NITROGEN SOURCES AND FERTILIZER RATES AFFECT GROWTH OF HYBRID POPLAR[1]

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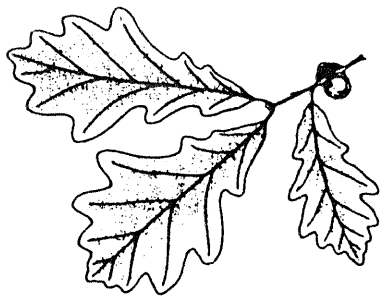

ABSTRACT.--In this study, we investigated the effect of an herbaceous legume cover crop, complete and incomplete weed control, and various rates of commercial fertilizer on Populus height growth and biomass. A randomized block design with three replications and nine treatments was established on both a sand and a silt loam soil. Trees were planted at a 1 x 1 m spacing. All study plots were irrigated whenever soil moisture tension reached -0.05 MPa. Ammonium nitrate was applied in mid-June and mid-July each year at rates of 0, 56, 112, and 168 kg/ha/yr of nitrogen. At the end of 5 years, survival was 98 percent on the sand site but only 80 percent on the silt loam site. Almost all of the mortality on the silt loam site occurred on fertilized plots. Fifth-year measurements showed a maximum 400-percent increase in biomass in response to nitrogen fertilizer on the sand site; the higher fertilization rates resulted in the greatest biomass. There was a maximum 50-percent increase in biomass on the silt loam site. With higher rates of fertilization and irrigation, biomass yields from both sites were similar. A legume cover crop showed little effect on tree growth. Tree height on the silt loam site was generally increased by weeding but not by fertilization. On the sand site, tree height was increased by fertilization but not by weeding. Maximum biomass was associated with mid-summer leaf tissue N concentration of 3 percent or greater.

INTRODUCTION

Poplars are prodigious accumulators of nitrogen. Accumulation rates of up to 86 kg/ha/yr have been reported in young plantations (Hansen and Baker 1979). In fertilizer tests, nitrogen has typically produced the greatest tree growth response; increases in tree height of 100 percent or more have been reported for eastern cottonwood (P. deltoides Bartr.) (Blackmon and Broadfoot 1970, Broadfoot and Ike 1968, Blackmon and White 1972). However, it is not clear how much growth response may result from fertilizing young hybrid poplar plantations nor what fertilization rates may be optimum for fast growth. In this study, we investigated the effect of various N fertilization rates on growth of hybrid poplar during the first 5 years. We also examined the effect that a N-fixing legume cover crop or complete weed control had on N fertilization requirements. In limited trials, we also examined the effects of P and K fertilization in the young plantation.

METHODS

The study area is located at the North Central Forest Experiment Station's Harshaw Forestry Research Farm west of Rhinelander, Wisconsin. Before becoming a forestry research area, Harshaw

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Farm was a potato farm for 50 years. Soils range from well-drained sands to silt loams; the plow pan is at 25 cm underlain by sand and gravelly sand. The predominant sand is a Pence (mixed, frigid, sandy, Entic Haplorthod) and the silt loam is a Padus (mixed, frigid, coarse loamy Alfic Haplorthod). Quackgrass (Agropyron repens (L.) Beauv.) is the main weed competitor.

The experimental design was a randomized block with nine treatments and three replications. The design was placed on two soil types; a sand and a silt loam. Each treatment plot was 15 x 15 m and contained 225 trees spaced at 1 x 1 m. Only the central 5 x 5 m core (25 trees) was used for data collection. The remaining 5-m-wide border zone around each core received the same treatment as the core.

The plots were planted in 1980 with 20-cm-long unrooted hardwood cuttings of Populus clone NC-9922 (the parentage of this clone is unknown but it appears morphologically identical to NE-252 P. deltoides var. angulata x P. trichocarpa). The border areas were machine planted, but the plot cores were hand planted to maintain exact spacing between trees. The mean cutting diameter for the plot cores was restricted to the narrow range of 8.8 to 10.6 mm to minimize the effect of diameter variability on first-year shoot growth.

The plots were irrigated overhead with a cart-mounted traveling irrigation gun whenever soil moisture tension reached -0.05 MPa at a 15-cm depth. Tensiometers were installed in each soil type to monitor soil moisture tension. The nine treatment combinations reported on in this study are shown in table 1. The two trefoil plots were treated with Treflan (1.1 kg active ingredient (a.i.)/ha) and then seeded to birdsfoot trefoil (Lotus corniculatus L.) at 6.6 kg/ha just before planting the cuttings. One trefoil plot was not fertilized and the other was fertilized with NH_4NO_3 at a rate of 112 kg N/ha/year. The remaining seven plots received a preplant application of linuron at 2.2 kg a.i./ha on the silt loam and 1.7 kg a.i./ha on the sand. Two of these seven plots were weeded to keep them bare, and weeds were allowed to re-invade the remaining five plots. One of the bare plots was not fertilized and the other was fertilized with NH_4NO_3 at a rate of 112 kg N/ha/year. The five weedy plots received NH_4NO_3 at the rates of 0, 56, 112, or 168 kg N/ha/year, which included the apparent optimum fertilizer rates of 112-168 kg N/ha/yr for the silt loam soil as determined by an earlier fertilizer gradient study. Granular NH_4NO_3 was applied manually to all fertilized plots in a split application in mid-June and mid-July each year. Before planting, 112 kg/ha of P and K was incorporated into the soil on Plot 9. The third year, 55 kg/ha of K was spread on the undisturbed litter layer in a 25-tree subplot located in the border area of Plot 9.

Weeds were controlled the first year on the bare plots by applying glyphosate herbicide with a ropewick applicator. However, this resulted in serious damage and occasional mortality to the hybrid poplars. Consequently, the bare plots were reestablished the second year and weeded by hand for 2 years. Thereafter, vegetation was controlled by spraying weeds with glyphosate before budbreak of Populus in the spring.

TABLE 1.--Plot treatments.

plot	Treatment: ground-cover	Treatment: nitrogen fertilizer kg/ha/yr
1	trefoil	0
2	"	112
3	bare	0
4	"	112
5 (control)	weeds	0
6	"	56
7	"	112
8	"	168
9	"	112[a]

[a]112 kg/ha P and K added the first year.

Leaf samples were collected from each plot on July 15 each year except for the fourth year. Samples were also collected on June 15 and August 15 during the second and third years. Samples were always collected just before scheduled fertilization. The first three-five fully expanded leaves on the terminal shoot were collected from three randomly selected trees in the plot core. These leaves were composited for a single sample, then oven-dried at 70° C to equilibrium, and ground in a Wiley Mill to pass a 40-mesh screen. Soil samples were collected in the spring before planting and in the fall each year (no samples in the fourth year). A composite sample of five cores from the upper 8 inches of soil was collected from each plot core. Soil was oven-dried at 40° C to equilibrium and sieved through a 2 mm sieve. All leaf and soil samples were analyzed for total N. In addition, samples from the two weedy plots fertilized with 112 kg N (one of which was also fertilized with P and K) were analyzed for P and K. Nitrogen was determined by total Kjeldahl, total soil P by HNO_3 and $HClO_4$ digestion, and extractable soil P by Bray's #1. Soil K was extracted by NH_4OAc. Soil K and plant tissue samples were analyzed by ICP atomic emission spectroscopy at the University of Minnesota Research Analytical Laboratory.

Height and dbh of the 25 trees in the plot cores were measured each fall from 1980-1984 (except for the fourth year) and were also measured periodically throughout the second year. Mortality within the same sets of trees was also recorded. Budset was defined as the date when seasonal height growth stopped. In the fall of the third and fifth years, trees were harvested, oven-dried, and weighed. Regressions developed from the harvested trees were used to calculate biomass production for each plot core. Significant differences in biomass production between fertilizer treatments were determined by ANOVA with $p = 0.05$ unless otherwise indicated.

RESULTS

Mortality

Survival was essentially 100 percent the first 2 years and still averaged 98 percent on the sand site at the end of the fifth year. However, substantial mortality began in the third year on the silt loam site and increased to 24 percent by the fifth year. Almost all the mortality on the silt loam site occurred on fertilized plots (table 2). However, within the group of fertilized plots, there was no evidence that mortality increased with higher fertilization rates.

Growth

Five years of N fertilization increased biomass production up to a maximum of 50 percent on the silt loam site and 400 percent on the sand site, as compared to the unfertilized plots (table 3). Biomass generally increased with increasing N, particularly on the less fertile sand site. Of plots fertilized with 112 kg N/ha, the trefoil plots consistently had the greatest biomass yields (table 3) and tree heights (table 4) and had about the same values as plots fertilized with 168 kg N/ha. Although this relation was not significant, it suggests additional N input from the legumes.

Biomass yields at the higher fertilization rates were similar on the silt loam site and the sand site. This suggests that high rates of irrigation and fertilization can compensate for poor site quality in producing high biomass yields. Without fertilization, yields on the silt loam site were more than 2½ times greater than those of the sand site.

On the sand soil, N affected the rate of tree height growth, the length of the seasonal growth period, and consequently total seasonal height growth (fig. 1). Early in the season height growth rate differed little between different fertilizer treatments. In July, height growth rates diverged, which produced some of the seasonal height growth differences. However, the major factor affecting tree height growth was that fertilization delayed terminal budset. Unfertilized trees set bud on July 23 and stopped height growth 2 weeks earlier than trees fertilized at 56 kg/ha and four weeks earlier than trees fertilized at either 112 or 168 kg/ha.

The large tree height growth differences shown in figure 1 are a result of fertilizing weedy plots on a sandy soil that has little available N. In contrast, unpublished data from a nearby study showed that fertilizing bare plots on a silt loam soil with 168 kg N/ha did not increase tree growth (fig. 2). The data in these figures suggest an interesting interaction between fertilization, weed control, and soil type. Two-year-old tree height data summarized in table 5 show this interaction more clearly. Tree height on the silt loam soil is increased by weeding but not by fertilization. In contrast, tre height on the sand soil is increased by fertilization but not by weeding. Although

TABLE 2.--Relation of mortality to nitrogen fertilization in 5-year-old hybrid poplar plantations on a silt loam and a sand site.

treatment		mortality	
ground cover	fertilizer	silt loam	sand
	kg/ha/yr	- - - percent - - -	
trefoil	0	4	1
bare[a]	0	0	3
weedy	0	17	0
weedy	56N	32	8
trefoil	112N	16	1
bare[a]	112N	24	1
weedy	112N	24	1
weedy	112NPK	28	1
weedy	168N	21	7

[a]Plots are 4 years old -- 1 year younger than other plots.

these relations were generally true throughout the 5-year period, a young plantation is highly dynamic and there were exceptions. For example, first-year data indicated that on a silt loam site, fertilization may compensate for poor weed control.

We found no evidence that fertilizing with P and K resulted in increases in either 5-year biomass (table 3) or 5-year tree height (table 4) greater than that obtained by fertilizing with N alone. Also, plant and soil samples showed little response to P fertilization during the first 3 years. Concentration of P in both plant and soil samples from the PK-fertilized plots were close to those from the control plots (table 6). In contrast, concentration of K was consistently higher in plant samples from the PK-fertilized plots on both sites and in soil samples from the silt loam site. Also, although post-treatment soil K concentrations were less in the PK-fertilized plots, they increased relative to the pretreatment control-fertilized ratio. The subplot in the border area fertilized with 56 kg/ha of K the third year likewise showed elevated levels of plant and soil K, but no increase

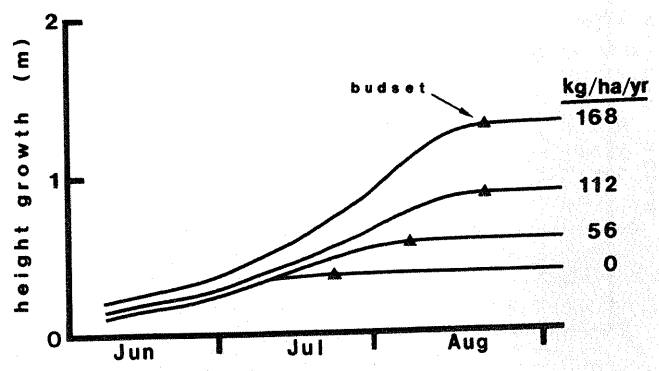

FIGURE 1.--Effect of different N fertilization rates on date of budset and total height growth during the second growing season on weedy plots on an infertile sand soil.

TABLE 3.--Relation of mean annual biomass production to fertilization in 5-year-old poplar plantations on a silt loam and a sand site. Treatments next to a common line are not significantly different. The ANOVA for the silt loam site was not significant.

silt loam			sand		
treatment			treatment		
ground cover	fertilizer kg/ha/yr	biomass Mg/ha/yr	ground cover	fertilizer kg/ha/yr	biomass Mg/ha/yr
trefoil	112N	7.6	weedy	168N	6.7
weedy	168N	6.5	trefoil	112N	6.4
weedy	112NPK	6.2	weedy	112N	5.8
weedy	56N	5.7	weedy	112NPK	5.1
weedy	112N	5.4	weedy	56N	2.8
weedy	0	4.8	weedy	0	1.8
trefoil	0	4.2	trefoil	0	1.6

TABLE 4.--Relation of tree height to fertilization in 5-year-old plantations on a silt loam and a sand site. Treatments next to a common line are not significantly different.

silt loam			sand		
treatment		tree	treatment		tree
ground cover	fertilizer kg/ha/yr	height m	ground cover	fertilizer kg/ha/yr	height m
trefoil	112N	7.03	trefoil	112N	6.35
weedy	168N	6.98	weedy	168N	6.04
weedy	56N	6.72	weedy	112N	6.03
weedy	112NPK	6.70	weedy	112NPK	5.56
weedy	112N	6.28	weedy	56N	4.52
trefoil	0	5.59	weedy	0	3.45
weedy	0	5.53	trefoil	0	2.90

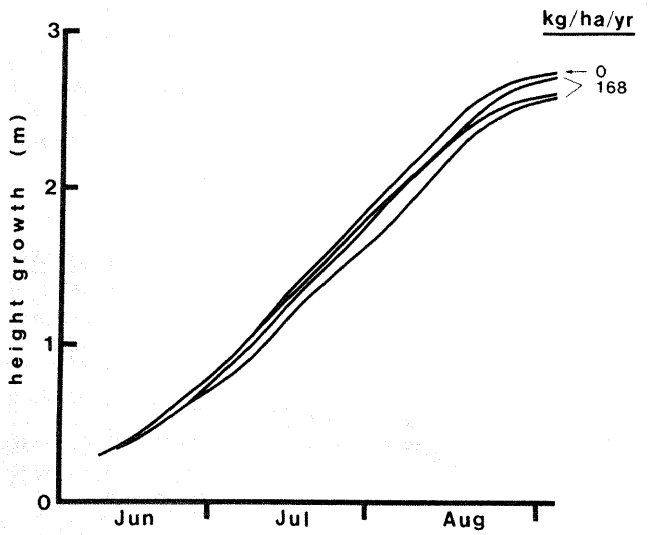

FIGURE 2.--Effect of 168 kg/ha/yr of N on total height growth during the second growing season on bare plots on a fertile silt loam soil.

in tree growth (data not shown). In summary, fertilization with P and K (in addition to N) produced no change in soil or plant P concentrations, an apparent increase in both soil and plant K concentrations, but no increase in tree biomass.

Pretreatment soil nitrogen concentration averaged .058 percent for the sand and .093 percent

TABLE 5.--Effect of weed control or fertilization on 2-year-old tree heights on a silt loam and a sand site. Weeded (bare) plot treatments are from a different growing period and are not strictly comparable. Treatments next to a common line are not significantly different; (p = 0.10 for the silt loam and p = 0.05 for the sand site).

silt loam		sand	
ground cover	tree height m	ground cover	tree height m
weeded	2.64	fertilized	2.36
fertilized	2.11	weeded	1.35
not weeded or fertilized	1.89	not weeded or fertilized	1.22

TABLE 6.--Trends in plant and soil P and K on plots fertilized with 110 kg/ha P and K in June 1980, as compared to unfertilized control plots.[a]

P and K kg/ha	Plant: silt loam 1980	silt loam 1981	silt loam 1982	sand 1980	sand 1981	sand 1982
	percent P					
0	.22	.32	.27	.33	.29	.23
112P	.28	.34	.28	.34	.28	.19
	percent K					
0	1.72	1.48	1.12	1.59	1.34	1.36
112K	1.91	1.71	1.39	1.98	1.45	1.55

P and K kg/ha	Soil: silt loam pretreatment	silt loam 1980	silt loam 1981	silt loam 1982	sand pretreatment	sand 1980	sand 1981	sand 1982
	ppm P							
0	540	675	582	212[b]	484	465	527	211[b]
112P	542	640	690	192[b]	396	435	393	202[b]
	ME/100g	ppm K			ME/100g	ppm K		
0	.41	104	69	101	.19	69	49	49
112K	.38	136	88	141	.10	66	40	51

[a]All plots received 112 kg/ha N annually. Data are average of three replications.

[b]Bray's phosphate #1; other years show "total" phosphorous.

for the silt loam. Nitrogen fertilization had no effect upon total soil N, but had a large effect upon leaf tissue N concentration. Leaf samples collected in June of the third growing season before that season's fertilization showed no increase in leaf tissue N concentration with an increase in N fertilization rate (fig. 3). However, both the July and August samples showed a strong relation of increasing leaf tissue N concentration with increasing fertilization rate. In all cases the trends were nearly linear and leaf samples from the silt loam site always had higher N concentration than samples from the sand site for similar fertilization rates.

There was also a strong linear relation between N concentration in leaves and seasonal tree height growth during the second and third years. Tree height growth increased with increasing leaf tissue N up to the highest observed concentration of 3.2 percent (fig. 4). Tree growth on silt loam soils was greater than on sand soils for comparable fertilization levels. This suggests that perhaps even higher fertilization rates on the sand soil might further increase leaf tissue N with a commensurate increase in tree growth. The July 1982 leaf N concentration - 1982 seasonal height growth relation shown in figure 4 was selected as a typical example; a complete presentation of the fertilization rate - leaf tissue N concentration - tree growth relationship is beyond the scope of this paper.

Although the data in figure 4 show that increasing N fertilization rates up to at least 168 kg/ha/yr results in increased height growth during the third year, similar data collected in August of the fifth growing season and plotted against the fourth and fifth years of biomass production give a somewhat different picture (fig. 5). The data again show a strong relation between leaf tissue N, fertilization rate, and tree biomass growth on the sand site. However, tree growth differed little for different leaf tissue N or fertilization rates on the silt loam site. The lack of a relation on the silt loam site might be partially due to the higher mortality in the fertilized plots. If the biomass were adjusted to compensate for the 24 percent mortality, the biomass of the fertilized plots would be about 25 t/ha -- about the same maximum production on the sand site. Mortality also might be associated with weakening and slower growth of the remaining live trees. This could account for the somewhat lower biomass production on the silt loam site as compared to the sand site during the fourth and fifth years. However, it still does not explain the relatively high biomass production of the unfertilized plot on the silt loam site despite its low leaf tissue N concentration. Evidently by the fourth year, factors other than N are dominant in affecting tree growth on the fertile silt loam site.

A tabulation of the ANOVA p values over the 5 years shows that fertilization treatments had a con-

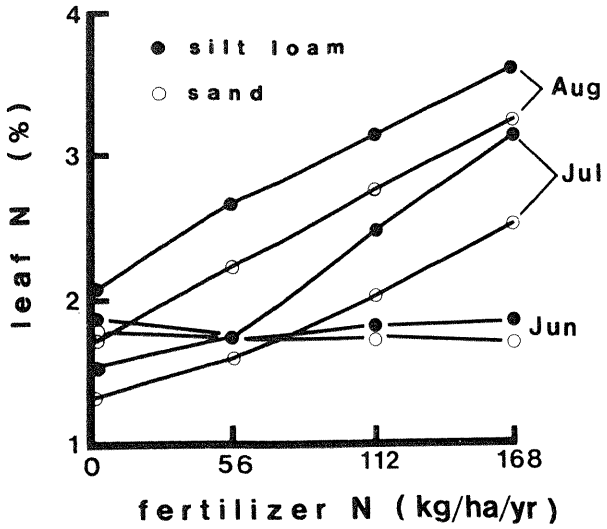

FIGURE 3.--Relation of leaf tissue N concentration (dry weight basis) to fertilizer rate measured monthly during the third growing season.

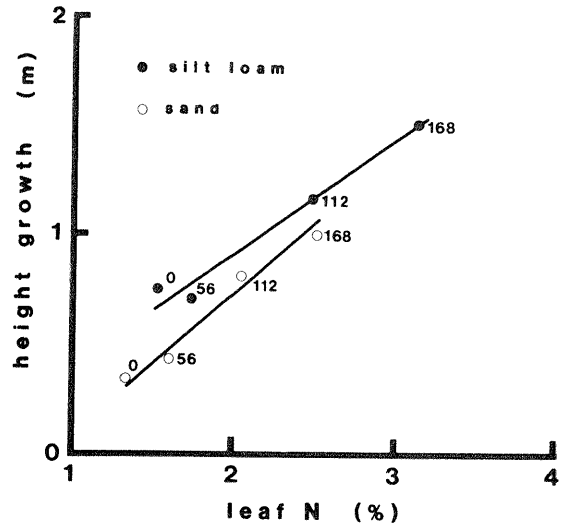

FIGURE 4.--Relation of tree height growth during the third growing season to leaf tissue N concentration (dry weight basis) on two sites. Leaf tissue N was that present July 15. Numbers by data points show N fertilization rate in kg/ha/yr.

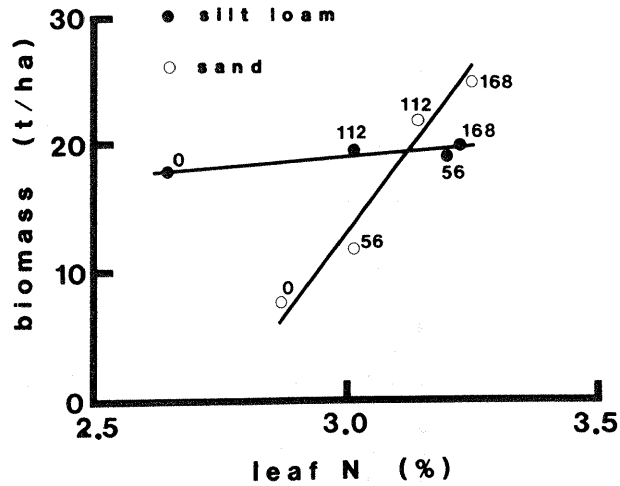

FIGURE 5.--Relation of tree biomass increment in the fourth and fifth years combined to leaf tissue N concentration (dry weight basis) on two sites. "Biomass" is the total above-ground biomass increment (excluding leaves). Leaf tissue N is that present August 15 of the fifth growing season. Numbers by data points show N fertilization rate in kg/ha/yr.

sistently significant effect on the sand site through time (table 7), However, on the silt loam site, fertilization had no significant effect the first year, significant effects in year 2 and 3, and no significant effect in years 4 and 5 (although there was a carryover of significance into year 5 for total tree height). This pattern on the silt loam site suggests that fertile soils can supply adequate nitrogen for the growth in the first year. Also, the lack of a fertilizer treatment response in the fourth year coinciding with canopy closure, suggests that internal N cycling within the various nutrient pools may be beginning to release sufficient N for good tree growth.

DISCUSSION

One question that follows from this study is "what is the cause(s) of the higher mortality associated with fertilization on the silt loam site?" One explanation is that the delayed budset shown in figure 1 results in reduced cold hardiness and consequently higher over-winter mortality. However, the data in figure 1 were from the sand site where mortality was low. Observation on the silt loam site indicated a smaller effect of fertilization on date of budset; yet most mortality was on the silt loam site. Consequently, it seems that budset is not a major factor in the mortality. Another possibility is the effect of nitrates on soil structure. Excess nitrate tends to promote soil puddling and a decrease in soil permeability (Resources Agency of California 1963), which in turn could lead to soil aeration problems. If nitrate effect on soil structure were the problem, we would expect to see greater effects on the silt loam than on the sand soils, as in fact occurred. Over the years we have noticed a marked tendency for higher mortality on fertilized and/or irrigated plots for some clones in several nearby studies. Yet, of the 100 or so acres that we have under irrigation and fertilization, many clones have survival near 100 percent. In another study we reported that tree growth was reduced on plots weeded by geese which we speculated may have been due to soil puddling from the goose traffic (Hansen and Netzer 1984). Whatever the cause, higher mortality associated with some intensively cultured clones on silt loam soils is a problem that needs to be furthered investigated.

In this study, we found a large increase in biomass production on sand soils and a slight increase on silt loam soils with increasing N fer-

TABLE 7.--Trend of ANOVA (p) values of fertilizer treatment effects over 5 years on two sites.

year	silt loam height	silt loam biomass	sand height	sand biomass
1	n.s.	---	.005	---
2	.05	---	.005	---
3	.005	.005	.005	.005
4	---	---	---	---
5	.01	n.s.	.01	.005
4 & 5[a]	n.s.	n.s.	.05	.005

[a]Growth increment in years 4 and 5.

tilization rates. Because fertilizer is expensive, high rates could be economically prohibitive. One alternative for fertile sites is to practice good weed control; weed control compensates for N fertilization for at least the first several years of the plantation. Weed control also conserves soil moisture that would otherwise be lost to competing herbaceous vegetation. On the other hand, bare plots lose too much NO_3-N in soil-water leachate with a consequent decrease in soil fertility and a potential for groundwater contamination (McLaughlin et al. 1985).

A fertilized legume cover crop showed a slight (non-significant) tendency towards increasing biomass production over that of fertilizer alone during the first 5 years. In addition, such a treatment might result in lower N fertilizer requirements over a longer period of time. If we consider the pros and cons of a ground cover vs. bare ground, a legume planted at a low density might provide the best compromise between nitrogen supply, ground cover-tree competition, and nutrient leaching.

Determining an optimum fertilization rate for a particular soil does not help much in estimating a suitable rate for another untested soil. Even in a complex study such as this, it is not completely clear if the optimum fertilization rate was achieved on the sand soil. Also, this study did not determine if fertilization every year was beneficial.

Analyzing soil and plant analysis help in interpreting nutrient status. In this study, tree leaf tissue N concentrations were usually above 3 percent in the fastest growing trees in July and August. However, August sampling is too late for scheduling fertilization for that season. And because June samples showed little variation in leaf tissue N concentration regardless of fertilization rate, they would not be a sensitive test for tree nutrient status. Consequently, it appears that the best indicator of tree N nutrition from this study is leaf tissue N sampled in mid-July. At that time N concentration should be greater than 3 percent for near maximum growth of hybrid poplar. The maximum leaf tissue N concentration of 3.25 percent in this study is somewhat greater than the 2.86 percent in leaves from 77-day-old eastern cottonwood grown in a complete nutrient solution (Hacskaylo and Vimmer-stedt 1967) and less than the 4.1 to 4.6 percent in the total top of 40-day old hybrid aspen seedlings (Einspahr 1968). This study's data also lie between the value of 2.94 percent N found in foliage of the tallest eastern cottonwood seedlings and 4.24 percent N in the seedlings with the greatest dry weight grown in a range of nutrient solutions designed to determine optimum leaf tissue nutrient concentrations (Bonner and Broadfoot 1967). Consequently, it appears that a reasonable interim goal in hybrid poplar plantations would be to main-tain mid-summer leaf tissue N above 3 percent for fast growth.

In conclusion, fertilization increased biomass up to a maximum of 50 percent on a silt loam site and 400 percent on a sand site. With fertilization and irrigation, maximum biomass production was about the same on both sites. The two treatments producing the greatest biomass on both sites (although not significantly greater than several other treatments) were 168 kg/ha/yr of N, and 112 kg/ha/yr of N with a legume cover crop. Maximum biomass was associated with mid-summer leaf tissue N concentrations of 3 percent or greater.

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