Ten-year Growth Response to Fertilizer of a 90-year-old Black Spruce Stand in Northwestern Ontario

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Abstract

A fertilizer experiment with three levels of urea, two of triple superphosphate and two of muriate of potash was established in a 90-year-old black spruce (*Picea mariana* [Mill.] B.S.P.) stand on a moist-to-wet site in northwestern Ontario. Response variables estimated or measured at 6 and 10 years after fertilization were mean DBH increment, BA increment (per cent and absolute), and total and merchantable volume increment. Analysis of variance and Duncan's New Multiple Range Test were carried out. Results indicated significant growth response only for one combination of N and P, and only in relation to mean DBH increment. No interactions were significant. Inspection of data revealed trends suggesting that response, which was limited, was generally to P and to a smaller degree to N. Compared with literature values, volume growth responses were generally low, about 9 m³/ha estimated total volume increment over controls in 10 years. Possible reasons for low response, including nutrient loss (particularly of N) from the root zone and low application rates are discussed.

Résumé

L'auteur décrit une expérience faite avec un fertilisant contenant trois concentrations d'urée, deux de triple superphosphate et deux de muriate de potasse dans un peuplement d'épinette noire (*Picea mariana* [Mill.] B.S.P.) âgé de 90 ans, dans une station humide ou mouillée située dans le nord-ouest de l'Ontario. Les variables de la réaction évaluées ou mesurées 6 et 10 ans après la fertilisation furent l'augmentation du d.h.p. moyen, l'accroissement de la ST (surface terrière), en pourcentage et en chiffres absolus, et l'augmentation du volume total et marchand. Une analyse de variance ainsi que le "Duncan's New Multiple Range Test" furent entrepris. Les résultats indiquèrent une réaction de croissance significative seulement pour une combinaison de N et P, et seulement relativement à l'augmentation du d.h.p. moyen. Aucune interaction ne fut significative. L'examen des données révéla des tendances indiquant que la réaction, laquelle fut limitée, favorisait habituellement le P et, à un degré moindre, le N. Comparativement aux données déjà rapportées, les réactions de croissance en volume sur une période de 10 ans furent généralement basses (on a évalué l'augmentation totale en volume à 9 m³/ha de plus que chez les arbres témoins). L'auteur étudie les raisons possibles d'une réaction aussi minime, y compris la perte en matières nutritives (en particulier de N) dans la zone racinaire, puis, les taux peu élevés d'application du fertilisant.

Introduction

The experiment described in this paper originated in 1964, as the offspring of an agreement between Great Lakes Paper Company Limited of Thunder Bay, Ontario and the Pulp and Paper Research Institute of Canada, and was one in a series of experiments in a cooperative program of forest fertilization research. Under the agreement, industry undertook to carry out all field work and the Institute all analyses. In late 1971 the Institute's responsibilities were transferred to the Canadian Forestry Service.

At the time this experiment was established there was very little information on response of semimature black spruce (*Picea mariana* [Mill.] B.S.P.) stands to mineral fertilizers. According to Armson's (1967) compilation, there were only two trials established before 1964 in semimature natural black spruce forest in eastern Canada. Even now little information on response of semimature black spruce forest to mineral fertilizers has been published. One early exception, however, involved black spruce growing under raised-bog conditions in northern Minnesota where, in terms of leader growth, marked responses were reported to nitrogen (N) and phosphorus (P) fertilizers singly and in combination (Watt 1966).

The following experiment was designed to determine long-term growth responses of semimature black spruce forest on a moist site in northwestern Ontario to various combinations of N, P and K supplied as urea, triple superphosphate and muriate of potash.

Study area

The study area is located (lat. 48°43'N; long. 90°07'W) on the limits of the Great Lakes Paper Company Limited, some 9 km directly north of Lower Shebandowan Lake, and some 70 km WNW of Thunder Bay, Ontario. It is within the Upper English River Section (B.11) of the Boreal Forest Region (Rowe 1972). The overall climate is modified-continental and falls within the Rainy River-Thunder Bay Climatic Region of Chapman and Thomas (1968). The average length of growing season is approximately 160 days, extending from May though September inclusive (ibid.). Mean annual total precipitation, as measured at the nearest weather station (Kakabeka Falls, Ontario), is 720 mm, with approximately 56% of this falling during the growing season (Anon. 1973). Potential evapotranspiration was estimated at 51 cm annually (Chapman and Thomas 1968).

The experiment is located on the boundary of the Savanne Site District of Site Region 3W—Lake Nipigon, and the Quetico Site District of Site Region 4W—Pigeon River (Hills 1959). The site is

heterogeneous with regard to moisture, because of a variable-depth, perched water table deriving from prominent bands of compacted fine sand which occurred at a depth of 50 cm in drier areas and much closer to the surface in wetter areas. In wetter areas water stood on the surface in the lower pits and channels during the early summer. In drier areas (in one of which was located the pit from which the samples for analyses were taken) the soil profile is characteristic of an Orthic Humo-Ferric Podzol (Anon. 1974), whereas in wetter areas, typified by high chroma mottling, it would be classed as Gleyed Humo-Ferric Podzol. Mineral soil texture (Table 1) is sandy loam over sand. Concentrations of total N and available P were low, though not unusually so. Levels of exchangeable cations were comparable with usual literature values.

The experiment was established in 1964 in a fully stocked, relatively pure stand approximately 90 years old. Mean height, diameter at breast height (DBH) and basal area (BA) were 14.8 m, 14.8 cm, and 34 m²/ha, respectively. The forest floor was occupied by a continuous moss layer with *Sphagnum* spp. and *Pleurozium schreberi* (BSG.) Mitt. predominating, and *Hypnum cristacastrensis* Hedw. and *Hylocomium splendens* (Hedw.) BSG. in lesser abundance. Herbs and shrubs that were relatively common included *Equisetum sylvaticum* L., *Lycopodium annotinum* L., *Cornus canadensis* L., *Gaultheria hispidula* (L.) Bigel., *Ledum groenlandicum* Oeder, *Smilacina trifolia* (L.) Desf., and *Petasites palmatus* (Ait.) Grey.

Methods

A completely randomized three-factor factorial experiment, with three levels of N (0, 112, 224 kg N/ha) supplied as urea, two levels of P (0, 25 kg P/ha) supplied as triple superphosphate, and two levels of K (0, 93 kg K/ha) supplied as muriate of potash, for a total of 12 treatments replicated three times for a total of 36 measurement plots was established in 90-year-old black spruce forest in October, 1964. Measurement plots were circular, 0.0182 ha in area, with buffer zones approximately 10 m wide. Trees were identified in

the field by numbered metal tags. Stems were rubbed to remove scaly bark and the breast-height position was marked with paint. Fertilizers in amounts appropriate to the experimental design were hand-broadcast on the soil surface the following May, at the beginning of the 1965 growing season. Initial DBH measurement to the nearest 0.025 cm was made by steel diameter tape in October, 1964. Through an oversight only 30 trees were measured on each plot at that time, precluding an accurate estimate of initial BA, total volume or merchantable volume. This was rectified in the fall of 1968 when the additional trees were identified and measured. Final remeasurement of DBH, also by steel diameter tape to the nearest 0.025 cm, was done in September, 1974. In accordance with standard procedure trees that died during the period 1964-1974 were deleted from the tally. All measurements were in English units with subsequent conversion to S.I. units.

The mean DBH increment estimate was based on DBH growth of originally measured trees only. Per cent BA increments of originals (1964 to 1974) and all trees (1969 to 1974) were derived from appropriate differences in sums of individual-tree BAs. Measured total and merchantable volume increments (1969 to 1974) were estimated in the following manner. A regression of height-on-diameter was derived from observations on 180 sample trees. This regression was used to estimate the height of each tree. From the estimated heights and measured DBHs, total and merchantable volumes, both for 1969 and 1973, were computed on a tree-by-tree basis for each plot using Honer's (1967) volume equations. Thus, change in tree form due to treatment was not considered. Increments of total and merchantable volume were calculated by subtracting 1964 values from remeasurement values. These various data were subjected to analyses of variance and Duncan's New Multiple Range Test for the detection of significant differences among means.

In order to obtain working data, it seemed desirable to produce estimates of 10-year increments of BA, and total and merchantable volume. This was done as follows. First, for BA, per cent BA increases (1964-1974) were calculated on the basis of growth of original trees only. These per-

Table 1. Soil physical and chemical properties

Horizon	Depth (cm)	Texture ¹ (%)			pH ²	O.M. (%)	Total ³ N (%)	Avail. ⁴ P (ppm)	Exchangeable ⁵			C.E.C. ⁵ (meq/100 g)
		S	Si	Cl					K	Ca (meq/100 g)	Mg	
L ⁶	0 — 9	—	—	—	4.4	82.4	0.92	104.0	6.85	19.86	4.52	62.5
F.....	9 — 20	—	—	—	3.6	68.2	0.94	29.3	2.30	13.12	3.70	93.4
H.....	20 — 22	—	—	—	4.0	28.4	0.42	16.7	0.49	6.14	2.71	43.3
A _o	22 — 24	71	26	3	3.6	12.2	0.15	2.5	0.13	0.65	0.25	21.2
B _t	24 — 37	68	29	3	4.6	3.0	0.08	3.4	0.08	0.67	0.08	11.4
B _m	37 — 59	68	30	2	5.6	1.2	0.04	1.9	0.10	0.92	0.29	27.1
C.....	> 59	93	06	1	5.5	0.9	0.03	3.0	0.01	0.80	0.04	18.2

¹Boyucos hydrometer procedure.

²Glass electrode pH meter.

³Semi-micro Kjeldahl procedure.

⁴Bray and Kurtz No. 1.

⁵1 N NH₄OAc (pH 7).

⁶Includes mosses.

centages were used to discount 1974 plot total BAs to 1964 values. Increments were obtained by difference. Estimates of 10-year total and merchantable volume increment were obtained in a like manner. As they were extrapolated, these data were not subjected to statistical analyses.

Results

Data pertaining to mean DBH increase are presented in Table 2. In relation to this parameter, treatment N112 P25 resulted in a significant (at the 5% level) increase in DBH growth over control. Diameter growth of controls was slower than under any other treatment. No interaction proved significant. Data pertaining to BA are presented in Table 3. Analyses of variance revealed no significant differences in per cent BA increase of either original trees only (1964 to 1974) or all trees (1969 to 1974). No interactions were significant. In terms of ranking, three treatments grew slower than controls; generally, the greater BA increments could be identified with P.

In relation to both total and merchantable volume increment (1969 to 1974), analyses of variance (Table 4) revealed significant differences related

Table 2. Mean DBH increment (cm.) with standard deviation by treatment for 10-year period 1964-1974, based on surviving original trees

Treatment	Mean DBH increment (cm)	Standard deviation (cm)
Control.....	.87	.05
K 93.....	.98	.09
N112.....	1.12	.28
N112 K93.....	.94	.22
N224.....	1.11	.38
N224 K93.....	1.04	.12
P 25.....	1.08	.14
P 25 K93.....	1.06	.20
N112 P25.....	1.28*	.16
N112 P25 K93.....	1.16	.21
N224 P25.....	1.20	.03
N224 P25 K93.....	1.00	.05

*Significantly different from Control at 5% confidence level.

Table 3. Basal area growth (%) of original trees for full 10-year period, and of all trees for last 6 years, and estimated basal area increment (m^2/ha) for full 10-year period

Treatment	Basal area growth		Estimated basal area increment 1964-1974 (m^2/ha)
	Originals 1964-1974 (%)	All trees 1969-1974 (%)	
Control.....	11.82	5.77	4.80
K 93.....	12.91	6.64	3.97
N112.....	15.01	7.02	3.49
N112 K93.....	13.70	6.08	4.83
N224.....	15.06	7.15	5.79
N224 K93.....	14.68	6.14	4.72
P 25.....	15.48	7.17	5.64
P 25 K93.....	14.52	7.17	5.09
N112 P25.....	18.33	8.56	6.02
N112 P25 K93.....	16.93	7.68	4.85
N224 P25.....	17.21	7.91	6.02
N224 P25 K93.....	14.11	6.72	6.05

to P. No treatment, however, proved significantly different from the control which ranked, in this case, sixth lowest out of twelve. No interactions were significant. In estimated 10-year growth (Table 4) the best treatment produced $9 m^3/ha$ in terms of total volume, and $8 m^3/ha$ in terms of merchantable volume, more than controls. In conventional timber measure this is approximately 1 cord per acre.

Table 4. Measured total and merchantable volume increment (m^3/ha) for the period 1969-1974, and estimated total and merchantable volume increment (m^3/ha) for the period 1964-1974

Treatment	Measured vol. incr. 1969-1974		Estimated vol. incr. 1964-1974	
	Total (m^3/ha)	Merch. (m^3/ha)	Total (m^3/ha)	Merch. (m^3/ha)
Control	20.02	19.63	38.17	37.00
K93	16.88	16.71	31.50	30.87
N112	14.98	14.82	27.43	26.53
N112 K93	16.94	16.62	35.00	34.30
N224	23.74	23.42	45.67	44.47
N224 K93	17.52	17.26	37.97	37.23
P 25	22.52	22.18	44.27	42.33
P 25 K93	21.20	20.48	40.00	38.63
N112 P25	24.16	23.83	46.80	44.93
N112 P25 K93	18.66	18.34	37.20	35.73
N224 P25	23.64	23.17	46.93	44.57
N224 P25 K93	24.30	24.04	47.17	44.87

Discussion

Watt and Heinselman (1965) working with natural black spruce forest on a wet organic soil in Minnesota (unlike the mineral soil of the present study) observed positive correlations between site index and foliar concentrations of N and P, but not K, suggesting N and P, but not K, deficiency. This was demonstrated to be the case in a subsequent manurial trial (Watt 1966). In the present study there is the suggestion of P and possibly N response, with virtually none to K. It is to be stressed, however, that with the exception of mean DBH increment where N112 P25 resulted in a significant increase over controls, none of the results were statistically significant. It should be added, though, that asymmetry in stem cross-section, which tends to increase standard error, could have obscured treatment differences.

Fertilizer experiments on both black spruce wetland sites and upland mor humus sites have been uncommon. The present experiment spanned both site conditions. In a study of a 65-year-old stand in eastern Quebec, net gains over controls (i.e., extra wood) attributable to urea fertilization at a rate of $444 kg N/ha$ were reported after 5 years as nearly $8 m^3/ha$ (Weetman 1968) and after 10 years as over $25 m^3/ha$ (Weetman), proportionately more than could be accounted for by the higher dosage. Also, by way of comparison, in a study with 60-year-old black spruce in Newfoundland, Van Nostrand and Bhure (1973) reported, after only 4 years, a net gain over controls (due to urea supplied at a rate of $202 kg N/ha$) of nearly $8 m^3/ha$, a rate approximately equal to the

10-year response of the present study. For jack pine (*Pinus banksiana* Lamb.) on sandy outwash sites in northern Ontario, responses to fertilization have been in excess of 12 m³/ha after only 4 years (Hegyi 1974).

Comparisons involving volume increment merit mention because of the methods of estimate used in the present paper, which were necessitated by the unfortunate start to the experiment. Certainly, from a user's viewpoint, total and merchantable volume are the parameters of interest. Thorough statistical analyses of the 10-year BA and volume growth estimates were not carried out, however, because of possible imprecisions attending the estimates. The use of the 1964-1974 BA and volume growth percentages derived from original trees which were taken from each plot as estimators of overall plot growth, and subsequently used in the prediction of 1964 BA and volume, was considered reasonable, as the original trees represented on the average more than two thirds of the 1974 (and presumably 1964) standing BA. Thus, while the subsequent estimates of 10-year BA and volume increment are projected rather than measured values, they are considered useful for comparative purposes.

Questions then arise as to why there was such a poor response to fertilizer in general, and why the weak response obtained was to P. In relation to N, several possibilities concerning N-loss from the root zone exist. First, pH increase associated with urea hydrolysis and wetness create conditions favorable to NH₃ volatilization. Second, in wet soils, readily soluble urea may diffuse rapidly beyond the reach of shallowly rooted spruce. Third, under conditions of elevated pH and high moisture, nitrification may occur and, subsequently, denitrification. Support for this comes from the work of Nommik and Thoren (1971) who, incubating forest humus, found considerable denitrification N loss. Contrary evidence, however, is found in the earlier work of Roberge and Knowles (1966), who failed to find significant nitrification in urea-fertilized black spruce humus. Fourth, under soil conditions like those of the present study area, there is likely rapid immobilization of N by microflora.

The suggestion of P response, though statistically nonsignificant, is interesting, as P deficiency is often associated with wet-site conditions. Well known examples include P deficiency of southern pines on poorly drained flatwood and soils in the southeastern United States, and of trees, particularly spruces, on P-poor peatlands in Britain. Reasons for lack of P on wet sites are varied: under anaerobic conditions mycorrhizal development is usually poor; root systems are shallow and confined to the organic horizons. Here, P occurs principally in organic forms (unusable by plants), and low initial content, poor aeration and cool climate all contribute to a slow rate of P release.

Dose adequacy also warrants mention. In the present experiment P was supplied at 25 kg/ha, whereas Watt's (1966) response was to approximately 150 kg P/ha. Pritchett (1968), with slash

pine (*Pinus elliotii* Engelm.), found increasing response to at least 39 kg P/ha. With Sitka spruce (*Picea sitchensis* [Bong.] Carr.) on peatlands in Scotland (Malcolm 1972) and Northern Ireland (Dickson 1971), 50 kg P/ha is a usual dose. There is the possibility then, that in the present experiment, had a greater amount been applied, the results might have been more clearcut.

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