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Fertilization of Established Douglas-fir Christmas Tree Plantations

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Fertilization of Established Douglas-fir Christmas Tree Plantations

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INTRODUCTION

Douglas-fir *(Pseudotsuga menziesii)* has many characteristics which make it a desirable species for Christmas tree planting. Needles are short (approximately ¾ to 1½ inches), soft to the touch, and are retained well on cut trees. In addition, basic conical shape of trees is good, and they can usually be sheared to produce high quality Christmas trees which bring premium prices on wholesale and retail markets.

Surveys made in 1978 indicated that approximately 35% of Christmas trees harvested in the United States were Douglas-fir, second only to Scotch pine (37%). However, most of those trees came from the West Coast. In Ohio, nearly 60% of trees cut in 1980 were Scotch pine, and only about 2% were Douglas-fir (1).

There are a number of reasons for the relatively small number of Douglas-fir planted and harvested for Christmas trees in Ohio. The species is much more exacting in its site requirements than Scotch pine, white pine, and most spruces. Douglas-fir grows best on moist, well-drained soils. Survival and growth are very poor on wetter soils and may also be reduced on droughty areas. Douglas-fir is also very sensitive to competition from broadleaved herbs and grasses, particularly the first few years after trees are planted. Research in Ohio has shown that survival, growth, and foliage characteristics can be improved on most sites by the use of chemical weed control (2). Trees often leaf out early in spring, and new growth may be killed, particularly in low-lying "frost pockets". In the past, many Christmas tree growers in Ohio planted Douglas-fir on sites for which it was not suited and often did not use suitable cultural practices. As a consequence, survival, growth, and foliage quality of trees were often poor.

Earlier studies in Ohio (2) showed that nitrogen applications made 1 or 2 years after trees were planted improved growth and foliage quality of Douglas-fir on well-drained, infertile sites but had little effect on trees planted on fertile and/or wet sites. The purpose of studies reported here was to investigate fertilization of established Douglas-fir plantations growing on soils having good physical characteristics but where trees had visual nutrient deficiencies.

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[2]Appreciation is expressed to Robert F. Donahey and Jack Schmidt, Jr., owners of the plantations on which studies were carried out. Appreciation is also expressed to James Finney, Eileen Smith, and Charles Vrotney, OARDC technicians, for their assistance on the project.

METHODS

Two separate studies were carried out. In the first, applications of nitrogen and phosphorus were made to established Douglas-fir plantings; in the second, nitrogen and lime applications were made.

Study 1. The experimental area used in this study is located in Licking County, Ohio. Soil on the area is deep, well-drained Alexandria silt loam, a fine, illitic, mesic Typic Hapludalf that developed in glacial till of Wisconsin age. Moisture supplying capacity of soils is good. Available P was low and exchangeable Ca and Mg were at the low end of the range of fertility considered adequate for agronomic crops (Table 1).

In the study, all combinations of three levels each of N (0, 50, and 100 lb of elemental N/acre applied as urea) and P (0, 225, and 450 lb of elemental P/acre applied as triple superphosphate) were applied. Trees were 8 years old from planting, had been sheared annually for 4 years, and averaged 5 feet in height. Fertilizers were broadcast in the spring on the surface of plots which consisted of 3 rows of 12 trees each, with the interior 10 trees in each plot used for sampling.

Needle measurements, shoot sampling, and soil sampling were done in October at the end of the first, second, and third growing seasons after fertilization. Because trees had been sheared, shoot length could not be used for evaluating response to fertilization. Therefore, uniform samples of the current year's shoots (three pieces per tree, each 3 inches long and including twigs plus attached needles) were collected from the upper one-third of tree crowns, oven dried at 70° C, and weighed, and those weights were used as one measure of response to fertilization. Needles of shoot samples were ground and analyzed for total N by Kjeldahl analysis and P (as well as 12 other elements) by emission spectroscopy by the Research Extension Analytical Laboratory (REAL) at the Ohio Agricultural Research and Development Center. Soil samples collected from the upper 8-inch soil layer of plots were air dried, rolled, and analyzed for pH, Lime Test Index (LTI), available P, and exchangeable K, Ca, and Mg by REAL.

Statistical analyses were made using means of measurements for the 10 trees in each plot or composited needle or soil samples as items. Analyses of variance were run for a completely randomized factorial, with nine treatments (three levels of N x three levels of P) and six replications. When analysis of variance indicated statistical significance at the 5% probability level, a least significant differences (LSD) test was used for mean separation.

Study 2. The experimental area used in Study 2 is located in Carroll County, Ohio. Soil on the area is

TABLE 1.—Average Physical and Chemical Properties (Before Fertilizer Applications) of Soils on Study Areas.

Location	Total Depth	Physical Properties: Ap Horizon Thickness	Ap Horizon Texture	Ap Horizon Available Moisture†	$B_1 + B_2$ Horizon Thickness	$B_1 + B_2$ Horizon Texture	$B_1 + B_2$ Horizon Available Moisture	Chemical Properties*: pH	P	K	Ca	Mg
	inches	inches		%	inches		%		lb/acre			
Licking County	60	7	silt loam	16	28	silty clay loam	15	5.1	15	215	796	146
Carroll County	30	6	silt loam	17	18	silt loam	14	4.8	35	175	466	220

* Chemical properties of samples collected from the upper 8-inch layer of soil.

† Available Moisture: percent moisture by weight, retained by soil between ⅓ atm. pressure ("field capacity") and 15 atm. pressure ("permanent wilting point"), as determined using porous plate apparatus.

Gilpin silt loam, a fine-loamy, mixed mesic Typic Hapludult of medium depth that developed in thin residual beds of acid siltstone, shale, and fine grained sandstone. Moisture supplying capacity is generally good. Available P was in the range considered adequate for agronomic crops, but exchangeable K and especially exchangeable Ca were low (Table 1).

In this study, all combinations of four levels of N (0, 75, 150, and 225 lb of elemental N/acre applied as urea) and three levels of dolomitic lime (0, 3, and 6 tons/acre) were applied. Trees were 9 years old from planting, had been sheared annually for 5 years, and averaged 5½ feet tall. Fertilizers were broadcast on the surface of plots, which consisted of four rows of trees, each 50 feet long, with the interior two rows used for sampling. Because of variable mortality in rows, numbers of trees sampled on individual plots ranged from 9 to 15. Half of each lime treatment was applied in the fall, with the remaining half plus all N applications made the following spring.

Measurements and shoot and soil sampling and laboratory analyses made at the end of the first, second, and third growing seasons after fertilization were essentially the same as those outlined for Study 1. In addition, exchangeable ammonium in soils was determined using an Orion ammonia electrode after extraction of soil with 2 M potassium chloride.

Statistical analyses were made using means of measurement for the 9 to 15 trees in each plot or composited foliage or soil samples from each plot as items. Analyses of variance were run for a completely randomized factorial, with 12 treatments (4 levels of N x 3 levels of lime) and 5 replications.

RESULTS

Study 1, Licking County Site

Foliage Quality. Fertilization significantly affected foliage quality of established Douglas-fir at the Licking County site, with all effects attributable to additions of nitrogen.

At the end of the first growing season after fertilization, needle lengths of trees receiving 50 lb of N per acre were approximately 6% longer than those which had not been fertilized. Needles of trees receiving 100 lb of N per acre were more than 18% longer than those of unfertilized trees, and the increase from 50 to 100 lb of N was statistically significant (Table 2). After two growing seasons, needles were generally shorter than at the end of the first year, but those on trees receiving 100 lb of N were still more than 10% longer than those on trees not fertilized with N.

Weights of shoot samples followed trends similar to those shown by needle lengths. After one growing season, shoot weights increased significantly with additions of both 50 (4% heavier) and 100 (9% heavier) lb of N per acre (Table 2). Shoot weights generally declined at the end of the second and third years, but for trees receiving 100 lb of N were still significantly heavier (5 to 6%) than those receiving 0 or 50 lb of N.

Qualitative estimates of foliage color made in December of the second year after trees were fertilized

TABLE 2.—Effects of Nitrogen and Phosphorus Fertilization on Growth and Foliage Color of Douglas-fir on Alexandria Silt Loam at the Licking County Experimental Site.

Fertilizer Level	Needle Length		Average Foliage Weight*			Foliage Color
	1st Year	2nd Year	1st Year	2nd Year	3rd Year	2nd Year
lb/acre	mm		gms/piece			Rating†
Nitrogen						
0	33	31	1.17	1.13	1.12	2.1
50	35	30	1.22	1.11	1.11	2.4
100	39	35	1.28	1.20	1.18	2.8
Phosphorus						
0	35	32	1.20	1.17	1.15	2.3
225	38	31	1.25	1.20	1.13	2.5
450	36	33	1.22	1.18	1.14	2.5
N: pF‡	0.02	0.01	0.001	0.01	0.05	0.001
LSD$_{05}$**	3	3	0.05	0.06	0.06	0.34
P: pF	0.63	0.57	0.30	0.73	0.65	0.27
LSD$_{05}$	--	--	--	--	--	--
NxP: pF	0.41	0.52	0.62	0.43	0.67	0.70

* Average foliage weight of uniform 3-inch twigs (needles and stems) from current year's growth in upper one-third of crowns of sample trees.

† Visual rating of color: 1=very chlorotic; 2=chlorotic; 3=green; 4=dark green.

‡ pF: Probability of statistical significance for analysis of variance F test.

** LSD$_{05}$: Least significant difference at 5% probability level for comparing differences between treatment means.

also showed the beneficial effects of N fertilization (Table 2). Trees not fertilized were rated "chlorotic", while needle color of trees receiving 100 lb of N per acre had improved to near the "green" rating.

Nutrient Levels in Foliage. Nutrient levels of both N and P in needles of trees were significantly affected by fertilization (Table 3). Average nitrogen concentrations (percent by weight) ranged from 1.29 to 1.55%, with significant increases only after the first growing season in needles of trees fertilized with 100 lb of N.

Average P concentrations in needles ranged from 0.25 to 0.36%, with significant increases at the end of the first and second growing seasons in needles of trees fertilized with 225 or 450 lb of P per acre (Table 3).

Weights of N and P in needles followed trends similar to those for concentrations in needles (Table 3). Nitrogen content at the end of the first growing season increased significantly with additions of both 50 and 100 lb of N per acre, while after 2 years, N content was higher only in needles of trees fertilized at the 100 lb rate. For P, contents were significantly higher at the end of the first and second growing seasons in trees fertilized at both the 225 and 450 lb per acre rates.

TABLE 3.—Effects of Nitrogen and Phosphorus Fertilization on Nutrient Levels in Needles of Douglas-fir on Alexandria Silt Loam at the Licking County Experimental Site.

Fertilizer Level	Concentration						Content					
	Nitrogen			Phosphorus			Nitrogen			Phosphorus		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
lb/acre	% by weight						weight, mg/piece*					
Nitrogen												
0	1.42	1.33	1.29	0.32	0.31	0.27	10.9	7.8	7.6	2.4	1.8	1.6
50	1.43	1.35	1.30	0.31	0.32	0.24	12.3	7.6	7.7	2.7	1.8	1.4
100	1.55	1.38	1.30	0.29	0.34	0.25	13.3	8.4	7.9	2.5	2.1	1.5
Phosphorus												
0	1.49	1.32	1.32	0.26	0.28	0.25	11.9	7.9	7.9	2.1	1.7	1.3
225	1.41	1.37	1.29	0.32	0.34	0.26	12.4	8.4	7.8	2.8	2.1	1.3
450	1.50	1.37	1.28	0.34	0.36	0.25	12.2	8.2	7.5	2.8	2.2	1.5
N: pF†	0.04	0.34	0.91	0.54	0.14	0.09	0.02	0.04	0.33	0.43	0.21	0.17
LSD_{05}‡	0.08	--	--	--	--	--	0.9	0.7	--	--	--	--
P: pF	0.37	0.31	0.23	0.002	0.001	0.93	0.27	0.19	0.39	0.003	0.05	0.38
LSD_{05}	--	--	--	0.04	0.03	--	--	--	--	0.5	0.4	--
NxP: pF	0.36	0.98	0.87	0.38	0.41	0.98	0.22	0.43	0.70	0.35	0.51	0.63
LSD_{05}	--	--	--	--	--	--	--	--	--	--	--	--

* Nutrient content in needles on uniform 3-inch twigs from current year's growth in upper one-third of crowns of sample trees.
† pF: Probability of statistical significance for analysis of variance F test.
‡ $LSD_{.05}$: Least significant difference at 5% probability level for comparing differences between treatment means.

TABLE 4.—Effects of Nitrogen and Phosphorus Fertilization on Soil pH and Soil Phosphorus on Alexandria Silt Loam at the Licking County Experimental Site.

Fertilizer Level	Soil pH			Soils Phosphorus		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
lb/acre				lb/acre		
Nitrogen						
0	5.1	5.0	5.1	16	17	13
50	4.8	5.2	5.1	19	20	16
100	5.0	4.9	4.9	18	17	14
Phosphorus						
0	5.1	5.1	5.0	14	13	9
225	4.8	4.8	5.1	17	18	15
450	5.0	5.1	4.9	21	22	20
N: pF*	0.30	0.51	0.49	0.09	0.15	0.53
LSD_{05}†	--	--	--	--	--	--
P: pF	0.57	0.63	0.86	0.001	0.007	0.003
LSD_{05}	--	--	--	2	4	5
NxP: pF	0.62	0.85	0.36	0.81	0.40	0.17
LSD_{05}	--	--	--	--	--	--

* pF: Probability of statistical significance for analysis of variance F test.

† LSD_{05}: Least significant difference at 5% probability level for comparing differences between treatment means.

Soil Chemical Properties. Some soil chemical properties were also affected by fertilization. Although some studies have found that soil pH may decrease with additions of N fertilizers, no such effect was noted in this study, possibly because N was applied only once at relatively low rates. Similarly, pH was not affected by P additions (Table 4).

Soil P levels were significantly affected by additions of P but not by N fertilizers (Table 4). Soil P was significantly higher after one, two, and three growing seasons on plots receiving 225 or 450 lb of P per acre, with levels on plots fertilized with 450 lb being significantly higher than on those receiving 225 lb.

Relationships Between Needle Weights and Foliar and Soil Nutrient Levels. Comparisons between weights and nitrogen levels in needles of 3-inch long shoots showed erratic results when comparisons were made for individual sample years. However, when data were combined for all 3 years, needle weights were significantly correlated ($r = 0.71$) with N concentration (percent by weight). Linear regression analysis showed that needle weight increased by approximately 0.1 gram for each 0.1% increase in N (Figure 1). As would be expected, there was a much closer correlation ($r = 0.91$) between needle weight and nitrogen content (weight of needles x percent N) of sample pieces, with needle weight increasing by about 0.05 gram for each 1.0 milligram increase in the weight of N (Figure 2).

No significant relationships were found between needle weights and P contents of needles or soil pH or soil P.

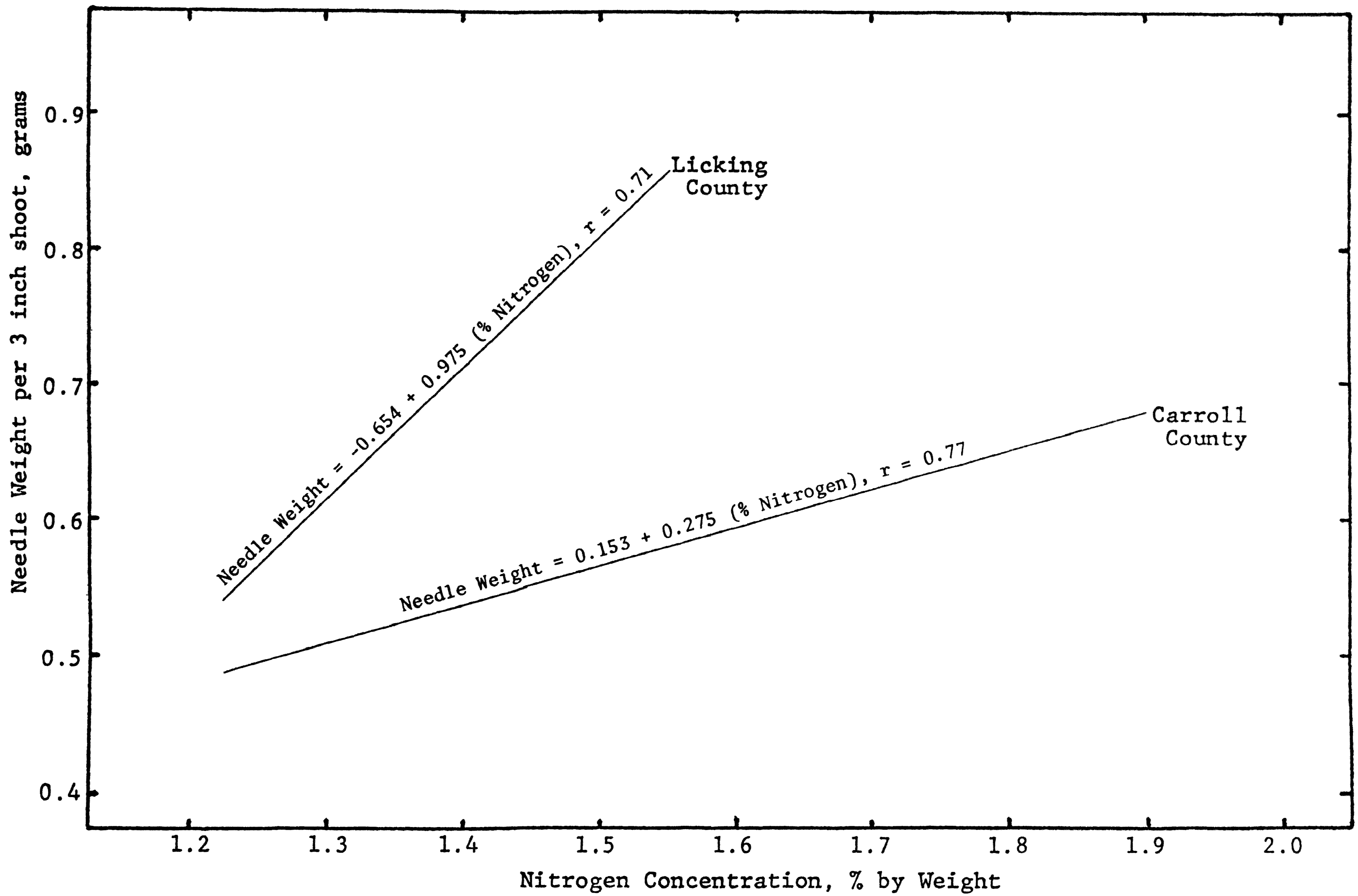

FIG. 1.—Relationship between needle weight and nitrogen concentration in needles of 3-inch shoot samples at the Carroll and Licking County experimental sites.

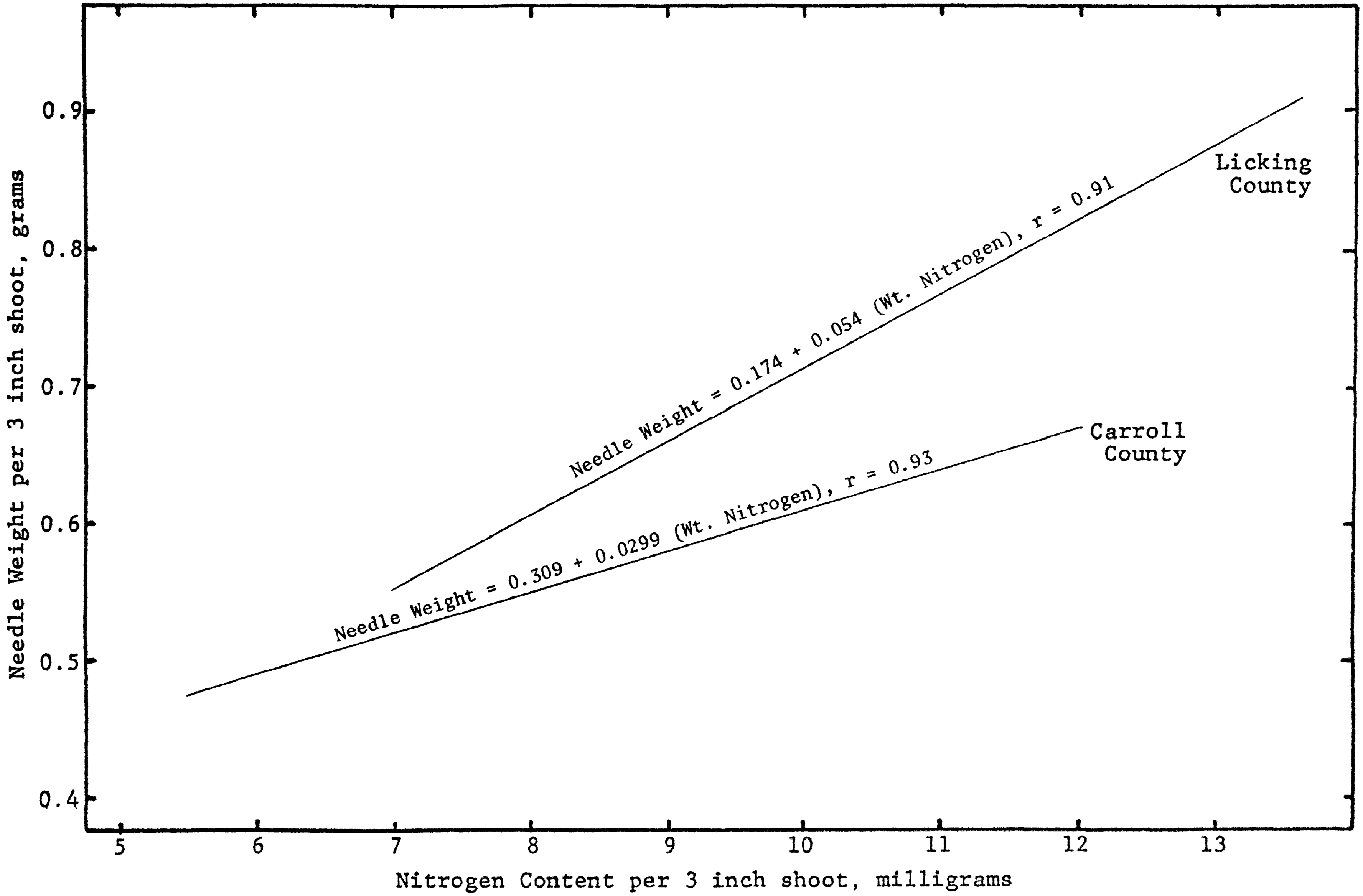

FIG. 2.—Relationship between needle weight and nitrogen content of needles of 3-inch shoot samples at the Carroll and Licking County experimental sites.

Study 2, Carroll County Site

Foliage Quality. Fertilization significantly affected foliage quality of established Douglas-fir at the Carroll County site, with all effects attributable to additions of nitrogen.

At the end of the first growing season, needle lengths of trees receiving 150 and 225 lb of N per acre were more than 10% longer than those fertilized at the 0 or 75 lb rates. After 2 years, needles of trees fertilized at 150 and 225 lb per acre were still significantly longer than unfertilized trees (17%), while those fertilized with 75 lb were slightly (7%) but not significantly longer (Table 5).

Weights of 3-inch shoots were also significantly increased by N fertilization. At the end of the first growing season, weights of shoots fertilized at the 150 and 225 lb per acre rates of N were more than 12% heavier than those receiving the 0 or 75 lb rates; after 2 years they were 5 to 9% heavier. After 3 years, differences in weights of shoot samples between unfertilized and fertilized trees were even greater: approximately 14% for those receiving 150 lb of N and 16% on trees fertilized at the 225 lb rate (Table 5).

Foliage color was also improved significantly. Qualitative estimates made in December of the first year after trees were fertilized indicated that needle color had improved from between the "very chlorotic" to "chlorotic" range to near the "green" rating for trees fertilized with 150 and 225 lb of N per acre (Table 5).

TABLE 5.—Effects of Nitrogen and Lime Fertilization on Growth and Foliage Color of Douglas-fir on Gilpin Silt Loam at the Carroll County Experimental Site.

Fertilizer Level	Needle Length		Average Foliage Weight*			Foliage Color
	1st Year	2nd Year	1st Year	2nd Year	3rd Year	1st Year
lb/acre	mm		gms/piece			Rating†
Nitrogen						
0	28	29	0.83	0.86	0.87	1.8
75	28	31	0.83	0.88	0.90	2.1
150	32	34	0.93	0.92	0.99	2.6
225	31	34	0.94	0.94	1.01	2.7
Lime						
0	30	32	0.89	0.90	0.93	2.3
6,000	29	34	0.88	0.89	0.94	2.5
12,000	30	31	0.88	0.92	0.95	2.4
N: pF‡	0.02	0.04	0.001	0.01	0.01	0.01
LSD_{05}**	1.5	2.3	0.05	0.04	0.05	0.42
Lime: pF	0.14	0.17	0.81	0.21	0.65	0.67
LSD_{05}	--	--	--	--	--	--
NxL: pF	0.84	0.75	0.67	0.64	0.85	0.77
LSD_{05}	--	--	--	--	--	--

* Average foliage weight of uniform 3-inch twigs (needles and stems) for current year's growth in upper one-third of crowns of sample trees.

† Visual rating of color: 1=very chlorotic; 2=chlorotic; 3=green; 4=dark green.

‡ pF: Probability of statistical significance for analysis of variance F test.

** LSD_{05}: Least significant difference at 5% probability level for comparing differences between treatment means.

Nutrient Levels in Foliage. Nutrient concentrations (percent by weight) of N, P, and Ca in needles of trees were significantly affected by fertilization (Table 6). Average N concentration ranged from 1.28 to 1.83%. At the end of the first growing season, levels in needles generally became progressively higher as nitrogen fertilization rates increased from 0 to 225 lb per acre (Table 6). After 2 and 3 years, N concentrations generally decreased, with no significant differences associated with N fertilization. N concentrations of needles were not affected by lime treatments.

Average P concentrations in needles ranged from 0.25 to 0.36%, with levels at the end of the first growing season being significantly lower in trees fertilized at all rates of N than in trees which had received no N (Table 6). After 2 years, concentrations of P were still significantly lower in trees fertilized with 150 and 225 lb of N per acre. Those decreases were apparently dilution

TABLE 6.—Effects of Nitrogen and Lime Fertilization on Nutrient Concentration in Needles of Douglas-fir on Gilpin Silt Loam at the Carroll County Experimental Site.

Fertilizer Level	Nitrogen			Calcium			Phosphorus		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
lb/acre	% by weight								
Nitrogen									
0	1.50	1.40	1.32	0.75	0.79	0.86	0.31	0.35	0.28
75	1.60	1.44	1.28	0.78	0.79	0.81	0.28	0.36	0.25
150	1.67	1.38	1.30	0.73	0.77	0.78	0.27	0.30	0.26
225	1.83	1.42	1.31	0.69	0.77	0.83	0.26	0.30	0.25
Lime									
0	1.67	1.43	1.30	0.74	0.79	0.83	0.28	0.34	0.27
6,000	1.65	1.40	1.32	0.73	0.77	0.83	0.29	0.32	0.26
12,000	1.63	1.41	1.29	0.74	0.78	0.80	0.26	0.32	0.26
N: pF*	0.01	0.11	0.30	0.05	0.94	0.31	0.01	0.01	0.26
LSD_{05}†	0.08	--	--	0.06	--	--	0.02	0.03	--
Lime: pF	0.23	0.39	0.53	0.93	0.89	0.88	0.10	0.23	0.12
LSD_{05}	--	--	--	--	--	--	--	--	--
NxL: pF	0.82	0.78	0.33	0.33	0.95	0.35	0.34	0.78	0.75
LSD_{05}	--	--	--	--	--	--	--	--	--

* pF: Probability of statistical significance for analysis of variance F test.
† LSD_{05}: Least significant difference at 5% probability level for comparing differences between treatment means.

TABLE 7.—Effects of Nitrogen and Lime Fertilization on Nutrient Content in Needles of Douglas-fir on Gilpin Silt Loam at the Carroll County Experimental Site.

Fertilizer Level	Nitrogen			Calcium			Phosphorus		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
lb/acre	weight, mg/piece*								
Nitrogen									
0	8.8	6.8	6.4	4.4	3.8	4.2	1.8	1.7	1.3
75	9.4	7.4	6.4	4.6	4.0	4.1	1.7	1.8	1.3
150	10.8	7.3	7.3	4.7	4.1	4.4	1.7	1.6	1.5
225	11.7	7.6	7.3	4.4	4.1	4.6	1.7	1.6	1.4
Lime									
0	10.2	7.3	6.7	4.5	4.0	4.2	1.8	1.7	1.4
6,000	10.2	7.2	7.0	4.5	3.9	4.4	1.8	1.7	1.4
12,000	10.2	7.4	6.9	4.6	4.1	4.3	1.6	1.7	1.4
N: pF†	0.01	0.01	0.01	0.55	0.52	0.19	0.12	0.07	0.09
LSD_{05}‡	0.70	0.50	0.50	--	--	--	--	--	--
Lime: pF	0.97	0.56	0.28	0.86	0.62	0.76	0.28	0.51	0.91
LSD_{05}	--	--	--	--	--	--	--	--	--
NxL: pF	0.67	0.68	0.67	0.18	0.72	0.70	0.73	0.14	0.51
LSD_{05}	--	--	--	--	--	--	--	--	--

* Nutrient content in needles of uniform 3-inch sample shoots from current year's growth in the upper one-third of crowns of sample trees.
† pF: Probability of statistical significance for analysis of variance F test.
‡ LSD_{05}: Least significant difference at 5% probability level for comparing differences between treatment means.

TABLE 8.—Effects of Nitrogen and Lime Fertilization on Exchangeable Ammonium Nitrogen, Lime Test Index (LTI), pH, and Calcium in Gilpin Silt Loam Soil at the Carroll County Experimental Site.

Fertilizer Level	Exchangeable NH_4 Nitrogen			Lime Test Index*			pH			Calcium		
	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year	1st Year	2nd Year	3rd Year
lb/acre	ppm									lb/acre		
Nitrogen												
0	5.7	1.3	2.5	60.1	60.7	62.3	4.83	4.90	4.94	466	453	461
75	6.8	1.1	2.5	59.9	60.1	61.2	4.80	4.86	4.86	535	443	518
150	7.8	1.0	2.8	59.6	60.7	61.8	4.88	4.90	4.98	502	450	579
225	7.8	1.7	2.6	60.6	60.7	61.7	4.85	4.89	4.85	485	497	572
Lime												
0	7.4	0.9	2.6	59.7	60.4	60.5	4.76	4.84	4.84	484	463	514
6,000	6.6	1.1	2.7	60.3	60.4	62.2	4.80	4.90	4.95	484	459	517
12,000	7.1	1.8	2.6	60.2	60.8	62.6	4.96	4.92	4.94	524	462	642
N: pF†	0.05	0.58	0.52	0.31	0.61	0.20	0.34	0.79	0.16	0.36	0.75	0 79
LSD_{05}‡	1.1	--	--	--	--	--	--	--	--	--	--	--
Lime: pF	0.78	0.06	0.50	0.07	0.09	0.22	0.01	0.21	0.13	0.50	0.99	0 12
LSD_{05}	--	--	--	--	--	--	0.06	--	--	--	--	--
NxL: pF	0.99	0.48	0.62	0.37	0.57	0.08	0.10	0.16	0.56	0.06	0.37	0 36
LSD_{05}	--	--	--	--	--	--	--	--	--	--	--	--

* Lime Test Index (LTI): Measure of total soil acidity and an index of lime required to raise pH to specified levels.
† pF: Probability of statistical significance for analysis of variance F test.
‡ LSD_{05}: Least significant difference at 5% probability level for comparing differences between treatment means.

effects associated with increased shoot weights of trees fertilized with N, because there were no significant differences in P content (weight per sample) as shown in Table 7. Concentrations of P in needles were not significantly affected by lime applications.

Average calcium levels in foliage ranged from 0.69 to 0.86%, with generally lower levels at the end of the first growing season in trees fertilized with 150 and 225 lb of N per acre (Table 6). Again, this was apparently a dilution effect associated with increased growth because there were no significant differences in weights of Ca in needles due to N treatments (Table 7). There were no significant differences in Ca concentrations in needles due to lime applications (Table 6).

Weights of N in needles were significantly affected by N fertilization but not by liming (Table 7). At the end of the first year, N content (weight per piece) became progressively higher with increasing additions of N fertilizers. In succeeding years, N content of needles generally declined; however, after 2 years, it was still significantly higher in fertilized than in unfertilized trees, while after 3 years N content was significantly higher only in trees fertilized with 150 or 225 lb of N per acre. There were no significant differences in weights of P (not shown in table) or Ca in needle samples associated with either N or lime applications (Table 7)

Soil Chemical Properties. Of the soil chemical properties analyzed over the 3-year study period, only two were significantly affected (5% probability level) by fertilization treatments (Table 8). At the end of the first growing season, exchangeable ammonium N (NH_4-N) in soil averaged approximately 7 ppm, with values nearly 20% higher on plots fertilized with 75 lb of N per acre than on control plots and over 35% higher on those receiving 150 or 225 lb of N. At the end of the second and third years, NH_4-N levels were considerably lower (approximately 1 to 3 ppm). Although there were no significant differences (5% level) in those years, NH_4-N levels in the second year did become progressively higher as lime levels increased (pF = 0.06). This was probably not related directly to N applications (pF for N x lime = 0.48) but rather to increased mineralization of organic N by soil organisms in soils with higher lime applications (Table 8).

Soil phosphorus levels on study plots (not shown in tables) were generally adequate, averaging 30 to 40 lb of P per acre, and levels were not significantly affected by either N or lime fertilizer applications.

Of the three soil properties analyzed which were most likely to be affected by lime applications, only pH at the end of the first year showed significant increases due to lime treatments (Table 8). Values ranged from pH 4.76 on control plots to 4.96 on plots fertilized with 6 tons of lime per acre. In succeeding years, pH generally increased slightly but treatment differences were not significant.

Lime Test Index (LTI) also showed some increases in the second and third years, but without statistically significant differences. Soil calcium values, which ranged from approximately 450 to 570 lb per acre, also showed some response to lime applications but again differences were not statistically significant (Table 8).

Relationships Between Needle Weights and Foliar and Soil Nutrient Analyses. As noted for the Licking County site, comparisons between weights and nitrogen levels in needles of foliage samples showed irregular results when comparisons were made for three individual sample years. When data were combined, however, needle weights were significantly correlated with both N concentration (r = 0.77) and N content (r = 0.93) of needles. Linear regression analyses showed that needle weights increased by approximately 0.03 gram for each 0.1% or 1 milligram increase in needle N (Figures 1 and 2). Both values were considerably lower than those noted at the Licking County site.

No other significant relationships were found between weights of needles and calcium levels in foliage or soil levels of NH_4-N, LTI, pH, or Ca.

DISCUSSION AND RECOMMENDATIONS

Established Douglas-fir at both experimental sites showed significant improvements in foliage quality in response to nitrogen fertilization. However, there was considerable variation in the magnitude and duration of response at the two areas. At the Licking County site, where a maximum of 100 lb of N per acre was used, greatest increases in both needle lengths and shoot weights occurred the first growing season after fertilization, with significant but lower increases in the second and third years. At the Carroll County site, where up to 225 lb of N per acre were used, beneficial effects of N fertilization were more pronounced, with maximum increases measured in the second (for needle lengths) or third (for shoot weights) years after treatment.

Lowest N concentrations (percent by weight) in needles were just under 1.3% at both sites and in both instances occurred in samples collected 3 years after fertilization (Tables 3 and 6). Although maximum N concentrations at both sites occurred in needles collected after the first growing season, values were considerably different: 1.55% for trees fertilized with 100 lb of N at the Licking County area and 1.83% for trees receiving 225 lb of N at the Carroll County site. This range in values is similar to that reported for Douglas-fir Christmas tree stands in Washington fertilized with 0.125 to 1.0 lb of N per tree (9). For young natural stands in Washington and Oregon fertilized with N, percent N in needles ranged from less than 1% to approximately 2.3% for trees fertilized with up to 450 lb of N per acre (3, 4).

At both experimental areas, there were significant linear relationships between weights of needles of shoot samples and concentrations (percent by weight) and contents (weight per sample) of N in needles. However, increases in needle weights per unit increase in concentration or weight of N were considerably greater at the Licking than at the Carroll County site (Figures 1 and 2). This may have been related to differences in weed control methods. At the Licking County area, mowing was used in combination with chemical weed control in 3- to 4-foot wide bands along rows of trees.

At the Carroll County site, only mowing was used, and it is probable that despite higher applications of N fertilizers, rate of increase in weights of needles (and other plant parts) was not as high because of greater competition for moisture.

Leyton (6) notes that growth and mineral concentrations in plants are positively and linearly correlated only within the deficiency range of nutrients and that there is a positive response only below some "critical percentage." Lavender (5) found the critical percentage for N in needles of greenhouse-grown Douglas-fir to be approximately 2.5%, well above the maximums found in the two studies reported here. He also found that Douglas-fir fertilized in the field still showed a positive, although declining, response to N additions as high as 450 lb per acre. This may indicate that higher rates of N fertilizers than those used could have given even greater improvements in foliage quality of trees at the Licking and Carroll County sites. One indication of this is that although needle color was improved considerably on trees receiving highest rates of N, ratings were still slightly below the "green" level (Tables 2 and 5).

Failure of liming to improve foliage quality on the Gilpin silt loam in Carroll County could have resulted from absence of soil changes or from lack of measurable tree response to soil changes. In this research, liming did not affect calcium concentration or content in Douglas-fir needles, nor did it appreciably affect soil pH, LTI, or exchangeable Ca. In Washington, thorough mixing of $CaCO_3$ with soil did increase soil pH, exchangeable Ca, and base saturation, and it also increased Ca concentrations in Douglas-fir needles (4). From this we conclude that the surface applications used in Ohio were ineffective during the first 3 years after application. The Agronomy Guide (8) indicates that pH of soils with LTI values of 60, such as those found at the Carroll County site, should be increased to approximately pH 5.5 by addition of 6 tons of lime per acre. However, research in Ohio (7) has shown that when lime is applied to the surface it may take several years for the material to be incorporated into the soil and to appreciably change soil levels. The nearly significant ($pF = 0.06$) interaction between calcium and nitrogen fertilization on soil Ca and the increase in exchangeable ammonium in the second year after liming suggest directions for future research.

In contrast to liming, P fertilization clearly increased both available P in the soil and P concentration and content of Douglas-fir needles on Alexandria silt loam at the Licking County site. However, these changes in P nutrition did not lead to improvements in the measures of foliage quality used, and marked benefits to Douglas-fir from P fertilization on Alexandria silt loam and other similar soils having comparable fertility cannot be predicted.

Intensive cropping for Christmas trees will deplete soil fertility eventually, so periodic applications of fertilizers to replace nutrients removed might be good insurance for a grower, even in the absence of discernible tree response. This could be especially important where growers are digging trees in plantations. The authors believe, however, that on Gilpin, Alexandria, and similar well-drained soils, with effective weed control, quality of chlorotic Douglas-fir will be improved most by practices that raise nitrogen concentrations in current year's needles (sampled in October) to 1.8% or above. This research shows that fertilization with urea is one such practice. Additional research is also underway, including repeated applications of different rates of N fertilizers and use of nitrogen-fixing legumes as a source of N in plantings.

Based on results from the two studies reported here, the following recommendations are made for fertilizing established Douglas-fir plantations on Alexandria, Gilpin, and similar soils which have physical characteristics suitable for growth but where trees show visual nutrient deficiencies:

- Foliage quality can be improved by applications of N fertilizers. Rates of at least 150 to 225 lb of N per acre are recommended. Although not tested in these studies, applications in 3- to 4-foot wide bands along rows of trees at recommended rates should be as effective as applications to the entire area. This would reduce the amount of fertilizer needed; *i.e.,* for 3-foot bands applied in plantings with 6-foot spacing between rows, only half as much fertilizer would be needed per acre of plantation. In addition, band applications would not stimulate weed growth between rows as much.
- N applications should be made 2 or 3 years prior to harvest rather than during the year of harvest. This will improve not only the outer foliage but also needles on the immediately older growth which are also visible on harvested trees.
- Effectiveness of N fertilization (and other elements as well) will be greatly improved by effective weed control, probably through use of herbicides.
- To be effective within a reasonable length of time, P and lime additions should be worked into the soil before trees are planted. However, potential benefits from those additions are not certain.

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