DIVISION S-7—FOREST AND RANGE SOILS

Response of Yellow-Poplar and Red Oak to Fertilization in West Virginia[1]

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ABSTRACT

Fertilization tests with small sawlog-size yellow-poplar (*Liriodendron tulipifera* L.) and red oak (*Quercus rubra* L.) were begun in the northern mountain section of West Virginia in the spring of 1970. Treatments were made with N, P, N-P, and N-P-K. During the first year, N was broadcast at 336 kg/ha, P at 97 kg/ha, and K at 93 kg/ha. Second season application included 112 kg/ha of N and 97 kg/ha of P. Basal-area response to N over a 3-year period amounted to a 47% increase for yellow-poplar and a 29% increase for red oak. There was no response to P, either alone or in combination with N. Negative effects on basal-area growth were observed where KCl was applied. Foliar response in leaf weight and color was attributed mostly to N, although P in combination with N produced slightly heavier and darker green leaves than N only. Foliar N in yellow-poplar corresponding to the best basal-area growth was about 3.0% N.

Additional Index Words: **forest fertilization, foliar analysis.**

IN THE NORTHEASTERN United States, high-quality hardwoods bring very high prices, but it takes a long time for these hardwoods to reach maturity. Forest fertilization offers a means to increase their growth rates (3). Earlier hardwood fertilization tests have demonstrated positive response of upland oaks and yellow-poplar to fertilization on a variety of sites (5, 6, 8, 9, 14). Generally, the greatest response with hardwoods has been associated with N and to a lesser degree P, but only when P has been applied in combination with N.

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This study summarizes 3-year-growth responses of yellow-poplar (*Liriodendron tulipifera* L.) and red oak (*Quercus rubra* L.) to fertilization in the northern Appalachian mountains of West Virginia. The major objective was to determine if deficiencies of N, P, or K were limiting growth on good growing sites. Also reported are relationships between foliar N and basal-area growth of yellow-poplar and the effects of fertilization treatments on foliar dry weight and nutrient composition for both species.

METHODS

The studied region is representative of about 0.4-million ha in Tucker and Randolph counties of West Virginia. The terrain is rugged and steep. Large differences in site quality, species composition, and stand density occur within short distances. Annual precipitation averages 140 cm (55 inches). The frost-free period is about 150 days.

Soils on the study areas are strongly acid, well-drained silt loams, about 90 cm (3 feet) deep to bedrock, belonging to either the Gilpin (*Typic Hapludults*) or Calvin series (*Typic Dystrochrepts*). These soils are residual, having formed from interbedded layers of sandstone and shale of Devonian age (Chemung and Catskill formations), but they have also been influenced considerably by colluvial action. They contain in their upper 21 cm (6 inches) of mineral soil approximately 2,061 kg/ha of N (1,840 pounds/acre), 12 kg/ha of P extractable with 0.002 N H_2SO_4 (10 pounds/acre), and 157 kg/ha exchangeable K (140 pounds/acre) (2). They are important forest soils, representing about 50% of the forest acreage within the study area.

Fertilization test areas were located in fully stocked, even-aged stands of sawlog-size trees on good growing sites. Red oak site index varied from 70 to 80 among the different study replicates, based on the soil site equation developed by Trimble (13). Estimates of yellow-poplar site index are unavailable, but exceed those for red oak. No plots were located on the very best cove sites. Individual test areas were restricted to sites having uniform topography, soil, and moisture regimes, though small differences among plots were unavoidable. Diameters of the sample trees at breast height ranged from 30 to 41 cm (12 to 16 inches) at the beginning of the study. Stand age varied from 55 to 70 years among replicates.

A separate series of test plots was established for each species, using randomized complete block designs. There were 7 yellow-poplar replicates for a total of 35 plots and 199 yellow-poplar trees, and 4 oak replicates for a total of 20 plots and 99 red oak trees. Each plot contained 3 to 10 dominant or codominant yellow-poplars or red oaks, which were measured for determining response. Other species growing on the plots and in association with the study trees were not measured. Associated species included basswood (*Tilia americana* L.), cucumbertree (*Magnolia acuminata* L.), beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and red maple (*Acer rubrum* L.).

Plot size varied between 0.08 and 0.13 ha (one fifth and one third acre) to include the necessary trees plus a 7.6-m (25-foot) fertilized buffer zone between the sample trees and the treatment boundary. Isolation distance between plots was at least 15 m (50 feet), but usually exceeded 46 m (150 feet). Test sites were well distributed over the entire study area.

The fertilizers used were urea, triple-superphosphate, and muriate of potash. All materials were uniformly applied with cyclone seeders. Fertilizer treatments were: (i) no fertilizer; (ii) 97 kg/ha P (87 pounds/acre); (iii) 336 kg/ha N (300 pounds/acre); (iv) 336 kg/ha N and 97 kg/ha P; and (v) 336 kg/ha N, 97 kg/ha P, and 93 kg/ha K (83 pounds/acre). Plots were initially fertilized during the first week in May 1970 at about the time of leafing out. A second application of 112 kg/ha N and 97 kg/ha P was made in May 1971 to all plots previously treated with these nutrients to insure N and P availability throughout the second season.

All study trees were equipped with aluminum band dendrometers located 1.4 m (4.5 feet) above ground level, from which diameter growth was recorded to the nearest 0.25 mm (0.01 inch) at the end of each growing season. Because after-treatment growth of study trees was strongly related to their before-treatment basal area, all growth data were adjusted by covariance, using initial basal area of the study trees to compensate for differences in before-treatment growth rates that occurred among the plots. The adjusted average annual basal-area growth of the study trees on each plot was used to indicate treatment response.

Table 1—Average adjusted basal-area growth per tree and percentage increase in basal area with fertilizer treatments, using the control plot as the base comparison.†

Treatment	Yellow-poplar			Red oak		
	Average basal-area growth‡	Absolute increase	Percentage increase	Average basal-area growth‡	Absolute increase	Percentage increase
	sq cm	sq cm	%	sq cm	sq cm	%
			First year, 1970			
C	16.9 a	--	--	19.5 a	--	--
P	20.4 a	3.5	21	26.7 b	7.2	37
N	23.2 a	6.3	37	24.3 a	4.7	25
N-P	25.7 a	8.8	52	25.6 b	6.0	31
N-P-K	21.2 a	4.3	26	22.7 a	3.2	16
			Second year, 1971			
C	22.3 a	--	--	31.8 a	--	--
P	25.7 a	3.4	15	38.4 a	6.6	21
N	34.9 b	12.6	56	41.2 a	9.4	30
N-P	34.9 b	12.6	56	43.4 a	11.6	37
N-P-K	31.4 a	9.1	41	39.4 a	7.6	24
			Third year, 1972			
C	25.6 a	--	--	36.8 a	--	--
P	28.1 a	2.5	10	43.1 a	6.3	17
N	36.2 b	10.5	41	44.8 a	8.0	22
N-P	35.2 b	9.5	37	48.2 a	11.4	31
N-P-K	31.1 a	5.5	21	45.3 a	8.6	23

† Tabular values are averages of not <38 codominant or dominant yellow-poplar trees and not <15 red oak trees.
‡ Values in *columns* followed by the same letter are not significantly different (Scheffé test, $P < 0.05$).

Foliar samples were obtained by climbing 3 study trees on all plots during late August 1970 (165 trees). Each sample consisted of 25 mature leaves that were insect- and disease-free and situated on current-season twigs of at least two branches growing in full sunlight in the upper 10% of the crown. Leaf color was determined from Munsell charts for plant tissue. Leaves, less petioles, were analyzed for N, P, K, Ca, and Mg, Nitrogen was determined by the Kjeldahl method. After wet-ashing with HNO_3 and $HClO_4$, P was determined colorimetrically and K, Ca, and Mg by atomic absorption. Treatment differences were tested for significance at the 5% level, using a Scheffé test (12).

RESULTS

Yellow-Poplar

Basal-area Growth—At all seven test locations, N fertilization increased basal-area growth of dominant and codominant yellow-poplar (Table 1). The increase (average for N and N-P treatments) was 45% for the first year, 56% for the second, and 39% for the third. The average increase for the 3-year period amounted to 47%. These increases were significant for years 2 and 3, but not for year 1.

Major differences in both relative and absolute growth responses occurred among the 7 installation sites. Relative 3-year growth response of individual test areas ranged from 34 to 123%, and absolute response from 18 to 44 cm². Sites with the slowest growth rates showed the greatest relative response, but absolute basal-area responses were not as closely related to initial growth rates. Differences in growth response among replicates are thought to be related to varia-

Table 2—Fertilizer effects on foliar characteristics of 50- to 70-years-old dominant and codominant yellow-poplar on good sites in northern Appalachians.†

Treatment	Concentration					Content					Oven-dry leaf weight	Leaf color, Munsell
	N	P	K	Ca	Mg	N	P	K	Ca	Mg		
	% dry weight					mg/leaf					g	
C	2.25 a	0.14 a	1.30 a	1.55 a	0.34 a	13.9 a	0.8 a	7.9 a	9.4 a	2.1 a	0.61 a	7.5 GY 5/6
P	2.37 a	0.20 b	1.36 a	1.54 a	0.33 a	15.7 ac	1.4 bc	9.0 a	10.0 a	2.2 a	0.64 a	7.5 GY 5/6
N	2.83 b	0.14 a	1.31 a	1.47 a	0.35 a	18.9 ad	1.0 ac	8.9 a	9.9 a	2.5 a	0.67 a	7.5 GY 4/4
N-P	2.91 b	0.19 b	1.29 a	1.73 b	0.40 a	22.0 bd	1.4 bc	9.8 a	12.9 a	3.0 a	0.76 a	7.5 GY 3/4
N-P-K	3.00 b	0.20 b	1.30 a	1.70 b	0.39 a	20.3 bcd	1.4 bc	8.7 a	11.4 a	2.7 a	0.68 a	7.5 GY 3/4

† Values in each *column* followed by the same letter are not significantly different (Scheffé test, $P < 0.05$). Each value is based on samples of 25 leaves obtained from upper-crown positions from each of 21 codominant/dominant trees.

tion in stand stocking levels, moisture regimes, and N availability, although genetic differences may be important as well.

The added P, either alone or in combination with N, did not significantly increase overall average growth rates of yellow-poplar during any any of the three seasons. Though the data indicate a small growth increase due to the P-only treatment for each of the 3 years (Table 1), this response was not significant. Moreover, examination of increment cores extracted from sample trees showed no apparent response to P, suggesting that the increment difference between the P-only and control treatments was the result of accelerated before-treatment growth rates that occurred on several of the P-only plots.

Muriate of potash (KCl) in combination with N and P depressed growth by an average of 12% from the N and N-P treatment levels during the 3-year period. The effect was statistically significant for years 2 and 3, and clearly evident in the growth data from six of the seven test areas.

Foliar Nutrition, Dry Weight, and Color—Nitrogen fertilization increased both the concentration and total amount of N in the foliage, resulting in leaves of a darker green color that were of generally greater weight than foliage from unfertilized control trees (Table 2). Application of P increased the concentration and total quantity of P in the foliage, but had little effect on leaf weight. Only when P was added in combination with N were leaves of darker green color than in N-only treatments. Calcium concentration and content were increased whenever triple-superphosphate (which contained 18% Ca) was applied in combination with N, but there was no change when P fertilizer was applied without N. Foliar K concentration and content were unaffected by the application of KCl, and none of the fertilizers significantly affected Mg concentrations.

Relationships between Foliar N and Growth.—To determine relationships between foliar N and basal-area increment, first-year foliar N (expressed as both percentage of dry weight and mg/leaf) was tested in regression equations against three measures of cumulative 3-year basal-area growth. These measures were: (i) relative growth (percentage of maximum basal-area increment); (ii) absolute growth response (basal-area deviation from the maximum observed increment); and (iii) absolute basal-area increment. Within each test area, the treatment plot having the highest average basal-area increment per tree (adjusted values) was considered to represent the maximum increment obtainable for existing site and stand conditions and was used to compute measures 1 and 2. Linear and second degree quadratic equations were fitted to each set of data. Data from plots showing a growth depression from application of KCl were not used in these analyses.

Foliar N, expressed as either percentage of N or mg N/leaf, was significantly related to each of the three measures of growth response (Table 3). Stronger regressions were obtained with percentage N than with mg N/leaf and relative growth (measure 1) was more closely related to foliar N than either absolute growth response (measure 2) or absolute increment (measure 3). Quadratic regressions generally made little improvement in standard errors and amounts of explained variation (R^2) over simple linear regressions, tended to overestimate optimum foliar N levels, and usually produced a better data fit at the lower N levels.

Table 3—Relationships among three measures of growth response and two measures of foliar N for sawtimber-size yellow-poplar trees.
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Growth measure	Foliar N measure	Regression form	Equation	F‡	Standard error	Explained variation
Relative growth (%)	% N	Quadratic	$Y = -212.03 + 185.81X - 27.74X^2$	3.02	9.92	0.71
		Linear	$Y = -31.65 + 43.16X$	53.54**	10.30	0.67
	mg N/leaf	Quadratic	$Y = -14.00 + 8.01X - 0.14X^2$	3.55	13.15	0.49
		Linear	$Y = 31.59 + 2.75X$	21.80**	13.29	0.46
Absolute growth response (sq cm)	% N	Quadratic	$Y = 208.00 - 107.38X + 13.20X^2$	0.47	11.98	0.57
		Linear	$Y = 122.18 - 39.50X$	33.87**	11.86	0.57
	mg N/leaf	Quadratic	$Y = 68.69 - 3.15X + 0.02X^2$	2.55	14.82	0.35
		Linear	$Y = 62.12 - 2.39X$	13.79**	14.54	0.35
Absolute increment (sq cm)	% N	Quadratic	$Y = -137.35 + 116.66X - 12.08X^2$	0.11	22.74	0.41
		Linear	$Y = -58.77 + 54.52X$	18.16**	22.35	0.41
	mg N/leaf	Quadratic	$Y = -27.47 + 8.28X - 0.11X^2$	0.31	22.56	0.42
		Linear	$Y = 7.55 + 4.24X$	18.51**	22.26	0.42

** Significant at 1% level.
† Each equation is based upon 28 data points. Growth measures for each data point are the average 3-year adjusted basal-area increment from 3 to 10 dominant or codominant yellow-poplars. Foliar N measures for each data point are the average of 25 leaf samples obtained from each of 3 trees.
‡ Degrees of freedom are 1 and 26 for linear equations and 2 and 25 for quadratic equations; F values are for X^2 in quadratic equations and for X in linear equations.

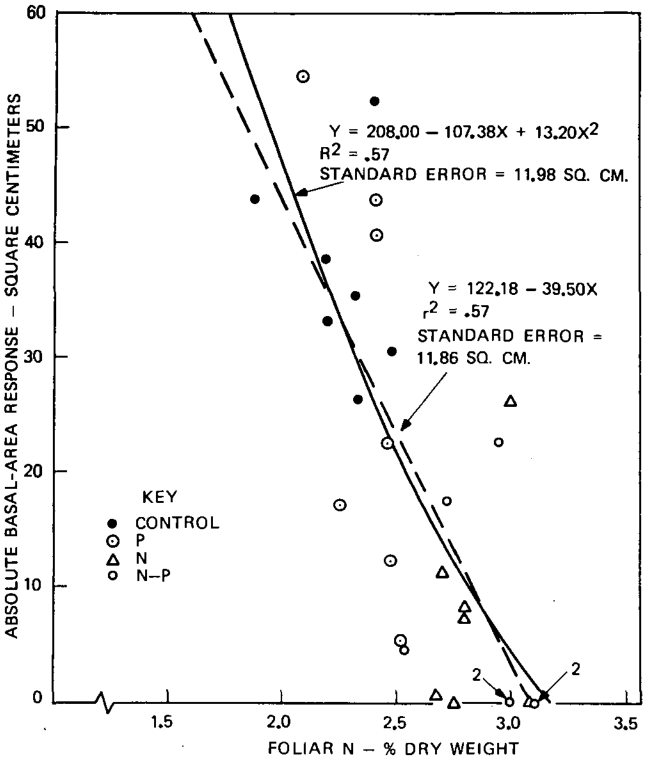

Fig. 1—Relationship between 3-year relative basal-area growth and first-year foliar N for fertilized and unfertilized yellow-poplar.

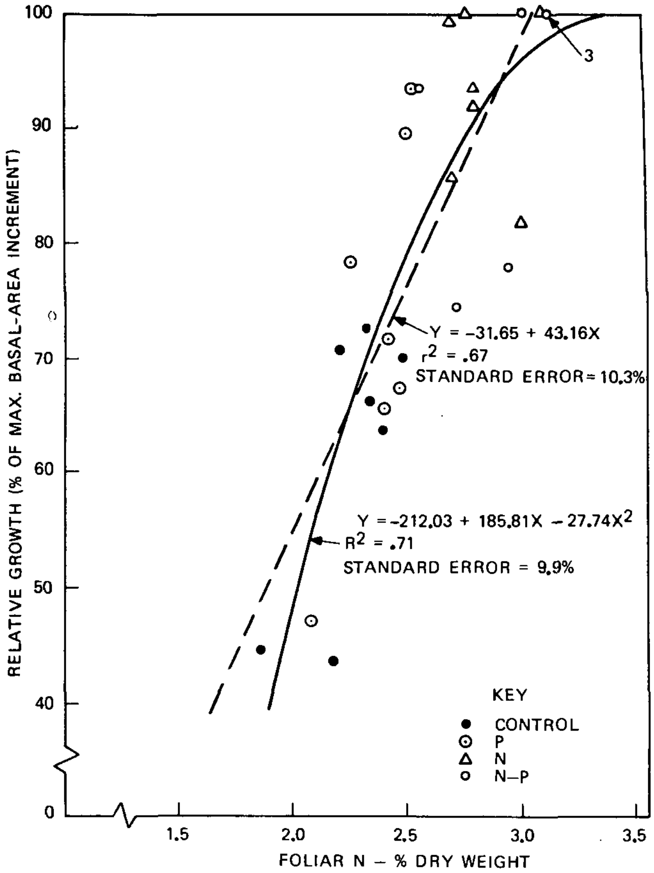

Fig. 2—Relationship between 3-year absolute basal-area growth response and foliar N for fertilized and unfertilized yellow-poplar.

The best relationship between foliar N and basal-area increment was obtained with percentage of N and relative growth (Fig. 1). The strongest equation explained 71% of the growth variation and was quadratic. Linear regression explained 67% of the growth variation. These data show that maximum increment was reached at about 3% N, although on several plots it occurred at levels as low as 2.7% N. The regressions between absolute basal-area response (measure 2) and percent N also indicate that maximum increment occurred at approximately 3% N (fig. 2).

Red Oak

Basal-area Growth—Red oak was less responsive to N fertilization than yellow-poplar (Table 1). The response to N (average of N and N-P treatments) was 28% for the first season, 33% for the second, and 26% for the third. The average increase for the 3-year period amounted to 29%. All test sites showed a positive growth increase, although relative response varied from about 12 to 53% and absolute response from 11 to 37 square centimeters among the four replicates. Examination of increment cores from sample trees showed that response was due entirely to N, and that the significant response to the P-only and N-P treatments for year 1 (shown in Table 1) was a sampling artifact associated with faster growing trees located on several of these treatment plots. Growth response in the N-P-K treatment was consistently less than in the N and N-P treatments, illustrating the adverse effects from KCl.

The lack of statistical difference in growth response from N fertilization may be attributed to the relatively small size of this test and to the fact that red oak characteristically shows highly variable growth patterns among trees. However, based upon verification of response from increment cores, these figures represent meaningful estimates of growth increases obtainable by N fertilization, even though statistical significance is lacking.

Foliar Nutrition, Dry Weight, and Color—Generally, fertilizer treatments affected foliar nutrition, leaf weight, and color in red oak in the same way that they affected yellow-poplar foliage (Table 4). Nitrogen fertilization increased the concentration and content of N in the foliage, producing heavier leaves of darker green color than leaves from unfertilized control trees. Likewise, P fertilization increased the concentration and content of P in the foliage and had a strong tendency to increase leaf weight when applied in combination with N. Foliar K concentrations were unaffected by the application of KCl, but K content per leaf was appreciably increased on N-P and N-P-K plots due to production of heavier leaves in these treatments. None of the fertilizer treatments significantly affected Ca or Mg concentrations and contents.

DISCUSSION

In this study, yellow-poplar was more responsive to fertilization than red oak, although both species showed positive response to N at all of the test locations. Nitrogen increased average 3-year basal-area growth rates of dominant and codominant yellow-poplar and red oak by 47 and 29%, respectively. These results indicate that N availability is one of the key factors controlling growth rates for these

Table 4—Fertilizer effects on foliar characteristics of 50- to 70-years-old dominant and codominant red oak on good sites in northern Appalachians.

Treatment	Concentration					Content					Oven-dry leaf weight	Leaf color, Munsell
	N	P	K	Ca	Mg	N	P	K	Ca	Mg		
	% dry weight					mg/leaf						
C	2.58 a	0.15 ac	0.89 a	1.04 a	0.17 a	33.7 ab	1.9 a	11.5 a	13.4 a	2.2 a	1.30 a	7.5 GY 4/4
P	2.46 a	0.18 b	0.92 a	0.90 a	0.18 a	30.3 a	2.2 a	11.2 a	11.0 a	2.1 a	1.24 a	7.5 GY 4/4
N	2.79 ab	0.14 c	0.80 a	0.88 a	0.15 a	41.5 ab	2.1 a	11.8 a	13.2 a	2.2 a	1.49 a	7.5 GY 3/4
N-P	3.02 b	0.18 b	0.81 a	0.84 a	0.13 a	52.7 b	3.0 a	14.1 a	14.5 a	2.3 a	1.73 a	7.5 GY 3/2
N-P-K	3.09 b	0.17 ab	0.90 a	0.91 a	0.14 a	52.2 b	2.8 a	15.4 a	15.2 a	2.4 a	1.70 a	7.5 GY 3/2

† Values in each *column* followed by the same letter are not significantly different (Scheffé test, $P < 0.05$). Each value is based on samples of 25 leaves obtained from upper-crown positions from each of 12 codominant/dominant trees.

species on these soils, and that N deficiency is likely to exist over a broad area on good sites in the northern Appalachians of West Virginia.

Although P applied in combination with N did not result in a significant overall growth response, the best growth was observed on N-P treatment plots at four of the seven yellow-poplar test sites and at two of the four red oak test sites. This suggests that P may also become limiting on some sites within the region after N demands have been satisfied. Because of large variation in individual tree growth rates on the experimental areas, and also because of the relatively small number of sample trees that were used to assess treatment effects, the sensitivity of these tests may not have been sufficient to detect growth increases from P.

Results agree closely with those reported by Farmer et al. (5) for mixed upland hardwoods in the Tennessee Valley and with those reported by Mitchell and Chandler (9) for yellow-poplar in southern New York. In both studies, yellow-poplar growing in natural forest ecosystems was responsive to fertilization, showing large consistent response to applied N. In the study by Farmer et al., additional secondary response to P also was obtained when P was applied simultaneously with N.

The growth response observed in the present tests was generally lower in percentage than reported elsewhere for yellow-poplar and red oak (5, 6, 8, 9, 14). The fact that most of these previous studies were conducted on unfertile soils and that our tests were all located on good growing sites and with fast-growing trees suggests a possible explanation for these differences. Also, results show that red oak is less responsive to fertilization than yellow-poplar, which is in agreement with previous work (5, 9).

Reasons for the reduction in growth response to N and P fertilizers when KCl was simultaneously applied are unclear. Detrimental effects of KCl have not previously been reported for forest trees, but there is evidence to suggest that it may occur. Ragland and Coleman (10) found that addition of KCl to acid soils increased soil solution Al to the point that corn root growth was drastically reduced. It is also known that certain crops, including fruit trees, are particularly sensitive to Cl (4); that deicing salts which contain Cl have adverse effects on roadside trees (11); and that soil nitrifying populations can be depressed from K (1). Collectively, this evidence suggests that reduced response from KCl application may be associated with Cl toxicity, damage to absorbing roots from increased salt concentrations, Al toxicity caused by displacement of Al by K from the soil exchange sites, and/or from suppression of soil nitrifying bacteria.

Diagnostic curves developed in this study show that concentrations below approximately 3.0% N in leaves growing in full sunlight in the upper crowns of large yellow-poplars represent the threshold of deficiency. Mitchell and Chandler (9) also estimated this concentration to be about 3.0% N in mature yellow-poplar trees, but estimates based on pot-culture tests with seedlings have ranged from 3.0 to 4.28% N (6, 7). Data from this study are in close agreement with published information dealing with large trees, but are conservative when compared to those from pot-culture tests.

Because N was not applied at rates in excess of 336 kg/ha, the possibility exists that maximum biological yields were not reached. Though this may be so, these curves can still be used for diagnostic evaluations because they cover the range of deficiency that is likely to yield the largest growth responses to N fertilization on good growing sites. However, because N was reapplied during the second season the present curves may overestimate 3-year response for single fertilizer applications. It is also possible that year-to-year foliar N variation, the size of which is unknown for yellow-poplar, may affect their reliability.

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