatic colorimetric spectrophotometry on a TRAACS 2000 (Bran & Luebbe Corporation, Oak Park, IL). The samples were then leached with 100 mL of a minus-N Hoagland solution and vacuum extracted to approximately -0.03 MPa (field capacity). N mineralization potential was calculated by fitting a first-order curve to the sequential N produced using PROC NLIN in SAS (SAS, 1990).

Table 2— Foliar biomass, weighted foliar N concentration and litter N concentration for two 4-year-old sweetgum plantations of different landuse history and soil type. Means within a site followed by the same letter are not significantly different at alpha=0.10

Treatment	Foliar Biomass kg/ha	Foliar N Concentration pct	Litter N Concentration pct
Ag field			
Control	2263a	1.37a	0.97a
56 kg/ha N	2475a	1.71a	0.97a
112 kg/ha N	3100a	1.69a	1.00a
Pine cutover			
Control	1337b	1.14c	0.63b
56 kg/ha N	1945ab	1.39b	0.73ab
112 kg/ha N	2825a	1.54a	0.76a

***In situ* nitrogen production—**Native soil N supply was measured from April 1999 to April 2000 with the buried bag method (Eno, 1960). For this procedure, two soil samples were collected for each sampling date. One was incubated in situ and the other returned to the laboratory for analysis. N supply was calculated as the difference between the N intensity in the soils incubated for approximately 1 month and the samples taken at the time of incubation, with negative values, representing net immobilization or denitrification, set to 0. At each of three subplots within each experimental plot, three subsamples were taken of the top 15 cm and composited for each of the two samples (bags). Each sample was air-dried, sieved to pass a 2 mm sieve, and the N extracted with 2 N KCl in a 10:1 solution:soil ratio. The NH4+ and NO3- concentration in each extract was determined via automatic colorimetric spectrophotometry on a TRAACS 2000 (Bran & Luebbe Corporation, Oak Park, IL).

Soil moisture—Volumetric soil moisture in the top 15 cm was measured monthly from April 1999 to September 2000 with Time Domain Reflectometry.

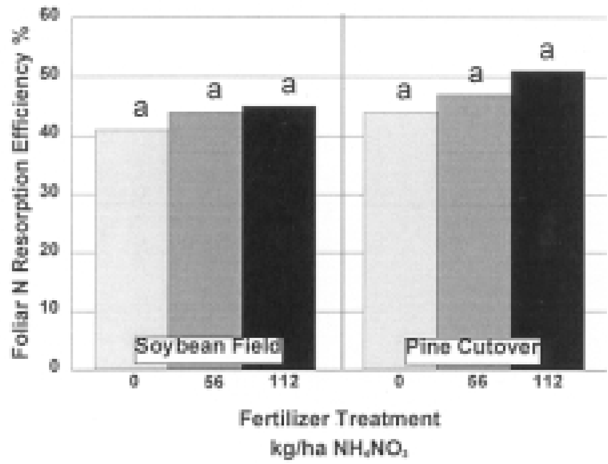

Figure 2—Foliar nitrogen resorption efficiency across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

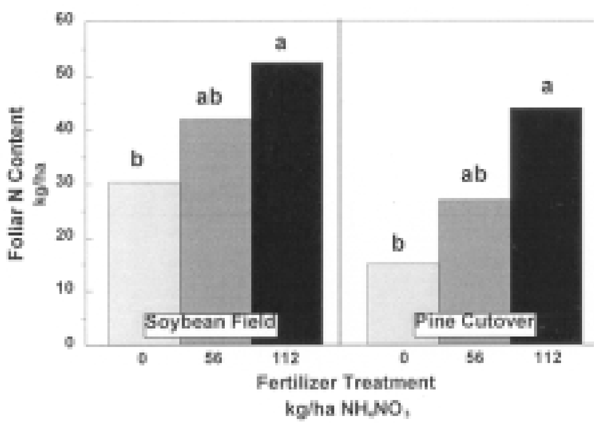

Figure 1—Foliar nitrogen content across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

RESULTS

Fertilization increased foliar biomass, N concentration, and N content at both sites, but the relative responses were greater on the pine cutover site. Foliar N content increased at both sites on fertilized plots (figure 1) due to increases in total foliage biomass and N concentrations (table 2). On the ag field, foliar N content of the 56 kg/ha N treatment was 40 percent higher than the control, while it was 73 percent higher than the control in the 112 kg/ha N treatment. In the cutover pine site, foliar N content increased 80 percent and 193 percent over the control in the medium and high treatments, respectively. Weighted foliar N concentrations ranged from 1.14 percent to 1.71 percent, and increased at both sites with fertilization.

Foliar resorption efficiency, which is calculated as the proportion of total foliar N resorbed, was not different among fertilization treatments, and the pine cutover site had greater resorption efficiency compared to the ag field site (figure 2). Foliar resorption proficiency, which is measured as the N concentration in the litterfall, was not

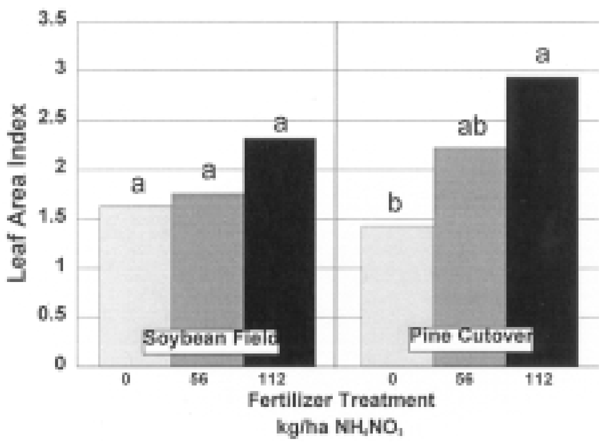

Figure 3—Leaf area index across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

affected by fertilization treatment at the ag field site. In the pine cutover site, resorption proficiency was greater than in the ag field site (litter N concentrations lower), and was significantly reduced (litter N concentrations higher) by the highest fertilization rate (table 2).

Leaf area index of trees on the ag field ranged from 1.6 to 2.3, but was not significantly affected by fertilization. LAI of the 112 kg/ha N treatment (3.0) was twice that of the control (1.5) in at the pine cutover site (figure 3). Plot volume index (PVI) did not differ among treatments on the ag field site (figure 4), and although not significantly different, PVI was 47 and 63 percent higher than the control in the 56 kg/ha and 112 kg/ha N treatments, respectively on the pine cutover site.

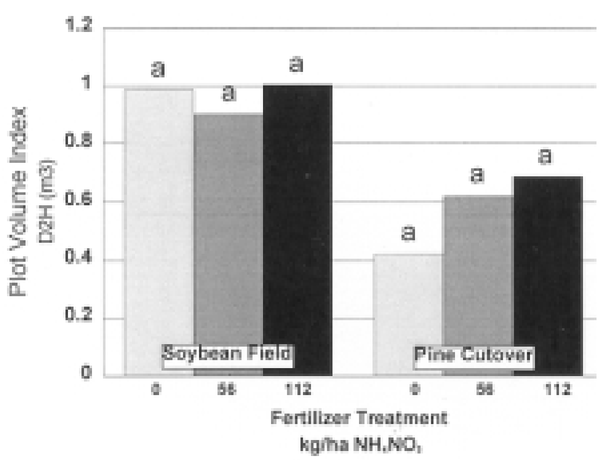

Figure 4—Plot volume index across three levels of N fertilization in two 4-year-old sweetgum stands of varying land use history and soil type. Means within a site type followed by the same letter are not significantly different at alpha=0.10.

Soil nitrogen differed widely between the sites and among indices (figure 5). Total soil N in the top 15 cm of the cutover pine site was 2.6 times higher than that of the ag field site, but the aerobic index of potentially mineralizable N was only 18 percent higher. Measured in situ N production was much less in the cutover pine site, averaging 72 percent less than in the ag field site.

Soil moisture varied seasonally and across both sites, but was consistently greater on the poorly-drained cutover site compared to the well-drained ag site (figure 6). Soil moisture averaged 9.7 percent on the ag site and was never greater than 20 percent, while soil moisture averaged 19.9 percent on the cutover site and was as high as 32 percent.

DISCUSSION

Foliar biomass production, N demand, and N resorption were each associated with site type and fertilizer treatments. Foliage production ranged from 1337 kg/ha to 3100 kg/ha, and foliar N content ranged from 15 to 53 kg/ha. Higher foliage biomass production, however, did not directly result in higher leaf areas (figure 3) nor tree growth (figure 4) in these young stands, but may in the future. Foliage production and foliar N content was greater overall at the ag field site compared to the pine cutover site, but fertilization responses were more dramatic on the cutover site. A host of factors may have contributed to these site differences, such as water availability and competition. The ag field site, although generally much drier than the pine cutover site, has virtually no competing woody vegetation, while the cutover site has substantially more woody competition.

Foliar N resorption efficiency was not significantly affected by fertilization, but tended to increase on the fertilized plots in both sites. These findings are in general agreement with Nelson and others (1995), who found no influence of fertilization on resorption efficiencies and Kuers and Steinbeck (1998), who observed an increase in resorption efficiency from 52.8 percent to 61.7 percent. The range of

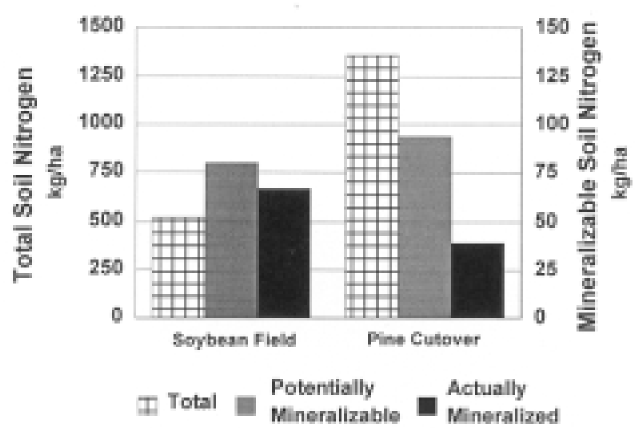

Figure 5—Total, potentially mineralizable, and actual soil N mineralized in two 4-year-old sweetgum stands of different land use history and soil type.

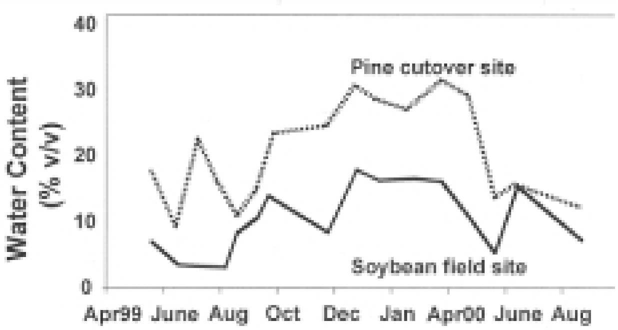

Figure 6—Volumetric soil water contents from April 1999 to September 2000 at two 4-year-old sweetgum stands of different land use history and soil type.

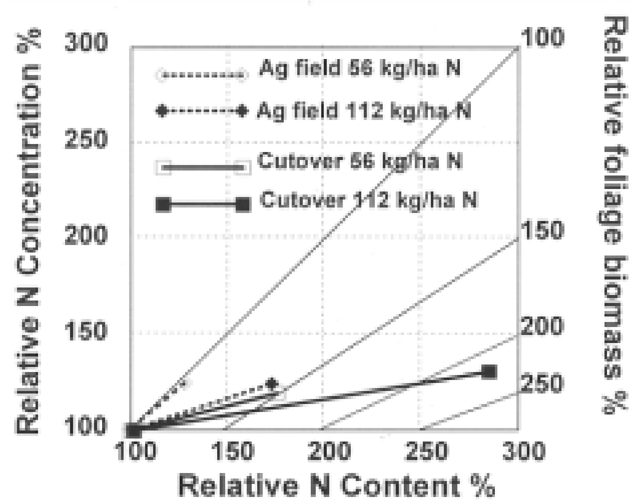

Figure 7—Vector analysis of relative responses in foliage biomass, N concentration, and N content in two 4-year-old sweetgum stands of varying land use history and soil type.

resorption efficiencies observed (41 percent to 52 percent) is low for sweetgum plantations. Resorption efficiency was higher on the cutover site than on the ag field site, indicating that factors other than nutrition, such as moisture availability, combined to control N resorption efficiency. del Arco and others (1991) found that resorption efficiency was lower on more xeric sites, suggesting that the drier soil of the ag field site may have reduced resorption efficiency.

Increases in foliar N content or concentration due to fertilization do not necessarily signify a foliar biomass response. Vector analysis (Krauss, 1965; Haase and Rose, 1995) was performed in this study using relative foliar N content, concentration, and foliage biomass for both sites (figure 7). In all cases except the 56 kg/ha N treatment on the ag field site, vector analysis indicated that the control plots were indeed deficient, and fertilization resulted in increases in foliar N content, concentration, and biomass. The length of the vectors gives an indication of the relative magnitude of the response to various treatments, and it is apparent from figure 6 that the response was much greater on the pine cutover site compared to the ag field site. The lower rate of fertilization on the ag cutover site was only enough to increase the foliar N content and concentration, but not cause an increase in foliar or tree biomass production relative to the control treatment.

Increasing foliar N concentrations can increase photosynthetic efficiency, but fertilizer applications in young stands are more useful as a means of increasing the total photosynthetic capacity through increased leaf area. In this study, the high rate of fertilization almost doubled the leaf area of the pine cutover stand, but fertilization had no significant effect on the ag field site. This indicates, like the vector analysis, that fertilization was much more effective on the pine cutover site compared to the ag field site.

Actual soil N supply, which would be predicted to be much higher at the pine cutover site due to its 6-fold greater soil organic matter (6 percent vs 1 percent), was almost half that of the ag field. Much more of the total organic N was in a recalcitrant form on the pine cutover site. Only 7 percent of the total soil N was potentially mineralizable on the cutover site, while 15 percent was potentially mineralizable on the ag field site. Furthermore, microbial immobilization and denitrification were likely much greater on the cutover site than at the ag site. The C:N ratio of the soil organic matter on the pine cutover site was 53, while only 28 at the ag site. Net immobilization is known to be greater as C:N ratios increase, and net N mineralization does not generally occur until the ratio is near 30. Preliminary findings from a related study indicate that fertilization may increase N mineralization on the pine cutover site. Denitrification may have been important on the cutover site due to wet but fluctuating moisture conditions (figure 6) and a high C energy source (Davidson and Swank 1987).

CONCLUSIONS

Developing efficient N management strategies for young sweetgum plantations and understanding plant responses to N fertilization requires an accurate estimate of actual soil N supply. This study showed that fertilizing young sweetgum plantations can result in large increases in foliar biomass, N content, and leaf area on some sites, but it may not be necessary on others. Simple estimates of soil N availability, such as organic matter content, total soil N, or even indices of potentially mineralizable N may not indicate the extent of plant response to N fertilizer; more accurate estimates of soil N availability that take environmental conditions into account as well are needed for developing N fertilizer recommendations for young hardwood plantations.

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