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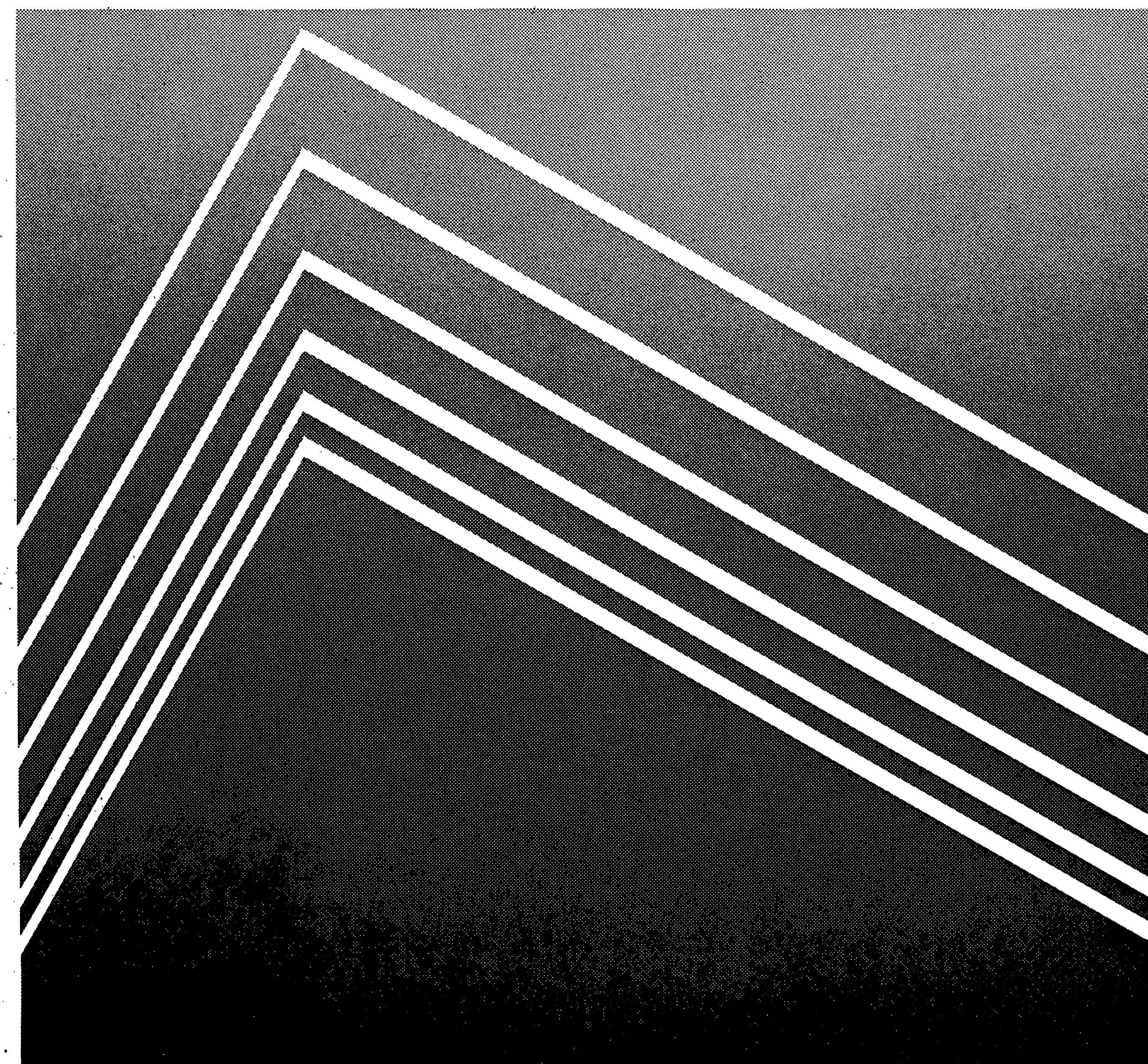

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Fertilization of poor site black spruce on organic soil with various rates of nitrogen and phosphorus increased height and diameter growth from 2 to 4 times. The growth response declined with time but was still apparent 16 years after fertilization. Shrub biomass and coverage, and nutrient levels of spruce foliage were strongly affected by fertilization.

KEY WORDS: foliar nutrients, nitrogen, *Picea mariana,* phosphorus, shrubs.

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FERTILIZATION OF BLACK SPRUCE ON POOR SITE PEATLAND IN MINNESOTA

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As population pressures force forestry to the poorer sites, organic soils will become more important for forestry purposes in the United States. In northern Europe, Scandinavia, and Great Britian a significant portion of trees are already grown on organic soils (Holopainen 1967). These soils are often fertilized to increase forest growth, and in some cases, to convert nonproductive to productive forests (Heikurainen 1967, Baule and Fricker 1970).

On organic soils low levels of phosphorus (P) and potassium (K) most often limit growth, but levels of nitrogen (N) frequently are also low, particularly on low pH soils (Huikari 1973). It is not uncommon for two or more elements to be deficient on organic soils (Heikurainen 1967, O'Hare 1967), and drainage in combination with fertilization can result in significant growth increases (Braekke 1977).

Black spruce (*Picea mariana* (Mill.) B.S.P.) growth has been enhanced by fertilization on both organic soils (Haveraaen 1967, Watt 1966) and mineral soils (Weetman 1975, Van Nostrand 1979). The current study reports on the long term growth and nutrient response of black spruce and understory species to fertilization.

THE STUDY AREA

The two stands we studied are located in northern Minnesota (48° 22′N, 93° 46′W) about 24 km north of the town of Big Falls and were previously described by Watt (1966). They are separated by about 1.2 km and have nearly identical vegetation dominated by uneven-aged black spruce (mean age prior to treatment of 80 years but ranging up to 135 years). The site index is poor (only 4.6 m at age 50), and the stands are noncommercial. The ground is almost completely covered with sphagnum moss, and the predominant shrubs are *Ledum groenlandicum* Oeder (Labrador-tea) and *Chamaedaphne calyculata* (L.) *Moench* (leather-leaf) with lesser numbers of *Andromeda glaucophylla* Link. (bog-rosemary), *Kalmia polifolia* Wang (swamp laurel), and *Vaccinium oxycoccos* L. (small cranberry).

The vegetation is similar to that classified as the sphagnum-black spruce-leatherleaf community by Heinselman (1963). This community type typically has a convex land surface and occupies the central part of large peatlands where it is isolated from mineral soils and water tracks.

The study area is a nearly level lacustrine plain. The soils are woody peats about 150 cm thick over loamy mineral soil and are classified as the Moose lake series (*Typic Borohemists*), (Soil Survey Staff 1975). The bulk density of the peat ranges from 0.06 to 0.12 g/cc and the pH ranges from 3.2 (in 0.01M $CaCl_2$) near the surface to about 4.9 near the interface between peat and mineral soil.

In 1973 when the first mensurational measurements other than height growth were made, the trees on the control plots had the following characteristics: 3,980 trees/ha, mean d.b.h. 5.3 cm, mean height 4.4 m, and stand basal area 8.8 m^2/ha. The largest trees on the control plots were about 9 m tall and 12 cm d.b.h. Tree and stand characteristics a decade earlier (prior to fertilization) would not be a great deal different because of the extremely slow growth and low mortality.

METHODS

Plots of 0.04 ha with 3 m buffer strips were laid out and fertilized by hand during the growing season in two separate trials (table 1). The major objective of trial 1 was to determine if the trees would respond to N or P, which had been shown by foliar analysis to be the elements limiting growth (Watt and Heinselman 1965). There were 12 plots in trial 1—3 were used as controls, 3 received only N, 3 received only P, and 3 received both N and P. The plots were fertilized equally in 1962 and 1963 with ammonium nitrate and treble superphosphate. The major objective in trial 2 was to determine the optimum rate of N and P fertilization. The 24 plots in this trial were fertilized in 1964 with various rates of diammonium phosphate, phosphoric acid, and ammonium sulfate.

In October of the year of fertilization and for the next 4 or 5 years height growth of 10 sample trees on each 0.04 ha plot was measured to the nearest cm. Thereafter height growth was measured every other year until 1973, and a final measurement was taken (for trial 1 only) in March of 1980. Each time height growth was measured, about 2 grams of current-year foliage was collected from three additional trees per plot and used for physical measurements and chemical analysis.

In 1973, 36 trees (trial 1) and 48 trees (trial 2) representing the full range of heights and diameters were felled and 2 cm discs at b.h. were cut to determine age and diameter increment by 5-year intervals for the last 20 years. The current year's diameter growth was also measured but because of the very small increments, large errors are involved in this measurement.

Table 1.—*Fertilizer rates*[1]

Treatment	Plots	Nutrient added N	Nutrient added P
TRIAL 1			
	no.	kg/ha	kg/ha
Control	3	0	0
NP	3	672	294
N	3	672	0
P	3	0	294
TRIAL 2			
Control	6	0	0
$P_1 N_1$	3	56	49
$P_1 N_2$	3	112	49
$P_1 N_3$	3	336	49
$P_2 N_1$	3	56	122
$P_2 N_2$	3	112	122
$P_2 N_3$	3	336	122

[1]Trial 1 fertilized equally in 1962 and 1963 with ammonium nitrate and treble superphosphate; trial 2 fertilized in 1964 with diammonium phosphate, phosphoric acid, and ammonium sulfate.

In 1964 three and in 1973 four 1-m^2 subplots were established on each 0.04 ha plot on trial 1. Each understory shrub species was identified and its coverage estimated. All above-ground portions of the shrubs were clipped to determine oven-dry weight and nutrient content. On each understory plot, live and dead sphagnum coverage was estimated and a sample of sphagnum moss was collected for nutrient analysis.

All vegetation samples were dried at 75 C to determine oven-dry weight. Chemical analysis was by emission spectroscopy for P, Ca, Mg, K, Fe, Mn, Cu, Zn, and B. Nitrogen was digested by the Kjeldahl method followed either by titration or specific ion determination with an ammonia electrode. Foliage samples collected in 1980 were analyzed for metals by atomic absorption spectroscopy and N as before.

Statistical comparisons were by Duncan's new multiple range test and significance testing was all at the 5 percent level.

RESULTS AND DISCUSSION

Height Growth

Height growth responded rapidly and dramatically to fertilization on both trials (figs. 1 and 2). Maximum height growth response occurred in the first or second year following fertilization at which time the height growth for the maximum treatment in trial 1 (NP) was three times the control and in trial 2 was 2½ times the control. (The two P levels in trial 2 resulted in no significant differences—hence they are combined for all analyses.) In 1973, the NP and PN_3 treatments still had height growth rates two to three times greater than the controls and in 1980 the NP treatment of trial 1 shows little evidence of slow down in height growth.

Fertilization with N or P alone resulted in an initial height growth response about ½ as large as for the NP treatment but still significantly greater than the control (fig. 1). Within a few years the height growth of the N and P treatments fell to levels no different from the control and for N this low level of growth has continued up to the last measurement period. Initially, height growth surged in the P-treated plots, then it declined, and then steadily increased. By 1979, height growth on the NP and P plots do not significantly differ (fig. 1). Obviously, N availability increases slowly over a long time on the plots fertilized with P only. In the current study the long term increase in height growth on the P-treated plots is probably due to movement of N

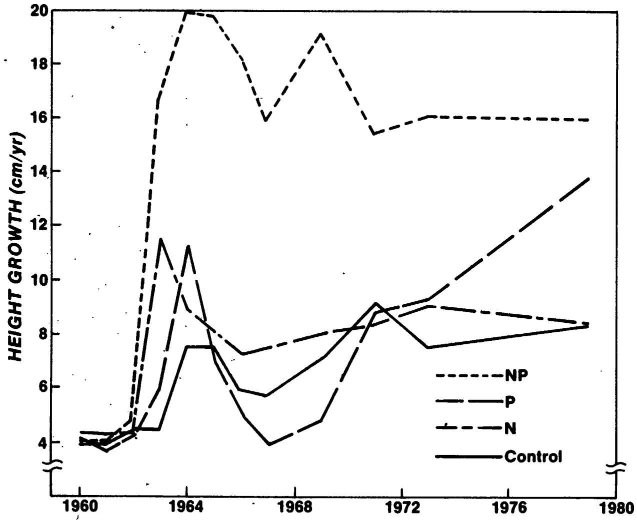

Figure 1.—*Black spruce height growth response to fertilization with nitrogen (N) and phosphorus (P)—trial 1.*

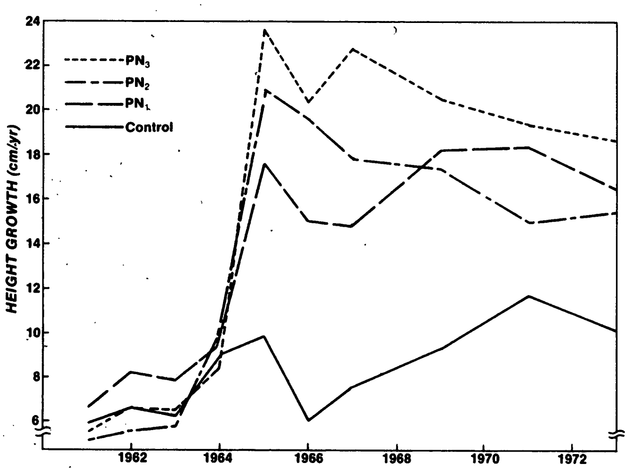

Figure 2.—*Black spruce height growth response to fertilization with nitrogen (N) and phosphorus (P)—trial 2.*

between the plots. By chance, every P plot was downslope from either a N or a NP plot. Thus, it is likely that N moved in the soil water and "contaminated" the P plots resulting in accelerated growth. Other possible sources of N increase on the P-only plots include increased N fixation or increased peat decomposition due to P addition. We have no measurements on these effects but it seems likely that each would be maximum soon after fertilization and decline thereafter. Thus these effects could play a role in the initial height growth increase on the P only plots but are probably not involved in the long-term height growth increase.

The initial height growth response of the P plots was 1 year later than the N or NP plots which again suggests movement of N across plot boundaries. One of the control plots was also immediately downslope from a NP plot and this control plot behaved similarly to the P plots, i.e., a 1 year delay in response and the magnitude of the initial Presponse was similar to that of the N or P plots. Because of its obvious contamination, we excluded this control plot from the analysis.

In trial 2 the initial response to N was directly related to the amount applied (fig. 2), although the differences between rates were less striking than between any of the rates and the controls. Part of the reason for the small differences between rates may be leakage between plots as was found in the P plots in trial 1. At the end of 9 years all three rates of N resulted in height growth still significantly greater than the controls.

For both trials we planned to use the control plots to show annual variations in height growth due to climatic factors. However, this effect may be masked by the nutrient leakage from plot to plot. In both trials height growth in the controls increased slightly shortly after fertilization followed by a decrease and then by a gradual increase. Part of this change may be climate related but most is probably due to contamination of the control plots from the fertilizer plots. Therefore, the height growth of the controls is greater than that of bonafide controls and the growth differential reported here between fertilizer and control plots is conservative.

The height of sample trees prior to fertilization was significantly related to annual height growth for the 3 years prior to fertilization. This relation was weakened by fertilization with N and P combined—the greater the amount of fertilizer applied, the poorer the relation. For the heaviest fertilizer treatment (NP trial 1) the height growth for any of the years 1963 through 1979 was not significantly related to height before fertilization. For lower levels of fertilization the relation was nonsignificant for the first few years following fertilization but became significant as the fertilizer effects began to lessen. With heavy fertilizer rates, all tree sizes responded equally (the longest single year's leader growth—49 cm—occurred on the NP treatment plot on a tree whose height before fertilization was only 2 m). With low fertilizer rates, height growth of the taller trees responded somewhat better than that of smaller trees.

Tree height and age were closely related ($r = 0.70$ trial 1, 0.79 trial 2), thus the height growth response was related to age in a manner similar to that for initial tree height. That is, heavy fertilization resulted in a height growth response that was not closely related to age. Young trees (about 40 years) responded as well as older trees (about 80 years). Therefore, fertilizers probably could have been used to increase growth at a much earlier age. With lower fertilizer rates or with time the height growth response of the older trees became larger than that of the younger trees.

Diameter Growth

Diameter growth on trial 1 was increased markedly by NP fertilization but no significant response occurred for N or P alone (fig. 3). Diameter growth on the NP plot was three times that of the controls during the first 5 years following fertilization. Thereafter it declined but even 10 years after fertilization the diameter growth of the NP plot was significantly greater than the controls. On trial 2 the maximum diameter growth response was somewhat less and the decline after the first 5 years was more rapid (fig. 4). Both PN_3 and PN_2 treatments resulted in diameter growth significantly greater than the controls for the first 5 years following fertilization, but only PN_3 was still significantly greater than the control after 9 years. Nine years after fertilization none of the fertilized treatments resulted in growth different from the controls (fig. 4). PN_2 had lower diameter growth than PN_1 prior to fertilization and a stronger response after the treatment. Both return to pretreatment levels by 9 years, however. It is clear that the maximum diameter growth response and its duration are directly related to the amount of N applied, increasing in the order PN_1, PN_2, PN_3 (trial 2) up to NP (trial 1). But the response to N only occurred when P was added also. Height growth followed a similar pattern but the duration of its response was longer.

Diameter growth of the control plots and all other plots prior to fertilization was directly related to d.b.h., but after fertilization such a relation no longer existed. Average diameter growth for 5 years after NP fertilization (trial 1) was 1.55 mm/yr irrespective of tree d.b.h., and the corresponding value for the PN_3 treatment was 2.00 mm/yr again irrespective of tree d.b.h.

Because basal area and volume are functions of diameter squared, it is obvious that the larger trees are increasing in these properties at a much faster rate than the smaller trees and that the heavily fertilized trees are increasing at rapid rates. For example, using the 1964 average and largest d.b.h.

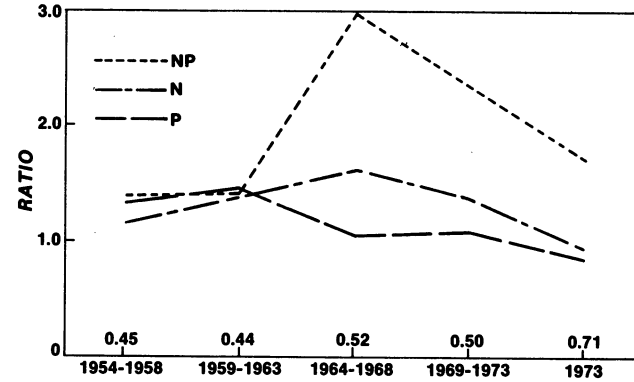

Figure 3.—*Ratio of diameter growth of black spruce on fertilized plots to that on controls (trial 1). The figures above the years are the diameter growth of the controls (mm/yr).*

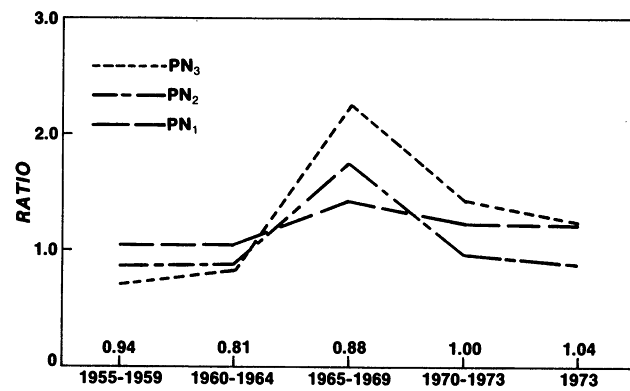

Figure 4.—*Ratio of diameter growth of black spruce on fertilized plots to that on controls (trial 2). The figures above the years are the diameter growth of the controls (mm/yr).*

trees on trial 1, the 5-year volume growth after NP fertilization was 4½ times greater for the largest trees compared with the average trees (table 2).

For both fertilized and unfertilized trees volume growth is much greater for the larger trees than for the smaller. Assuming that the average d.b.h. tree represents average stand growth, volume growth for the first 5 years following maximum fertilization (NP or PN_3) increased 3 times over that of the controls on both trials. During the second 5-year period, height and diameter growth response to fertilization tapered off but because the increased growth is on larger trees, the final result is fertilization increasing volume growth by three and two times over the controls for trials 1 and 2, respectively.

Table 2.—*Five-year growth for average (4.8 cm) and largest (11.0 cm) d.b.h. trees on trial 1*

Treatment	Initial D.b.h.	Five-year growth 1964-1968 D.b.h.	Height	Volume
	cm	cm	m	dm^3
Control	4.8	0.26	0.38	0.7
	11.0	0.41	0.64	5.2
NP Fertilization	4.8	0.78	0.90	2.0
	11.0	0.78	0.90	8.9

Foliar Characteristics

In general, all fertilizer treatments in trial 2 and the NP treatment in trial 1 resulted in increased needle length and weight (table 3). In 1973 (10 and 9 years after fertilization for trials 1 and 2, respectively) foliage weight was still significantly greater than the controls for all plots fertilized with both N and P, and for trial 2 needle lengths were still significantly greater than the controls (table 3). Sixteen years after fertilization the NP treatment of trial 1 still had significantly larger and heavier needles than the controls (table 3). At this time the P-only fertilizer treatment had needles no different in length or weight than the NP treatment and this is probably due to N leakage into the P plots from upslope plots.

It was the relation between site index and foliar concentrations of N and P that initially suggested the possibility of nutritional deficiencies in poor site black spruce stands (Watt and Heinselman 1965). The application of fertilizers resulted in dramatic increases in foliar levels of these nutrients (figs. 5-8). In trial 1 application of NP or N alone significantly increased foliar N levels above those of the controls from 1963 to 1965; from 1966 onward foliar levels of all treatments were not significantly different (fig. 5). Foliar P levels were significantly greater than that of the controls for application of NP or P alone until 1973, but by 1979 only the NP treatment was still significantly greater than the controls (fig. 6).

For trial 2 foliar N level was directly related to rate of N application for the first 2 years following fertilization (fig. 7). In 1965, all three rates of N fertilization resulted in significantly higher N levels in black spruce foliage than the controls; by 1966 only at the two higher rates were foliar levels still above the controls and after that no differences were significant. P levels in the foliage were significantly higher than the controls for all fertilizer treatments from 1965 to 1973 (fig. 8).

Foliar levels of K, Ca, Mg, and Fe in 1973 were not significantly affected by fertilization but foliar levels of Mn, Cu, and Zn were all significantly lower than the controls (table 4). A similar depression of Mn, Cu, and Zn levels in Scotch pine (Pinus sylvestris L.) needles on peatlands was reported after fertilization with NPK (Veijalainen 1977). Addition of macronutrients may stimulate foliage growth and thereby reduce the level of micronutrients by simple dilution. But nutrient interactions may also be involved and high levels of foliar P (as found after fertilization in this study) are commonly associated with low levels of foliar B and Zn (Olsen 1972). Only rarely do micronutrients limit tree growth (Stone 1968) but

Table 3.—*Black spruce foliage characteristics*

Treatment[1]	Needle length 1964	1965	1966	1973	1979	Needle weight 1964	1965	1966	1973	1979
	mm					mg				
TRIAL 1										
Control	7.5	7.0	7.3	6.3	5.4	1.38	1.35	1.32	1.29	1.62
NP	11.1[2]	10.2[2]	9.1[2]	6.8	6.9[2]	1.46	1.81[2]	1.49	1.42[2]	2.09[2]
N	6.8	7.4	6.8	5.9	5.9	1.08	1.51	1.20	1.21	1.71
P	8.3	7.1	6.8	6.5	6.7[2]	1.22	1.02[2]	1.05[2]	1.32	1.92[2]
TRIAL 2										
Control		6.7		6.1		1.54	1.37	1.40		
PN_3		10.7[2]		7.2[2]		2.26[2]	2.08[2]	1.65[2]		
PN_2		9.8[2]		7.1[2]		2.05[2]	1.45	1.65[2]		
PN_1		8.7[2]		7.0[2]		2.04[2]	1.62[2]	1.56[2]		

[1]See table 1 for fertilizer rates.
[2]Indicates values significantly different from the control at the 5 percent level.

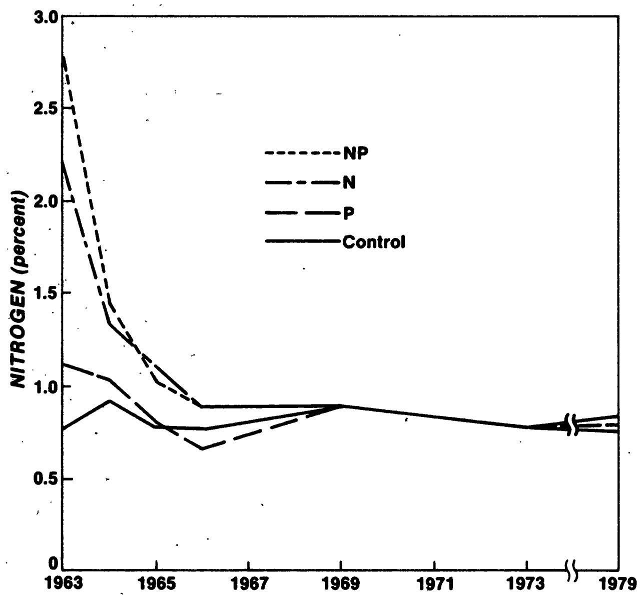

Figure 5.—*Foliar nitrogen concentration of black spruce on trial 1.*

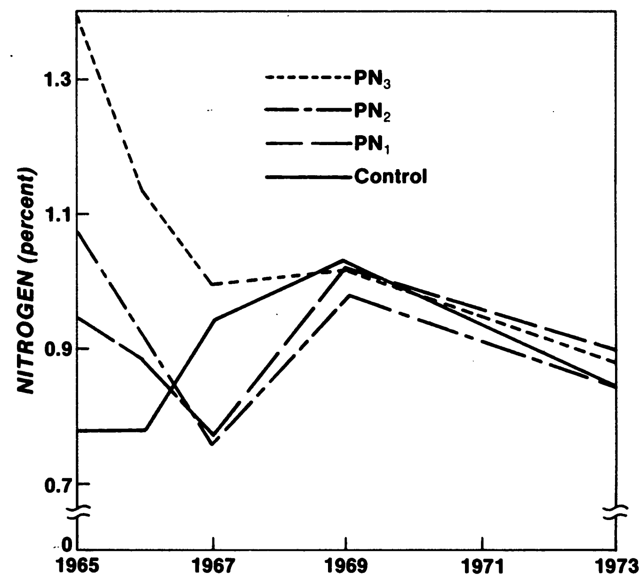

Figure 7.—*Foliar nitrogen concentration of black spruce on trial 2.*

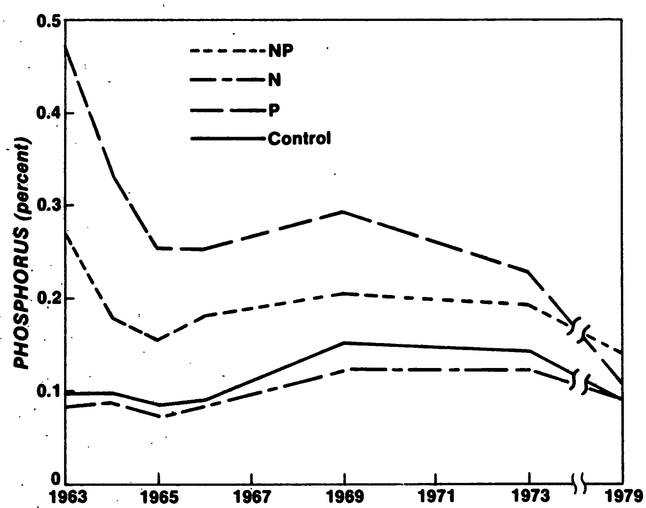

Figure 6.—*Foliar phosphorus concentration of black spruce on trial 1.*

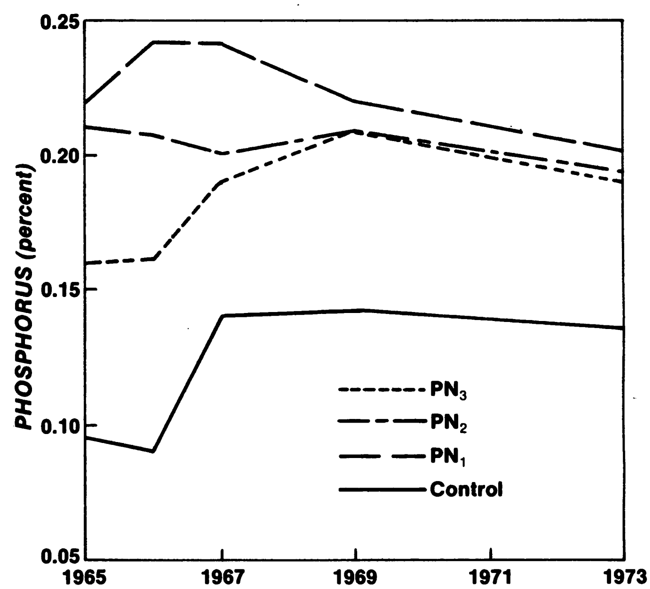

Figure 8.—*Foliar phosphorus concentration of black spruce on trial 2.*

Table 4.—*Black spruce foliage nutrient concentration in 1973*

(In ppm)

	Trial 1		Trial 2	
Element	Control	NP fertilizer treatment	Control	Mean of all fertilizer treatments
N	7,500	7,720	8,380	8,720
P	1,450	1,960[1]	1,350	1,960[1]
K	5,700	5,260	5,070	5,750
Ca	5,390	4,920	4,730	4,820
Mg	932	1,170	1,160	1,350
Fe	43	47	66	70
Mn	1,423	977[1]	1,282	909[1]
Cu	54	45[1]	52	40[1]
Zn	31	22[1]	28	21[1]

[1]Indicates values significantly different from the control at the 5 percent level.

when they do, it will be extremely difficult to diagnose by foliar analysis due to the strong effect macronutrients exert on foliage micronutrient levels (Veijalainen 1977).

For the control plots mean black spruce foliar concentrations (1963-1966) of N and P averaged 0.80 and 0.093 percent, respectively. These values indicate acute deficiency levels for these elements (Swan 1970). The other macronutrients (K, Ca, and Mg) were not measured until 1969 but because they showed no significant changes with time or between treatments, the average values (0.54, 0.51, 0.10) from 1973 (table 3) probably represent prefertilizer levels as well. These values indicate moderate deficiency of Mg but adequate levels of K and Ca (Swan 1970).

The low levels of N and P indicated a likely response to fertilization by these elements. But the accelerated growth due to fertilization has continued long after the foliar N concentrations returned to levels no different from the controls (figs. 5 and 7). Conversely, high foliar levels of P if not accompanied by N fertilization have not resulted in a long term growth response. The only plots showing a long term growth response were those fertilized with both N and P (although for trial 1 the P plots received their N inadvertently through seepage). Obviously, increased growth can continue without commensurate increases in the foliar concentration of the fertilizer element, and increased foliar nutrient levels are not necessarily translated into increased growth.

A major effect of fertilization is often to increase the foliage biomass (Fornes *et al.* 1970, Brix and Ebell 1969). The increased foliage is not only able to photosynthesize more carbohydrates but also contains more N and P which can be translocated to active growing regions of the tree. In the current study total foliage biomass was not measured but the longer, heavier needles suggest the likelihood of increased foliage biomass.

The Understory

Before fertilization live sphagnum moss covered 86 percent of the ground surface of trial 1. One year after fertilization with NP, N, and P live sphagnum covered 66, 39, and 37 percent, respectively. However, by 1973 sphagnum covered an average of 90 percent on all plots.

In trial 1 in 1964 shrub biomass was approximately double that of the controls on the NP and N fertilized plots but was the same as the controls on the P fertilized plots (table 5). By 1973 shrub biomass was still significantly greater on the NP fertilized plot than on the controls but more striking was the coverage response of *Ledum* and *Chamaedaphne*. On the NP and P fertilizer plots *Ledum* coverage was about three times as great as on the controls, while *Chamaedaphne* coverage was reduced to about ⅓ of the controls (table 5). Nitrogen fertilization alone did not significantly change the coverage of these shrub species but appeared to favor *Kalmia*.

Thus not only has NP fertilization significantly increased the shrub biomass, but it has also reversed the relative coverages of *Ledum* and *Chamaedaphne*. Heinselman (1963) found *Chamaedaphne* to be an indicator of black spruce site index because it occurred on the poorest peatlands but never occurred on the better ones. Therefore fertilization with NP has changed the understory species coverage from that indicating poor black spruce site to that indicating good black spruce site.

The chemical composition of the shrub leaves and the sphagnum still showed the effects of fertilization 10 years after treatment (table 6). Fertilization with NP or P resulted in higher levels of macronutrients than in the controls whereas N fertilization resulted in no significant differences from the controls. Levels of K, Ca, and Mg in understory tissue is consistently higher for the NP and P fertilizer treatment than for the controls or the N treatment indicating that the understory may be more responsive to fertilization than black spruce foliage.

Table 5.—*Shrub biomass and coverage, Trial 1*

Treatment[1]	Above-ground shrub biomass		Shrub coverage in 1973		
	1964	1973	Ledum groenlandicum	Chamaedaphne calyculata	Kalmia polifolia
	kg/ha		percent		
Control	153	532	12	38	4
NP	388[2]	841[2]	41[2]	12[2]	3
N	304[2]	698	17	36	9
P	161	790	39[2]	17[2]	3

[1]See table 1 for fertilizer rates.
[2]Indicates values significantly different from the control at the 5 percent level.

Table 6.—*Chemical composition of understory plants on trial 1 in 1973 (1964 values in parentheses)*

(In percent)

Treatment[1]	N	P	K	Ca	Mg	Mn
SPHAGNUM						
Control	0.66(0.88)	0.09(.06)	0.43	0.39	0.08	0.076
NP	.80(1.40)[2]	.13(.30)[2]	.49	.48	.12[2]	.067
N	.66(1.46)	.08(.12)	.37	.35	.09	.067
P	.74(1.30)	.14(.28)[2]	.47	.50	.11[2]	.077
SHRUB LEAVES						
Control	1.13	0.14	0.37	0.58	0.12	0.16
NP	1.32	.17[2]	.42	.68[2]	.20[2]	.11[2]
N	1.24	.14	.37	.58	.13	.14
P	1.22	.18[2]	.40	.70[2]	.18[2]	.12[2]

[1]See table 1 for fertilizer rates.
[2]Indicates values significantly different from control at the 5 percent level.

Mn was the only micronutrient to show a significant change due to fertilization. This occurred in shrub leaves, but it should be realized that the shrub foliage data are confounded because species composition changed on fertilized plots. The lower Mn concentration in shrub foliage after NP or P fertilization agrees with the results from black spruce foliage. But the lower concentration of Mn is also due to the fact that *Chamaedaphne* foliage has much higher Mn concentrations than does *Ledum* (Gerloff *et al.* 1964) and *Chamaedaphne* decreased markedly after fertilization with NP or P. Micronutrient concentrations in the control plots were as follows:

	Micronutrient concentrations: Sphagnum	Micronutrient concentrations: Shrub leaves
	(ppm)	
Fe	521	120
Zn	62	32
Cu	4.4	2.8
B	6.0	20.3

Part of the reason for the long-lasting effect of forest fertilization on tree growth may be because the added nutrients are incorporated into the nutrient cycling regime. Nutrient cycling occurs primarily through the leaf litterfall of overstory and understory plants, both of which are at least temporarily enriched in N and P by fertilization (tables 4 and 6, figs. 5-8). Unfortunately, we have no measurements of tree litterfall on the study area, but from our data for the understory shrubs it is clear that they play only a minor role in nutrient cycling. The maximum total accumulated N and P in the shrubs of trial 1 in 1973 was in the NP plot and represented only 1 percent of the applied N and 0.3 percent of the applied P.

The sphagnum moss is a much larger nutrient sink, and the death of a large part of the sphagnum after fertilization released nutrients previously tied up in the living moss. This nutrient release may have contributed to the initial growth response (e.g., height growth, fig. 1) to fertilization with N or P individually. We estimate the accumulation of N and P in the sphagnum in the control plots at the time of fertilization to have been 132 and 18 kg/ha, respectively. The release of part of these nutrients (through sphagnum death) after fertilization would ensure that each fertilizer plot received both N and P, each of which appears necessary to increase growth.

SUMMARY AND CONCLUSIONS

Fertilization with N and P in combination dramatically increased the height and diameter growth of black spruce. The effects are long lasting, particularly for the heaviest fertilizer rate in which height growth was several times greater than the controls even after 16 years. Foliar nutrient concentrations responded rapidly to fertilization but by 9 to 10 years only foliar P was still significantly greater than on the controls. Shrub biomass was increased by fertilization and *Ledum* increased markedly at the expense of *Chamaedaphne*. Sphagnum was killed by the fertilizer treatments and its death may have contributed significant amounts of nutrients to the site. Within 10 years sphagnum coverage had returned to prefertilizer levels.

All the evidence points to fertilization as having improved the site. The average annual height growth for all plots fertilized with N and P has been about 17 cm/yr. This is excellent growth for 85-year-old black spruce. Based on limited data from this study it appears that a similar height growth response could be obtained with younger trees. Assuming that an average annual height growth of 17 cm could be obtained at age 40 by fertilization, this would correspond to a site index of 10 m at age 50 (Gevorkiantz 1957), which is about average for black spruce on organic soils. Thus, fertilization may have the potential to convert some marginally nonproductive muskeg sites into commercial forest stands.

Clearly much more work is needed to better define the kinds of sites that will respond to fertilization, to evaluate fertilizer movements off of the application site, and to determine the impacts of drainage in combination with fertilization.

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