FIVE-YEAR GROWTH IN TWO NITROGEN-PHOSPHORUS FERTILIZATION EXPERIMENTS IN SPRUCE AND SPRUCE-FIR UPLAND FOREST IN NORTHERN ONTARIO

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ABSTRACT

Two factorial experiments incorporating four levels of N supplied as urea and three levels of P supplied as triplesuperphosphate were established in spruce upland forest west of Black Sturgeon Lake, Ontario. One experiment was in a relatively pure 65-year-old black spruce (*Picea mariana* [Mill.] B.S.P.) stand, the other in a white spruce (*Picea glauca* [Moench] Voss)-black spruce-balsam fir (*Abies balsamea* [L.] Mill.) mixed stand. Despite shallow soil, both stands were relatively thrifty. Gross PAI (estimated from controls) for the black spruce stand was 6.3 m^3/ha/yr and for the mixed stand (all species combined) 9.0 m^3/ha/yr. After five years the following response variables were determined: mean DBH increment, BA increment, % BA growth, total volume increment and merchantable volume increment, all calculated on survivor growth. Analyses of variance revealed significant treatment differences related to N, with some suggestion of a positive N-P interaction. Subsequent means separation tests, however, yielded few significant increases over controls. Best response to N alone was in the black spruce stand where urea at 150 kg N/ha produced approximately 4 m^3/ha of extra wood over five years. In the spruce-fir stand additional N when supplied alone suppressed growth at all levels, as did P in both experiments. N-P combinations at low levels produced responses differing little from controls. At high dosages, however, N and P together produced substantial but mostly non-significant gains over controls.

RÉSUMÉ

Deux expériences factorielles comportant quatre niveaux de N sous forme d'urée et trois niveaux de P sous forme de triple superphosphate ont été établies dans une forêt d'Épinettes sur collines à l'ouest de Black Sturgeon Lake (Ontario). L'une des expériences a eu lieu dans un peuplement relativement pur d'Épinette noire (*Picea mariana* [Mill.] B.S.P.) âgée de 65 ans et l'autre dans un peuplement mélangé d'Épinette blanche (*Picea glauca* [Moench] Voss), d'Épinette noire et de Sapin baumier (*Abies balsamea* [L.] Mill.). Malgré un sol peu profond, les deux peuplements étaient relativement vigoureux. L'APA (accroissment périodique annuel) (évalué à partir de témoins) pour le peuplement d'Épinette noire a été de 6.3 m^3/ha/an, et de 9.0 m^3/ha/an pour le peuplement mélangé (combinaison de toutes les espèces). Au bout de cinq ans, on a déterminé les variables de réaction suivantes: accroissement moyen du DHP, accroissement de la ST, pourcentage de croissance de la ST, accroissement du volume total et du volume marchand, tous calculés en rapport avec la croissance des survivants. Les analyses de variance ont révélé des différences significatives dans les traitements reliées à N, avec une indication d'interaction N-P positive. Des tests de moyennes de séparation effectués subséquemment ont cependant produit peu d'augmentations, comparé aux témoins. La meilleure réaction à N seul a été observée dans le peuplement d'Épinette noire, alors que l'urée à raison de 150 kg N/ha a produit approximativement 4 m^3/ha de bois additionnel en cinq ans. Dans le peuplement d'Épinettes-Sapin un traitement supplémentaire de N seul a supprimé la croissance à tous les niveaux, tout comme l'addition de P lors des deux expériences. De faibles concentrations de N-P ont produit des réactions peu différentes de celles des témoins. Cependant un traitement à forte teneur en N at P réuins a produit des gains substantiels, mais pour la plupart non significatifs par rapport aux témoins.

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INTRODUCTION

During the 1960s, interest grew in eastern Canada in forest fertilization as a possible means of increasing forest growth and counteracting wood supply problems projected for the pulp and paper industry in the future, on both a short-term and a medium-term basis. This interest led to the establishment of various programs of forest fertilization research by the Canadian Forestry Service, provincial agencies and other parties. This research concentrated chiefly on wild stands of the principal raw material species of the eastern Canadian pulp and paper industry: black spruce (*Picea mariana* [Mill.] B.S.P.) and jack pine (*Pinus banksiana* Lamb.) in Ontario and, further east, balsam fir (*Abies balsamea* [L.] Mill.), white spruce (*Picea glauca* [Moench] Voss) and red spruce (*P. rubens* Sarg.) as well. Stands fertilized were largely in the semimature age classes, that is, a decade or so short of harvest. The objective, it was suggested, should be to add wood to existing stems so as to realize a short-term payoff in terms of actual extra wood, while at the same time minimizing carrying charges on investment. In addition to the overall growth promotion objective, there was another major reason advanced for such use of mineral fertilizers: to permit restructuring of age class distribution in order to provide a constant supply of wood to the mill.

An early study by Weetman (1968) in a 65-year-old black spruce upland stand near Baie Comeau, Quebec, provided some preliminary indication of gains to be hoped for through the application of fertilizers to pure black spruce uplands. Weetman reported 6.0 m^3/ha of extra wood over five years in response to urea applied at a rate of 112 kg N/ha and 7.8 m^3/ha of extra wood in response to urea at 448 kg N/ha. In another early study, Van Nostrand and Bhure (1973) in a 60-year-old stand near Badger, Newfoundland, reported 7.8 m^3/ha of extra wood over four years in response to urea at 200 kg N/ha. Notwithstanding difficulties attending silvicultural trials in wild mixtures, i.e., problems of uniformity, differential species response, etc., the present investigation was extended into a mixed white spruce-black spruce-balsam fir forest as well.

The objectives of the present study were to ascertain the effects of N and P fertilizers, singly and in combination and at different levels, upon growth of typical semimature black spruce and white spruce-black spruce-balsam fir wild forest on an upland site in the Black Sturgeon Lake area of northern Ontario.

STUDY AREA

The two experiments are located approximately 6 km apart along the Dorion-Armstrong Road in an unorganized portion (lat. 49°25'N, long. 89°04'W) of Thunder Bay District, Ontario, approximately 65 km northwest of the town of Nipigon on the north shore of Lake Superior. They are located within the Nipigon Forest Section (B.10) of the Boreal Forest Region (Rowe 1972). The climate is modified-continental, and the study site is in the Height-of-Land Climatic Region of Chapman and Thomas (1968). The average length of growing season based on a 5.5°C index is approximately 153 days, extending roughly from May through September (ibid.). Mean total precipitation as measured at the nearest weather station (47 km ESE), Pine Portage, Ontario, is approximately 760 mm annually, with about half falling during the growing season (Anon. 1973). Potential evapotranspiration in the area has been estimated at 480 mm annually (Chapman and Thomas 1968).

Both experiments are located within the Black Sturgeon Site District of Site Region 3W--Lake Nipigon (Hills 1955). Bedrock is close to the surface and is dominated by late mafic igneous rocks, chiefly of diabase, gabbro and diorite. Surficial geology throughout the area is characterized by morainal deposits.

The stand in which Experiment 1 is located is a medium volume (mean total standing volume, all species, at the beginning of the experiment: 226.7 m^3/ha) but thrifty (gross periodic annual increment [PAI]: *ca.* 6.3 m^3/ha/yr) 65-year-old black spruce forest on a boulder till upland of site class Ia (Plosnki 1974). The stand is well stocked with an initial overall basal area (BA) of 38.8 m^2/ha. At the beginning of the experiment, black spruce contributed 81.6% of the standing BA. Other species were white spruce, which contributed 5.3%, balsam fir (6.5%), and white birch (*Betula papyrifera* Marsh.) (6.0%). Mean diameter at breast height (DBH) for all species at the beginning of the experiment was 11.7 cm. Other species present were trembling aspen (*Populus tremuloides* Michx.), jack pine and white pine (*Pinus strobus* L.). These three species accounted for only slightly over 0.5% of the total BA, and hence were disregarded for purposes of the calculation.

The stand in which Experiment 2 is located is likewise of medium volume (186.0 m^3/ha) but thrifty (gross PAI: *ca.* 9.0 m^3/ha/yr). The principal species, white spruce, black spruce and balsam fir, accounted for 42.6%, 18.0% and 20.8%, respectively, of the initial standing BA of 31.9 m^2/ha. The remaining BA was composed of white birch, trembling aspen and jack pine. Of these, only white birch (3.2%) was sufficiently ubiquitous to permit statistical evaluation. To reduce experimental variation, plots were established only in well stocked portions of the stand. Mean DBH for all species at the beginning of the experiment was 11.4 cm.

METHODS

Foliar Analysis

In Experiment 1, a large-bore, full-choke shotgun with large pellets was used to obtain samples of mid-crown foliage in mid-September from eight dominant or codominant black spruce trees. Current foliage only was taken for analysis. From the stand in which Experiment 2 was located, 10 trees each of white spruce, black spruce and balsam fir were similarly sampled. Samples were removed immediately to a field laboratory for drying at 70°C in a forced-draught oven. Following drying, leaves were separated from twigs, finely ground in a laboratory knife mill and stored, away from light, in airtight glass phials.

Percent N in dry leaves was determined using a Hewlett-Packard Model 185 CHN Analyzer and cysteine as a primary standard. Following dry-ashing of samples at 500°C and nitric-hydrochloric acid extraction, other elements were determined as follows: P colorimetrically, by a molybdophosphoric blue method; K by flame emission spectrophotometry using a Perkin-Elmer Model 290 Spectrophotometer; Ca and Mg, both in the presence of lanthanum oxide, by atomic absorption spectrophotometry, using a converted form of the same instrument. Duplicate determinations were made in all instances.

Fertilization Experiments

Experiment 1 was set out as a 4 x 3 factorial with four levels of N (0, 150, 300 and 450 kg/ha) supplied as urea prills, and three levels of P (0, 50 and 100 kg/ha) supplied as triplesuperphosphate. The 12 combinations were replicated three times for a grand total of 48 treatment plots. Treatment plots were each 28.3 m x 28.3 m (giving an area of 0.08 ha), and contained inner 20.0 m x 20.0 m measurement plots (giving an area of 0.04 ha). The experiment was arranged in a single block, with shared treatment-plot boundaries. Buffers were provided by the portion of the treatment plot external to the measurement plots. Trees were identified by numbered metal tags and the breast-height (1.37 m) position marked on each tree. At the beginning of June, 1972, fertilizers were hand-broadcast to the treatment plot in a systematic two-or-more pass pattern to attempt uniform coverage. At that time measurements of DBH (by steel diameter tape) and heights of selected trees (by Haga Altimeter) were made and recorded.

Experiment 2 was set out as a 4 x 3 factorial, likewise with four levels of N (0, 150, 300 and 450 kg/ha) supplied as urea prills and three levels of P (0, 50 and 100 kg/ha) supplied as triplesuperphosphate. In design it differed from Experiment 1 only in that the 12 combinations were replicated just twice for a grand total of 36 plots and that the experiment was located in the mixed stand. Beyond this, plot sizes, application dates, methods, etc., were similar to those of Experiment 1.

Remeasurement and Data Analysis

Diameters of all trees were remeasured after five growing seasons, in early June, 1977. All response variables were calculated in terms of gross periodic increment or survivor growth, i.e., trees which died during the course of the experiments were deleted from the calculation. For both experiments, five-year mean DBH increment, BA increment, and % BA growth responses were calculated for survivors by species by subtracting initial values from remeasurement values. Total and merchantable volume increments for the response periods were calculated as follows: a regression of height-on-DBH was derived from observations on selected sample trees and used to estimate the height of each tree. Total and merchantable volumes by plot for the beginning and end of the experimental period were computed on a tree-by-tree basis for survivors using local volume tables derived from these estimated heights and Honer's (1967) volume equations. Increments were likewise calculated by subtracting initial values from remeasurement values.

The various data were subjected to analysis of variance and Duncan's New Multiple Range Test for the detection of significant differences among means.

RESULTS

Foliar Analysis

Black spruce trees in the less vigorous though still productive stand (Experiment 1) exhibited lower concentrations of foliar elements, with the exception of Mg, than did trees in the more vigorous (Experiment 2) stand (Table 1). Concentration differences were greatest for P and K. Comparisons among three species, *viz.*, black spruce, white spruce and balsam fir, grown side by side revealed generally higher concentrations of all elements (with the exception of K) in the leaves of balsam fir than in those of the spruces.

Table 1. Mean concentrations of principal macroelements in mid-crown, current foliage of unfertilized trees sampled in autumn.

Experiment number	Species	Concentration (% oven-dry weight)				
		N	P	K	Ca	Mg
1	black spruce	0.99	0.09	0.34	0.33	0.10
2	black spruce	1.03	0.15	0.49	0.43	0.09
	white spruce	0.95	0.16	0.43	0.62	0.10
	balsam fir	1.25	0.19	0.48	0.77	0.12

Fertilization Experiments

In Experiment 1, for all species combined, N produced a significant effect on all growth variables with the exception of periodic merchantable volume increment (Table 2). No one species was seen to carry the overall result, although there is a suggestion that white birch, despite its low frequency within the stand, may have contributed substantially to the mean DBH increment and % BA growth results. Significant differences in relation to P are indicated for some parameters for both white spruce and white birch. The suppression of growth at higher P levels suggests that P may have had an adverse effect on growth. However, interactions between N and P, at least for some parameters, are indicated for black spruce and white birch.

In this experiment, no treatment produced a significant response over control when all species were considered in combination (Table 3). For convenience, five-year periodic total volume increment over control is extracted from Table 3 and is presented as Table 4. Nitrogen alone increased total growth up to 150 kg N/ha; thereafter, with successive increments, the increase fell off. Phosphorus alone generally depressed growth. However, the combination of N and P at higher levels, viz., N300 P50 and N450 P50, produced a distinctly positive effect that supported the interaction indication of the variance analysis (Table 2), and suggested that P shifted the N maximum response to the higher N application rates, whereas the higher levels of N brought out some positive P responses.

Table 2. Analysis of variance: summary of F-ratios (Experiment 1) illustrating significant treatment effects and interactions for N and P fertilizers applied to black spruce upland forest, Black Sturgeon Lake, Ontario.

Species	Fertil- izer	Mean DBH incre- ment	BA incre- ment	% BA growth	Total volume incre- ment	Merchant- able volume increment
black spruce	N	.41	2.00	2.08	2.37	2.40
	P	.34	.27	.79	.85	.75
	NP	1.48	1.81	1.29	2.60*	2.60*
white spruce	N	1.04	1.49	1.59	1.58	1.60
	P	1.87	4.51*	3.39*	3.98*	4.00*
	NP	1.01	1.82	1.49	1.69	1.66
balsam fir	N	1.83	.14	1.78	1.62	1.46
	P	.13	1.30	.07	.68	.57
	NP	1.08	.73	.32	1.80	1.84
white birch	N	5.83**	.69	15.85**	1.53	1.52
	P	3.77*	1.48	3.88*	1.63	2.31
	NP	.70	.66	2.84*	.62	.64
all species combined	N	4.08*	3.28*	4.25*	2.84*	2.73
	P	1.06	2.56	1.86	2.01	1.56
	NP	.78	.73	.81	.68	.63

*Statistically significant, P = .05
**Statistically significant, P = .01

In Experiment 2 significant differences in relation to N are indicated for all species combined for all growth variables with the exception of % BA growth (and for some variables in relation to individual species). Interaction of N with P was likewise significant for periodic BA increment and for periodic total volume and merchantable volume increments for all species combined (Table 5).

In Experiment 2 treatment means for all species combined reveal only one significant difference over the control, *viz.*, N450 P50 for % BA growth (Table 6). Five-year periodic total volume increment over control indicates that N and P, when applied alone, each have depressing effects on total volume growth. The combination of the two elements rectifies this (Table 7) and indeed, at the higher levels of N in combination with P, *viz.*, N450 P50 and N450 P100, there is a substantial increase in total volume increment. As with Experiment 1, however, when analyzed on a treatment-by-treatment basis, differences were, with one exception, not significant.

Table 3. Five-year periodic growth responses to N and P fertilizers, of all species combined, in upland black spruce forest, Black Sturgeon Lake, Ontario.

Treatment (kg/ha)	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Basal area growth (%)	Total volume increment (m^3/ha)	Merchantable volume increment (m^3/ha)
Control	0.66	4.36	11.30	31.43	30.15
P50	.74	4.39	12.12	31.60	30.33
P100	.71	3.82	11.40	27.11	26.13
N150	.67	4.95	11.78	35.69	34.52
N150 P50	.72	4.57	11.98	32.15	31.18
N150 P100	.82	4.64	12.55	33.39	32.40
N300	.86	4.67	13.50	34.18	32.58
N300 P50	.90	5.24	13.72	37.60	36.03
N300 P100	.81	4.63	12.85	33.14	32.11
N450	.77	4.61	12.18	32.96	31.72
N450 P50	.83	5.03	14.20	35.10	33.73
N450 P100	.76	4.41	12.30	31.31	30.41

Table 4. Five-year-old periodic total volume growth over control for 65-year-old black spruce upland forest subjected to N and P fertilizer treatments, Black Sturgeon Lake, Ontario.

	Total volume growth over control (m^3/ha)			
	N0	N150	N300	N450
P0	0.00	4.26	2.75	1.53
P50	0.17	0.72	6.17	3.67
P100	-4.32	1.96	1.71	-0.12

Table 5. Analysis of variance: summary of F-ratios (Experiment 2) illustrating significant treatment effects and interactions for N and P fertilizers applied to spruce-fir upland forest, Black Sturgeon Lake, Ontario.

Species	Fertil-izer	Mean DBH incre-ment	BA incre-ment	% BA growth	Total volume incre-ment	Merchant-able volume increment
black spruce	N	.35	1.64	.63	.47	.47
	P	.65	2.04	.92	.48	.49
	NP	.75	2.06	.04	.74	.74
white spruce	N	2.89	.28	3.53*	.31	.31
	P	.12	.05	.60	.04	.04
	NP	1.03	1.07	1.09	1.12	1.11
balsam fir	N	5.39**	.58	10.84**	.73	.85
	P	1.00	.86	1.13	.96	1.04
	NP	.63	.41	2.40	.36	.31
white birch	N	3.24*	1.56	4.60*	1.65	1.89
	P	.57	2.54	.07	1.96	.87
	NP	1.92	.55	.40	.34	.57
all species combined	N	5.13**	4.24*	2.84	3.73*	3.89*
	P	.83	1.80	.94	1.15	1.03
	NP	2.18	2.99*	1.22	3.66*	3.42*

*Statistically significant, P = .05
**Statistically significant, P = .01

Table 6. Five-year periodic growth responses to N and P fertilizers, of all species combined, in mixed upland white spruce-black spruce-balsam fir forest, Black Sturgeon Lake, Ontario.

Treatment (kg/ha)	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Basal area growth (%)	Total volume increment (m^3/ha)	Merchantable volume increment (m^3/ha)
Control	1.26	5.78	19.20	46.78	44.95
P50	.93	5.16	16.13	38.48	36.56
P100	.89	4.42	14.63	32.01	30.83
N150	1.30	6.24	20.53	45.81	44.00
N150 P50	1.27	5.93	20.80	43.61	42.38
N150 P100	1.19	5.98	19.20	46.35	44.70
N300	1.25	4.53	17.30	36.68	35.38
N300 P50	1.67	5.92	23.93	45.24	43.65
N300 P100	1.19	6.88	24.07	51.57	48.72
N450	1.30	5.40	18.83	39.80	38.63
N450 P50	1.40	7.70	25.07*	57.89	55.14
N450 P100	1.54	7.02	22.80	52.76	50.93

*Significant over control, P = .05

Table 7. Five-year periodic total volume growth over control for mixed white spruce-black spruce-balsam fir upland forest subjected to N and P fertilizer treatments, Black Sturgeon Lake, Ontario.

	Total volume growth over control (m^3/ha)			
	N0	N150	N300	N450
P0	0.00	-0.97	-10.10	-6.98
P50	-8.30	-3.17	-1.54	11.11
P100	-14.77	-0.43	4.79	5.98

DISCUSSION

In general, responses to conventional rates of fertilizer application in these two spruce upland stands were modest, the only worthwhile (but still non-significant) gain to N alone being in Experiment 1, where urea at 150 kg N/ha produced in excess of 4 m^3/ha extra wood over the response period. This contrasts with our previous experience with jack pine where, with dosages of 100-200 kg N/ha, both with and without P, gains of 5-15 m^3/ha of extra wood over 4 to 5 years were observed (e.g., Morrison et al. 1976a, b, 1977a, b, Winston 1977). This poor response contrasts also with the aforementioned good responses of Weetman (1968) in Baie Comeau, and Van Nostrand and Bhure (1973) in Badger, where modest dosages of N alone produced extra volume in the order of 6-8 m^3/ha over the five-year and four-year response periods of the two studies, respectively. The Baie Comeau and Badger stands were similar to those of the present study in that all were spruce stands on uplands and all were approximately the same age. However, there were substantial differences with respect to stand vigor. Gross PAI calculated from control plots at Baie Comeau (Weetman 1968) and Badger (Van Nostrand and Bhure 1973) were indicated as 2.4 and 3.2 m^3/ha per annum, the Baie Comeau value increasing slightly to 2.8 m^3/ha/yr when calculated over a 10-year period (Weetman 1975). In contrast, gross PAI values for control plots of the pure black spruce and the mixed spruce-fir stands of the present investigation are calculated as 6.3 and 9.0 m^3/ha/yr, respectively. In general, the Black Sturgeon Lake forest without fertilizer is more productive than either the Baie Comeau or the Badger forests with fertilizer. These studies seem to confirm the general trend that, for comparable dosages and for conifers (at least jack pine and black spruce) on upland boreal sites in eastern Canada, best responses are found with low-vigor stands and poorest responses with high-vigor stands. Interestingly, this trend, if it holds, would be in direct contrast with that experienced with Norway spruce (*Picea abies* [L.] Karst.) and Scots pine (*Pinus sylvestris* L.) in Sweden (Möller, 1971, Malm and Möller 1975) where responses to fertilizers in terms of additional increment would appear to increase with increasing stand vigor.

The general response by black spruce in terms of extra wood produced is in keeping with findings of other investigators (Weetman et al. 1976, 1978, 1979). Within the Interprovincial Forest Fertilization Program where, for black spruce, a total of 18 standardized trials involving N and P have been reported upon to date, actual growth suppressions have been recorded in four, whereas in the others, positive gains (in terms of extra total volume over five years) averaged *ca.* 3.4 m^3/ha for N112, 4.0 m^3/ha for N224 and 4.2 m^3/ha for N224 P112. In the Interprovincial black spruce data, the addition of P appeared to enhance the effect of N in 12 and diminish its effect in 6 of 18 trials. With white spruce, comparable data are more limited. However, within the Interprovincial results (Weetman et al. 1976), growth enhancement was reported in four instances and depression in one. Periodic annual increment of the stand where N-manuring did lead to decreased growth was 9.5 m^3/ha/yr. On the other hand, periodic annual increments of responding stands ranged from 2.6 to 7.3 m^3/ha/yr. The addition of P improved response over N alone at three of five locations. Responses by balsam fir to N and P fertilizers as reported from the Interprovincial program ranged up to 17.6 m^3/ha in five years. Unlike the general tendency for high-vigor stands of these species to respond well, no trends seemed evident for balsam fir. Further, with the Interprovincial balsam fir data (all from pure stands in Quebec) the addition of P resulted in increases over responses to N alone in only five of 12 locations (Weetman 1976, 1978, 1979). In one further comparison of the effect of N and P in balsam fir, Hoyt (1973), with 50-year-old fir (PAI, 5.3 m^3/ha/yr) in New Brunswick, reported a five-year 4.3 m^3/ha gain over control in response to urea alone at 168 kg N/ha, but with the addition of 112 kg P/ha to the N, the response increased to 7.7 m^3/ha.

One further comparison of interest is that with Norway spruce in Sweden. Following analysis of a large number of trials, Möller (1971) deduced a relationship enabling him to predict that Norway spruce with the same general growth rate as black spruce in the present Experiment 1 (i.e., PAI *ca.* 6.3 m^3/ha/yr) would produce 10 m^3/ha extra wood over five years in response to urea in the 115-140 kg N/ha range in comparison with the much smaller response for the equivalent treatment in the present stand. In another report, Möller (1972), averaging various results, suggested that Norway spruce of average vigor, (i.e., annual increment 5.8 m^3/ha/yr) would produce 5.6 m^3/ha extra wood over 5 years in response to urea at 100 kg N/ha. Malm and Möller (1975) reported best response by Norway spruce to urea alone to be around 180 kg N/ha.

The relationship between stand vigor as measured by current annual increment (CAI) or, as in the case of the present study, PAI, and black spruce foliage N concentration has been demonstrated by Lowry and Avard (1968) and Lowry (1970). This is supported by our observations that black spruce foliage in the more productive of the two stands, i.e., the mixed spruce stand, exhibited slightly higher N concentration than in the less productive stand. The results of foliar analysis of these two stands were compared with Swan's (1970) "suggested standards for the evaluation of the results of foliar analyses" for black spruce; here Swan's calibration was adjusted to reflect mid-crown current (as sampled in the present study) as opposed to upper-crown current (Swan's position) foliage values. The latter was done using Lowry and Avard's (1965) observed element contents in upper- versus mid-crown foliage and deflating Swan's (1970) limits proportionately. Against the adjusted calibration, foliar analysis in the present study suggested that supplies of K, Ca and Mg were adequate, all values falling at least within Swan's "transition zone from deficiency to sufficiency". Comparison with Swan's adjusted index did suggest, however, that response should be forthcoming to both N and P manures in Experiment 1 and to at least N in Experiment 2. Except for a modest response to N at 150 kg/ha in Experiment 1, responses to N or P singly were generally not forthcoming. On the other hand, the generally good response to N and P in combination at the higher levels suggests that these elements do, at some point, become limiting.

Whereas N and P alone, especially at very high levels, generally suppressed growth (the exception being the aforementioned response to N150 in Experiment 1), low level N-P combinations produced effects differing little from those of the controls. However, at high levels of N plus P, particularly N at 300 to 450 kg/ha, there would appear to be substantial response. This was especially evident in the Experiment 2 data, where in excess of 11 m^3/ha extra wood was produced in response to N450 P50.

Modest responses to fertilizers of black spruce and spruce-fir upland stands suggest that fertilizer treatment of spruce forest should be approached with caution. Whereas a definitive economic appraisal of fertilizer treatment has yet to be made, experience to date generally suggests that five-year response would have to be in the order of 15 m^3/ha for fertilization to be economically viable, considerably above the 4 m^3/ha of the present study. Cost of fertilizer treatment (made up of fertilizer and application costs) is generally proportional to the dosage added. Using quoted 1978 northern Ontario bulk prices and average application costs, the N150 treatment, for example, would cost about $115 per hectare ($47 per acre); with other responding treatments, viz., N300 P50, N450 P50, and N450 P100, this figure increases 2.8 times, 3.8 times, and 4.5 times, respectively.

It should be noted that substantially greater gains were reported in the 10-year (Weetman 1975) compared to the earlier five-year (Weetman 1968) analysis of the Baie Comeau data. This suggests a considerable lingering effect of fertilizers when they are applied to spruce forests. This is evident, too, in the various examples given by Viro (1972) in regard to fertilization of spruce and pine stands on mineral sites in Finland, with a further suggestion that P in addition to N may in certain cases at least prolong the N effect. Some additional evidence for prolongation of initial N response in middle-aged spruce on mineral soils through the addition of other elements comes from a stand in Denmark where Møller and Lundberg (1977), having obtained an impressive response to urea fertilizing during the first half-decade, followed responses both to N alone and to N with P and K. Increment on trees supplied with urea alone peaked about the fifth year; thereafter it declined and, starting about the ninth year, the trees began to grow more slowly than the controls. On the other hand, trees supplied with P and K in addition to N continued to post impressive excess increments well into the second decade. A clearer picture of the response of the present black spruce and spruce-fir stands, however, will have to await the 10-year analysis.

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