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Effects of Fertilizer Nitrogen on Tree Growth, Foliar Nitrogen, and Herbage in Eastern Cottonwood Plantations[1]

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ABSTRACT

When five rates of nitrogen fertilizer (0 to 672 kg/ha) were tested in two eastern cottonwood (*Populus deltoides* Bartr.) plantations 7 and 10 years old in the Mississippi River floodplain, first season volume growth was more than doubled by fertilization. By the end of the third season, the direct effect of fertilization had apparently disappeared although a volume advantage caused by the large initial response was still evident. In one plantation, volume growth for the 3 years after fertilization was greatest at 336 kg N/ha, and in the other volume growth was greatest at 672 kg N/ha. However, lower rates gave more volume growth per unit of applied N. Fertilizer also increased the N content of herbaceous plants.

***Additional Index Words: Populus deltoides* Bartr., fertilization, volume growth, ammonium nitrate, herbaceous N, herbaceous biomass.**

NITROGEN DEFICIENCY is an important problem on many old-field soils in the Mississippi River floodplain (Blackmon and Broadfoot, 1969; Blackmon and White, 1972). Studies have demonstrated that eastern cottonwood (*Populus deltodies* Bartr.) growth can be stimulated by fertilization with 168 kg of nitrogen/ha from ammonium nitrate (Blackmon and White, 1972). Less is known, however, about the reaction of cottonwood plantations to various levels of applied nitrogen. This paper describes tree and herbage response to several rates of N applied to two established cottonwood plantations in the Mississippi River floodplain.

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METHODS

The two study plantations are on Crown Zellerbach's Fitler Managed Forest in western Mississippi. The area was in agriculture before fertilizers were commonly used, and its soils were depleted of much of their nitrogen.

Both plantations were established at about 2.7- by 2.7-m spacing. Site A was in a 7-year-old plantation on Commerce silt loam. Site B was in a 10-year-old plantation on Convent silt loam. Both soils, members of the mixed, thermic family of Aeric Fluvaquents, developed in alluvial deposits from the Mississippi River. The Commerce soils have 18-35% clay in the 25-100 cm control section, and the Convent soils have 10-15% clay. Before treatment, total Kjeldahl N levels in the surface 30 cm were 0.054% for the Commerce and 0.058% for the Convent. Similar soils in their virgin state contain up to twice these N concentrations.

Annual rainfall in the area averages 125 to 140 cm with approximately 60 cm between May and September. Summer rainfall for 1972 was about 25 cm below normal.

Prior to treatment, trees on site A were 7- to 13-cm DBH ($\bar{x}$ = 11.7), 10 to 13 m in height ($\bar{x}$ = 12.2), and the stand contained 34.6 m^3/ha total stem volume. On site B trees were 8- to 12-cm DBH ($\bar{x}$ = 10.2), 8 to 11 m in height ($\bar{x}$ = 9.1), and stand volume was 33.7 m^3/ha. Analysis of variance indicated no initial differences among plots.

Treatments (kg N/ha) were: (i) control (no fertilizer), (ii) 84 N, (iii) 168 N, (iv) 336 N, and (v) 672 N. Nitrogen was applied as ammonium nitrate (33% N) to the soil surface in April 1971 with a tractor-drawn spreader. Immediately after application all plots, including controls, were disked lightly.

Treatments were replicated three times in a randomized complete block design on each site. Each plot area was 0.08 ha and contained about 100 trees. Measurements were taken on the center 24 trees. Tree heights and diameters were measured in 1971, 1972, and 1973. Diameter measurements were taken also in 1974 and 1975. Volumes (outside bark) were computed with the equations of Mohn and Krinard (1971).

Composited samples (20 leaves with petioles from each of three trees) of mid-crown sunlit foliage were collected in mid-August 1971, 1972, and 1973. Samples were dried at 70°C, ground, and analyzed for N using the macro-Kjeldahl method. Foliar N contents (kg/ha) were determined by multiplying foliage biomass,

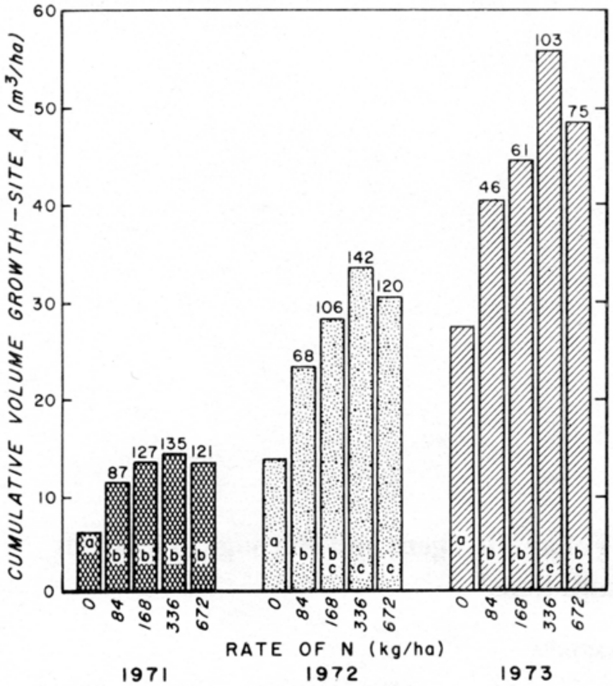

Fig. 1a—Nitrogen effect on site A cumulative volume growth, 1, 2, and 3 seasons after fertilization. Numbers above bars represent percent increase over controls. Bars containing the same letter are not significantly different.

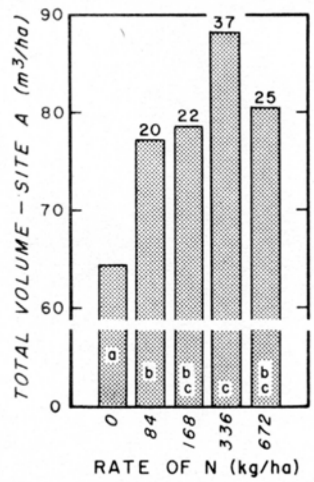

Fig. 1b—Nitrogen effect on site A total volume, 3 years after fertilization. Numbers above bars represent percent increase over controls. Bars containing the same letter are not significantly different.

calculated using the equations of C. W. Mueller (1976),[3] by percent N in the foliage.

In early September 1971 and 1972, during peak herbaceous biomass accumulation, herbaceous vegetation was sampled by clipping two randomly assigned 0.4-m^2 plots within each 0.8-ha plot. No effort was made to separate and identify species; however, herbaceous material on both sites was primarily Johnson grass (*Sorghum halepense* L. Pers.). The material was dried at 70°C, weighed, ground, and analyzed for N by the macro-Kjeldahl method.

Differences in tree growth, foliar N, herbaceous biomass, and herbaceous N were tested at the 0.05 level by analyses of variance. All means were compared by Duncan's new multiple range test. Regression analysis was used to relate tree growth to foliar N.

RESULTS AND DISCUSSION

Fertilizing with nitrogen caused marked increases in height, diameter, and volume growth, and temporarily increased foliar nitrogen levels. Maximum response occurred at the two higher rates (336 N and 672 N), but the two lower rates produced more tree growth per unit of applied N.

Growth

Site A—Stem volume growth during the first season indicated a significant response to fertilization. All N treatments produced about twice the volume as the control, but volume growth did not differ significantly among fertilized treatments (Fig. 1a). During the second season, cumulative volume growth on plots fertilized with 336 N and 672 N had about the same advantage over controls as during the first season. However, the growth advantage for 84 N and 168 N diminished slightly. Peak growth occurred with 336 N, but was not statistically different from 168 N or 672 N. Greatest volume growth for the 3-year period was produced by 336 N which had 103% more growth than plots receiving no nitrogen. Total stem volume on fertilized plots was 20-37% greater than controls at the end of the 3-year period (Fig. 1b).

During the first season, diameters on control plots increased an average of 7 mm, and diameters of trees treated with 336 N increased 18 mm. Diameter increases by the end of the third season were 26 mm for controls and 51 mm for 336 N. In 1971, height growth was 0.7 m for controls and 1.6 m for those receiving 336 N and 672 N. By 1973, control trees had grown 2.7 m and trees given 336 N had grown 4.8 m.

Site B—During 1971, stem volume growth among the 84 N, 168 N, and 336 N plots was not statistically different, but was 96-159% greater than the controls (Fig. 2a). The use of 672 N increased volume growth by 224% over controls but was not statistically better than 336 N. Growth response to fertilizer declined sharply during the second season on the 84 N and 168 N plots, but not on plots fertilized with the two higher rates. The 672 N was more productive than all other treatments. Treatment effects had decreased further by the end of the third year. Trends in height and diameter growth were similar to those for volume growth.

Plots treated with 672 N had 91% more total stem volume than the control plots (Fig. 2b). The three lower rates produced from 31-61% more stem volume than the control, but no statistical differences occurred among these fertilizer treatments.

Diameter increments for 1973, 1974, and 1975 showed no significant fertilizer response beyond the second season after fertilization for site A and beyond the third season for site B.

Nitrogen Efficiency

The volume of wood produced per kilogram of applied N calculated as

$$\frac{\text{Cumulative volume, treated - Cumulative volume, control}}{\text{N rate}}$$

[3]C. W. Mueller, 1976. The accumulation of dry matter in plantations of eastern cottonwood on alluvial sites of the Mississippi River valley. M.S. Thesis (Unpublished). Mississippi State Univ.

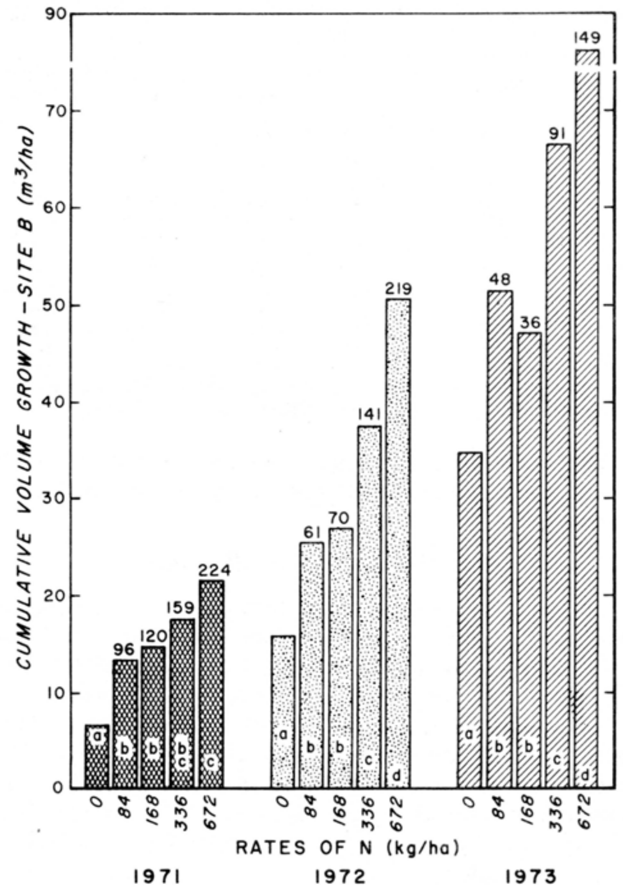

Fig. 2a—Nitrogen effect on site B cumulative volume growth, 1, 2, and 3 seasons after fertilization. Numbers above bars represent percent increase over controls. Bars containing the same letter are not significantly different.

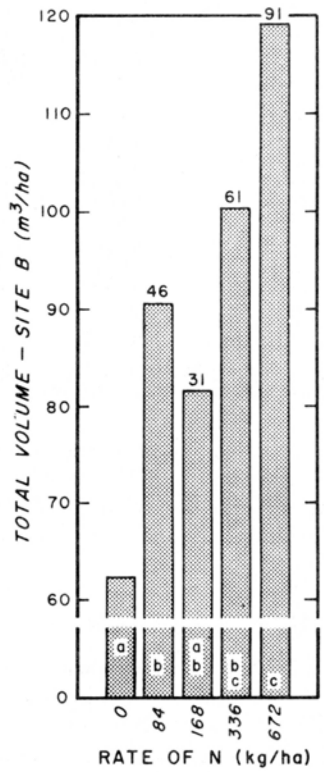

Fig. 2b—Nitrogen effect on site B total volume, 3 years after fertilization. Numbers above bars represent percent increase over controls. Bars containing the same letter are not significantly different.

indicates the efficiency of the fertilizer treatments. On both sites, greatest volume per kilogram of applied N was produced by 84 N, although actual volume growth response for 84 N was generally poorer than for the higher rates. On site A over the 3-year period, actual volume growth was 12.7 m^3 for 84 N and 28.4 m^3 for 336 N. However, 0.15 m^3 of wood was produced per kilogram of applied N at the 84 N rate, and only 0.08 m^3 was produced per kilogram of applied N at the 336 N rate (Table 1). On site B, 84 N produced more than twice as much wood per kilogram of applied N as the other treatments, although actual volume growth increased with increasing rates of N.

Foliar N

On site A during 1971, 336 N increased foliar nitrogen to 2.45%, compared with 1.41% for the control; the foliar N level for the control was significantly lower and the foliar N level for 336 N was significantly higher than those for the other rates (Table 2). At the end of the second season, foliar N levels were somewhat lower than in the first season except for the control and 672 N. Only with 672 N did the foliar N level remain above 2%, a level previously reported critical for eastern cottonwood (White and Carter, 1970; Blackmon and White, 1972). Volume growth for 1971 was well correlated with foliar N ($r^2 = 0.68$). By the end of the 1972 growing season, the relationship had weakened ($r^2 = 0.45$) but remained significant.

Initial foliar N levels on site B control plots were somewhat lower than those on site A. In 1971 foliar N was least (1.26%) for controls and greatest (2.28%) for 672 N (Table 2). As on site A, foliar N decreased slightly during 1972; only the 2.06% foliar N level for 672 N was significantly greater than the controls. For both seasons, volume growth and foliar N were strongly related, having r^2 values of 0.78 for 1971 and 0.73 for 1972.

By August 1973, foliar N was about 1.80% on both sites and for all treatments, including controls. Apparently, the added N was no longer in the tree foliage since there were no differences in foliar N content (kg/ha) between treatments. And since controls averaged only 1.26 and 1.41% N in 1971, both stands apparently increased in vigor, even in plots receiving no fertilization. The increase in controls for 1972 and 1973 may be due to the disking operation in 1971. Cottonwood plantations, particularly those growing on Johnson grass infested old fields, respond markedly to cul-

Table 1—Volume of fiber produced per kg of applied N (3 seasons after treatment).

Rate of nitrogen	Site A	Site B
kg/ha	m³/ha	
0	--	--
84	0.15 a†	0.20 a
168	0.10 ab	0.07 b
336	0.08 bc	0.09 b
672	0.03 c	0.08 b

† Means followed by the same letter (vertically) are not significantly different by Duncan's new multiple range test (0.05 level).

Table 2—Effect of N rates on foliar N levels.

Site	Rate of nitrogen	Nitrogen concentration		
		1971	1972	1973
	kg/ha	%		
A	0	1.41 a†	1.49 a	1.82 a
	84	1.82 b	1.55 a	1.79 a
	168	2.07 bc	1.62 a	1.78 a
	336	2.45 d	1.80 a	1.73 a
	672	2.11 c	2.12 b	1.81 a
B	0	1.26 a	1.52 a	1.80 a
	84	1.63 b	1.42 a	1.71 a
	168	1.73 b	1.51 a	1.68 a
	336	2.04 c	1.59 a	1.51 a
	672	2.28 d	2.06 b	1.86 a

† Within each site, means followed by the same letter (vertically) are not significantly different by Duncan's new multiple range test (0.05 level).

tivation.[4] Also, in 1973 both sites were flooded by backwater from the Mississippi and Yazoo Rivers. Additional nutrients resulting from the floodwater could be another factor contributing to increases in foliar N concentrations of control trees.

Herbaceous Vegetation

Except for 336 N and 672 N on site B in 1972, fertilization did not significantly increase the herbaceous vegetation biomass (Table 3). The two highest levels of fertilizer significantly increased N concentration of herbaceous vegetation in 1971 on site A, and 672 N increased the concentration in 1972 on site B. The trends in herbaceous biomass and N concentration were probably caused by competition for N immediately after fertilizer application. All plots were disk-harrowed within a few hours after treatment, leaving them nearly free of herbaceous vegetation. Apparently, at rates of 84 N and 168 N, and in some cases at 336 N, nitrogen was either taken up by the trees or leached before the site was repopulated with understory vegetation. Although regrowth of grassses and weeds occurred within 4 weeks, it is possible that only with the highest rate was there sufficient residual N to be taken up by herbaceous vegetation. Within 4 weeks of application, the cottonwood trees showed a marked response in foliage color, indicating that they were indeed taking up fertilizer nitrogen.

These results suggest that if medium to low rates of N are incorporated by disking, there is little, if any, loss of N to herbaceous vegetation. At the 672 N rate, as much as 30 kg

[4]Second-year intensive cultivation of eastern cottonwood plantations. Crown Zellerbach Corp., South. Timber Div. Res. Note 71-3, 2 p., 1971.

Table 3—Effect of N rates on herbaceous biomass and nitrogen levels.

Site	Rate of nitrogen	Biomass		Nitrogen concentration	
		1971	1972	1971	1972
	kg/ha	metric tons/ha		%	
A	0	2.9 a†	4.7 a	0.81 a	0.70 a
	84	3.1 a	4.9 a	0.80 a	0.76 a
	168	2.7 a	3.6 a	0.84 a	0.62 a
	336	4.7 a	3.8 a	0.99 b	0.78 a
	672	4.7 a	5.4 a	1.25 c	1.09 a
B	0	4.0 a	2.0 a	0.77 a	0.76 a
	84	4.9 a	2.0 a	0.74 a	0.67 a
	168	4.3 a	2.0 a	0.82 a	0.66 a
	336	5.8 a	4.0 b	0.98 a	0.62 a
	672	6.3 a	3.6 b	1.07 a	1.28 b

† Within each site, means followed by the same letter (vertically) are not significantly different by Duncan's new multiple range test (0.05 level).

N/ha was in the herbaceous understory. Much of this N should be released with decomposition of the herbaceous material.

Duration of Nitrogen Response

This experiment helps to confirm earlier results (Blackmon and Broadfoot, 1969; Blackmon and White, 1972) that N deficiency limits cottonwood growth on medium-textured old fields. The direct effect of N fertilization was short-lived; 3 years after treatment the growth advantage of fertilized plots was declining even at the highest application rates. Foliar N concentrations, foliar N content, and annual diameter increments were no higher than in controls. But the large initial responses created a greater base on which to add future growth.

In view of the short-term direct effect of fertilizer and the relative inefficiency of high rates of N, moderate rates such as 168 kg N/ha applied at 3-year intervals should be more effective than the single application of a higher rate.

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