EFFECT OF NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZERS ON GROWTH OF SEMIMATURE JACK PINE FOREST, CHAPLEAU, ONTARIO: FIFTH-YEAR RESULTS

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ABSTRACT

A factorial experiment involving three levels of N supplied as urea, three of P as triple superphosphate, and three of K as muriate of potash, was established in a 45-year-old relatively pure jack pine (*Pinus banksiana* Lamb.) stand in the Chapleau area of north-central Ontario. The PAI on controls was approximately 5.6 m^3/ha. After 5 years the following response variables were determined: mean DBH increment, BA increment, % BA growth, total volume increment and merchantable volume increment. Analysis of variance revealed significant treatment responses only to N; no interactions were significant. Ranking of means suggested, however, that some benefit may have resulted from P and K treatments in combination with N. The best response was to N336 P112 K112, and this resulted in an increase in PAI over control (total volume basis) of approximately 2.6 m^3/ha/yr.

RÉSUMÉ

On a procédé à une expérience factorielle concernant trois concentrations de N (sous forme d'urée), trois de P (sous forme de triple superphosphate) et trois de K (sous forme de muriate de potasse), dans un peuplement relativement pur de Pin gris (*Pinus banksiana* Lamb.) âgé de 45 ans, dans la région de Chapleau, dans le centre-nord de l'Ontario. L'accroissement périodique annuel (APA) sur les témoins fut approximativement 5.6 m^3/ha. Après 5 ans, on détermina les variables de réponse au traitement comme suit: accroissement moyen du D.H.P., accroissement de la ST, accroissement en % de la ST, accroissements du volume total et du volume marchand. L'analyse des variances révéla une réponse marquée au traitement, seulement en ce qui concerne N; aucune interaction significative ne fut observée. Cependant, le classement des moyennes fit croire que certains avantages auraient résulté des traitements au phosphore et au potassium avec de l'azote. La réponse la plus favorable fut celle provenant de N336 P112 K112, qui eut pour résultat un APA supérieur d'approximativement 2.6 m^3/ha/année comparativement aux témoins (sur la base du volume total).

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INTRODUCTION

In the spring of 1970, five fertilizer field experiments, part of a larger series of such trials with the chief objective of "determining the significant biological and economic factors and effects of fertilizing pulpwood stands in northern Ontario", were established in a continuous, relatively pure, 45-year-old jack pine (*Pinus banksiana* Lamb.) stand in the Chapleau area of north-central Ontario. At the time these experiments were initiated, it was widely believed that nitrogen (N) is the chief soil-derived element whose lack limits growth of adult conifers on upland sites in the boreal region. This belief has been substantiated by the results of fertilizer experiments that have subsequently become available.

It was recognized, however, that when N demand is satisfied in soils, the supply of a second element such as phosphorus (P) or potassium (K) could become limiting. (See Russell [1961] on Liebig's Law of the Minimum: "The amount of plant growth is regulated by the factor present in minimum amount and rises or falls as this factor is increased or decreased.")

That both P and K are essential to vegetable life has been proven amply over the course of a century, not only in numerous culturing experiments in which the elements are either withheld or provided in controlled amounts, but also in various physiological investigations wherein P has been implicated in energy transfer and K in osmotic regulation. With particular reference to jack pine, Swan (1960, 1970) has, in culture, demonstrated the effects of deprivation of both elements in seedling growth.

Typical jack pine soils of the Chapleau area (represented by those of the present experiment) are developed in geologically young, glacio-outwash and glacio-lacustrine materials evidencing extensive reworking by wind. The mineral materials themselves are of low weatherability, and are generally low in available nutrients. Their ability to supply sufficient P or K to fulfil growth expectations after N-melioration is unknown.

Various indirect diagnostic techniques, e.g., soil analysis, pot-trials, visual symptoms, foliar analysis, have been investigated for the determination of tree nutrient status and for the prediction of fertilizer response (Morrison 1974). Of these, foliar analysis has probably been the most successful. The fertilizer field trial, however, because it is most direct and most closely simulates operational practice, remains the method-of-choice for the prediction of fertilizer response and the standard against which other techniques are judged. As Leyton (1957) states: "Ultimate proof of the benefits to be obtained by fertilizer amendments is undoubtedly obtainable only by actual fertilizer trials in the field."

Consequently, to determine whether these sites can provide sufficient P and K to fulfil growth expectations after N-manuring and to establish a standard against which results of foliar analysis could be judged, a factorial experiment was designed to test for response to various levels of N, P and K fertilizers alone and in all combinations.

STUDY AREA

The stand in which this experiment and others (Morrison et al. 1976b) were established simultaneously is located at lat. 47° 38'N, long. 83° 15'W, some 25 km SSE of Chapleau, Ontario in Nimitz Township on the border of Dupuis Township, Sudbury District. It is within the Missinaibi-Cabonga Section (B.7) of the Boreal Forest Region (Rowe 1972), and on the common boundary of the Foleyet Site District of Site Region 3E and the Mississagi Site District of Site Region 4E (Hills 1955), approximately on the height-of-land separating the Arctic and Great Lakes watersheds. The soil, which is unmapped, is in profile a Mini Humo Ferric Podzol (Anon. 1974) developed in silt loam over loamy sand, the strata separating at a depth of 30 cm below the mineral surface. The growing season, which extends from May through September, averages 161 days on the basis of a 5.5°C index (Chapman and Thomas 1968). Annual mean total precipitation measured at the nearest weather station (Chapleau) is 810 mm, with approximately 53% of this falling during the growing season (Anon. 1973). Annual potential evapotranspiration has been estimated at 480 mm (Chapman and Thomas 1968). The area is within the Height-of-Land Climatic Region (ibid.).

At the beginning of the experiment the stand was 45-year-old (stump age), relatively thrifty, uniform jack pine forest of fire origin. In the immediate vicinity of this experiment mean dominant height was approximately 16.8 m; mean DBH 11.4 cm (range 2.5-25.9 cm); BA 27.8 m^2/ha; total standing volume 164.3 m^3/ha; merchantable standing volume 128.5 m^3/ha; and number of trees 2,720/ha. Site Class was I (Plonski 1974).

A continuous moss layer with *Pleurozium schreberi* (BSG.) Mitt. predominating and *Dicranum polysetum* SW and *Hypnum crista-castrensis* Hedw. in lesser abundance occupied the forest floor. Frequently occurring species in the shrub and herb layers, which in themselves were light, were *Vaccinium angustifolium* Ait., *V. myrtilloides* Michx., *Comptonia peregrina* (L.) Coult., *Cornus canadensis* L., *Oryzopsis asperifolia* Michx., *Maianthemum canadense* Desf. and *Anemone quinquefolia* L. (see Appendix).

METHODS

Samples of current foliage were collected in the fall of 1969 from the upper portions of the crowns of eight jack pine trees of either dominant or codominant crown class in the immediate vicinity of the experiment. Following removal to the laboratory, samples were dried at 70°C in a forced-draught oven, ground in a laboratory knife mill and analyzed as follows: N by a semi-micro Kjeldahl procedure, digesting with a mercury catalyst and steam distilling for titrimetric estimation; P colorimetrically upon development of phospho-molybdenum blue; K by flame emission spectroscopy using a Perkin-Elmer Model 290 Spectrophotometer, and calcium (Ca) and magnesium (Mg) by atomic absorption spectroscopy using a converted form of the same instrument.

The field experiment was set out as a 3x3x3 factorial consisting of three levels of N (0, 168 and 336 kg N/ha) supplied as urea prills, three levels of P (0, 56 and 112 kg P/ha) supplied as triple superphosphate, and three levels of K (0, 56 and 112 kg K/ha) supplied as muriate of potash. Block I of the experiment was established in late May, 1970 and remeasured 5 years later in late May, 1975. A replicate (Block II) was established in the adjoining forest in late May, 1971 and remeasured in late May, 1976. For purposes of analysis, data from both blocks were pooled for a total of 54 treatment plots. Treatment plots were square, 0.08 ha in area, each with an inner 0.02 ha measurement plot. Within blocks, treatment plots were arranged in a grid pattern with shared boundaries, the portion of the treatment plot external to the measurement plot serving in each case as a buffer. Trees were identified with numbered metal tags. Fertilizers were hand broadcast, in a systematic two-or-more-pass pattern to provide uniform coverage, on Blocks I and II in late May, 1970 and late May, 1971 respectively. Initial measurements of DBH by steel diameter tape were made and recorded at the same time. Heights of one randomly selected tree per 2.5 cm diameter class in each plot were also measured. In accordance with standard procedure, trees which died during the period of the experiment were deleted from the tally. All measurements were in English units with subsequent conversion to S.I. units.

After the respective 5-year periods for Blocks I and II, the following response variables were calculated: mean DBH increment, BA increment, % BA growth and total and merchantable volume increments. Five-year mean DBH and BA increments and % BA growth were calculated in the usual manner. Total and merchantable volume were estimated as follows: a regression of height-on-diameter, derived from pooled measurements on sample trees (augmented by data from similarly selected trees in nearby experiments), was used to estimate the height of each tree. Total and merchantable volumes, for both the beginning of the experimental period and 5 years after (1970-1975 in the case of Block I, 1971-1976 in the case of Block II), were computed on a tree-by-tree basis for each plot, using estimated heights, measured DBHs, and Honer's (1967) volume equations. (Thus, any change in form which may have resulted from fertilization was not taken into account.) Total and merchantable volume increments were calculated for each plot by subtracting initial from final volume figures. 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 results are given in Table 1, as are foliar concentrations of N, P, K, Ca and Mg purportedly associated with good to very good growth of jack pine (Swan 1970). Compared with these "suggested standards for the evaluation of the results of foliar analyses" (ibid.), N and Mg concentrations fell within the transition zone from deficiency to sufficiency, P within the range of acute deficiency, and K and Ca within the range of sufficiency for good to very good growth.

Results of analysis of variance (Table 2) indicate, in relation to all parameters tested, a highly significant (1%) response to N, but no significant response (up to at least the 5% level) to P or K, nor any interaction associated with any combination of N, P or K. Table 3 presents treatment means, with means significantly greater than control (as determined by Duncan's New Multiple Range Test) indicated by asterisks. Diameter growth increased significantly (5%) in response to only one treatment (N336 P56 K56) and was associated with a corresponding significant increase in % BA growth. In the same treatment, increases in BA (absolute) and total and merchantable volume were non-significant and, at best, mediocre. Close inspection of the data revealed that the N336 P56 K56 plots were associated in at least one case with a low initial standing volume, such that while individual tree and percentage increases were considerable, they were not sufficient to overcome in absolute growth the effect of understocking.

Five-year volume (total or merchantable) growth on control plots (Table 3) was approximately 28 m^3/ha, corresponding to a mean periodic annual increment (PAI) of 5.6 m^3/ha/yr. The best and only statistically significant response in terms of total volume increment (similar for merchantable volume increment) was obtained with the N336 P112 K112 treatment where growth over controls (Table 4) over the 5-year period was approximately 13 m^3/ha, corresponding to an increase in PAI of 2.6 m^3/ha/yr. Thus, the most beneficial treatment increased total volume growth over control by approximately 46%. While the analysis of variance indicated significant response only to N, examination of the data, with particular reference to volume increase over control (Table 4), revealed

Table 1. Pre-fertilization concentrations of elements in current, upper-crown, jack pine foliage compared with (published) levels of sufficiency for good to very good growth

	Concentration (%)				
	N	P	K	Ca	Mg
Present study	1.32±.08	.08±.01	.50±.13	.16±.04	.08±.02
Sufficient*	1.50-2.50	.18-.35	.35-.70	.11-.40	.09-.16

* Suggested as sufficient for good to very good growth (Swan 1970).

Table 2. Analysis of variance: summary of F-ratios

	Response variables				
Treatment	Mean DBH increment	Basal area increment	Basal area growth %	Total vol. increment	Merch. vol. increment
N	8.06**	10.77**	8.28**	13.46**	12.30**
P	1.20	1.45	.37	1.99	1.88
K	.10	.32	.57	.41	.35
NP	1.24	1.70	.23	2.25	2.36
NK	.86	.89	.80	1.28	1.12
PK	.05	.36	.19	.47	.43
NPK	.16	.13	.23	.23	.19

** Statistically significant, P = .01.

Table 3. Five-year growth response of 45-year-old jack pine to various combinations of nitrogen, phosphorus and potassium fertilizers

	Response variables				
	Mean DBH increment (cm)	Basal area increment (m^2/ha)	Basal area growth (%)	Total vol. increment (m^3/ha)	Merch. vol. increment (m^3/ha)
CONTROL	0.83	3.64	13.90	27.98	27.91
K 56	.75	2.88	12.95	21.72	21.91
K 112	.69	3.52	12.75	26.49	26.72
P 56	.79	3.95	13.35	29.53	29.79
P 56 K 56	.75	3.81	13.20	28.89	28.99
P 56 K 112	.73	3.50	12.40	26.50	26.50
P 112	.86	3.67	14.25	28.73	28.48
P 112 K 56	.69	3.49	13.95	26.19	26.31
P 112 K 112	.69	3.19	12.20	24.10	24.15
N 168	.87	4.19	14.75	31.72	31.67
N 168 K 56	.95	3.72	16.00	27.77	28.03
N 168 K 112	.98	4.49	17.55	33.81	33.66
N 168 P 56	.92	4.51	17.35	34.22	34.85
N 168 P 56 K 56	.93	4.41	15.80	33.24	33.24
N 168 P 56 K 112	.99	4.62	17.15	34.96	34.66
N 168 P 112	.86	4.72	16.10	35.46	35.65
N 168 P 112 K 56	.86	4.69	17.70	34.95	34.97
N 168 P 112 K 112	.93	5.06	18.50	38.04	38.16
N 336	.83	4.21	15.90	31.66	31.83
N 336 K 56	.93	4.75	17.05	36.10	36.25
N 336 K 112	.95	4.92	18.90	36.81	37.29
N 336 P 56	1.11	3.64	16.60	27.68	27.45
N 336 P 56 K 56	1.37*	4.33	24.40*	32.26	31.81
N 336 P 56 K 112	1.19	3.86	18.80	28.64	28.43
N 336 P 112	.89	4.61	16.65	34.83	35.05
N 336 P 112 K 56	1.01	4.88	20.60	36.47	36.82
N 336 P 112 K 112	1.08	5.39	18.60	41.02*	41.21*

* Significant over control, P = .05

Table 4. Five-year total volume growth-over-control for 45-year-old jack pine subjected to various nitrogen, phosphorus and potassium treatments

Treatment	Total volume growth-over-control (m^3/ha)		
	N 0	N 168	N 336
K 0	0	3.74	3.68
K 56	-6.26	- .21	8.12
K 112	-1.49	5.83	8.83
P 56	1.55	6.24	- .30
P 56 K 56	.91	5.26	4.28
P 56 K 112	-1.48	6.98	.66
P 112	.75	7.48	6.85
P 112 K 56	-1.79	6.97	8.49
P 112 K 112	-3.88	10.06	13.04*

* Significant over control, P = .05.

some (non-significant) trends. Generally growth increased with increasing level of N; without N, P appeared to have little effect, whereas *with* N, P generally increased growth further; without N, K may have a depressing effect and, whereas with P and *low* N it appeared to have no effect, with P and *high* N it generally furthered growth.

DISCUSSION

Analysis of variance revealed significant effects from treatment with N only; in no case was any interaction significant up to the 5% level. Inspection of trends suggested that, without N, P and/or K may have had deleterious effects on growth, but when N-demand was satisfied some additional growth may have been realized from P and even further from K with N and P. This is generally in keeping with the earlier findings for 55-year-old jack pine in the Dryden area of northwestern Ontario reported by Hegyi (1974) and Morrison et al. (1976a). There, in a factorial experiment involving N, P and K on a till site, treatment effects were significant only for N and only in terms of BA and total and merchantable volume increment. As in the present experiment no interactions were significant, although better responses were associated with combinations of N and P. In two other experiments (Hegyi 1974, Morrison et al. 1976a), both involving N and P, along with K in one case and Mg in the other, in factorial combination, and both on sandy outwash sites, main treatment effects likewise occurred only for N, but in both, N-P interactions were significant. Better treatments, likewise, consisted of combinations of N and P. By way of further comparison, Hoyt (1973), assessing 5-year BA response in NPK factorial trials in 39- and 45-year-old jack pine stands on clay loam and podzolic sand sites, respectively, in New Brunswick, reported significant response only to N, but concluded that it was possible that stands on sandy sites "could benefit from applications of both N and P". Weetman and Algar (1974), working with a 42-year old jack pine stand on a deep outwash sand in Quebec, reported that the addition of P or K to N (supplied as urea at a rate of 224 kg N/ha) did not produce any significant increase in 3-year BA increment over that produced by the N alone. More recently, Weetman et al. (1976), in four experiments all involving combinations of N, P and K in 40- to 60-year-old jack pine forest in Ontario and Quebec were unable to report any significant response in terms of 5-year volume increment to P or K over that to N alone. Elsewhere, and with other species and excluding those sites with proven P or K deficiencies, Farmer et al. (1970) with loblolly pine (*Pinus taeda* L.), short leaf pine (*P. echinata* Mill.) and Virginia pine (*P. virginiana* Mill.) at a variety of locations in the southeastern United States were unable to report significant responses to P in terms of 5-year BA increment, over and above those to N alone, although in most cases some extra growth did accrue when P was added. With Scots pine (*P. sylvestris* L.) in Norway, Brantseg et al. (1970), on the basis of 4- to 6-year BA responses of stands in 19 locations, noted that the addition of P or K generally did not result in significantly increased increment. Likewise, with 55-year-old Scots pine on a fine sandy site in Germany, Tolle (1975) was unable to report any additional increase in 5-year volume increment resulting from K-application over and above that resulting from N-application alone.

In this particular experiment, confidence to be accorded to the individual means (for use as working values) is diminished by the low level of replication. A further dimension of variability entered into the present analysis in that, for reasons beyond the control of the authors, Blocks I and II were installed one year apart. It might be noted, however, that such variability, as this might introduce, would undoubtedly result in a more conservative estimate of significance. Some comment also must be made with respect to several anomalous values, most obvious when data are arranged in matrix form as in Table 4. Upon further inspection, it was discovered that at least some of these values were associated with plots of low initial standing volume where even good percentage growth responses were not enough to overcome the effect of understocking.

The magnitude of better responses in this experiment relative to responses observed to similar treatments elsewhere is of practical interest. Better responses in terms of total volume PAI over controls in the present experiment were in excess of 2.6 m^3/ha/yr, whereas in 55-year-old jack pine in northwestern Ontario (Hegyi 1974, Morrison et al. 1976a) one response to a combination of urea plus triple superphosphate was as high as 3.2 m^3/ha/yr. By way of comparison, Hoyt (1973), working with jack pine in New Brunswick, reported an increase in PAI over controls associated with NPK fertilizing of 1.7 m^3/ha/yr for a 55-year-old stand, and for a 39-year-old stand an increase of 1.4 m^3/ha/yr associated with P-fertilizing. Weetman et al. (1976) with jack pine in Ontario and Quebec reported increases in PAI over controls generally in the order of 1-2 m^3/ha/yr, although in one case a response of nearly 3 m^3/ha/yr to a combination of 224 kg N and 112 kg K/ha was observed. Cochran (1975), working with lodgepole pine (*Pinus contorta* Dougl.) in the northwestern United States, reported an increase in PAI over controls, associated with 672 kg N, 336 kg P and 672 kg S/ha, of 1.6 m^3/ha/yr. Wells et al. (1976), working with loblolly pine in the eastern United States, observed on coastal plain sites responses as high as 5.7 m^3/ha/yr associated with ammonium nitrate fertilizing, and on a Piedmont site in Virginia a response in the order of 3 m^3/ha/yr associated with 336 kg N/ha as urea. Experience in Sweden suggests that a response of 2-4 m^3/ha/yr over controls might be expected to urea fertilizing at rates of 200-250 kg N/ha (Möller 1971, 1974).

On the basis of 1976 prices quoted in Sault Ste. Marie for bulk urea, triple superphosphate and muriate of potash, of reported application costs, and of a 3:1:1 application ratio for elemental N:P:K (as in the N336 P112 K112 treatment), it would appear to be approximately 68% more costly to apply P plus N than it would be to apply N alone, and to add the K treatment would increase the overall cost another 21%. While these figures will vary somewhat as the relative prices of urea, triple superphosphate and muriate of potash change, and as application costs change, they can be used to judge the cost-effectiveness of the additional treatments, which in the case of the present study would appear to be beneficial. This is meant by way of illustration, however, and caution must be employed as differences between individual means were, in most cases, non-significant.

Finally, concerning foliage analysis values, as there was a response to N but not to K (when applied singly) the observed values (Table 1) are commensurate with Swan's (1970) "transition zone from deficiency to sufficiency" and "range of sufficiency for good to very good growth", respectively. The lack of response to P applied singly, despite a foliar concentration of only 0.08%, suggests that the critical value for that element may be somewhat lower than Swan's (ibid.) suggested standard.

In conclusion, the analysis of variance clearly indicates that N was the only element which, when applied alone, evoked a growth response in this stand. While interactions with P and K were not significant, ranking of means provides some evidence that when N-demand is met some additional benefit may accrue as a result of P or even K application.

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APPENDIX

APPENDIX

Occurrence of lesser plant species prior to treatment, expressed as percentage of plots on which species occurred, based on sample of 81 m^2 quadrats.

Species	Occurrence (%)
LICHENS	
Cladonia spp.	18
MOSSES	
Polytrichum spp.	15
Dicranum polysetum SW.	37
Hypnum crista-castrensis Hedw.	15
Pleurozium schreberi (BSG.) Mitt.	100
CLUBMOSSES	
Lycopodium obscurum L.	4
SEED PLANTS	
Picea mariana (Mill.) B.S.P.	33
Oryzopsis pungens (Torr.) Hitchc.	11
Oryzopsis asperifolia Michx.	100
Carex spp.	52
Maianthemum canadense Desf.	100
Goodyera repens (L.) R. Br.	4
Salix spp.	59
Comptonia peregrina (L.) Coult.	93
Anemone quinquefolia L.	96
Coptis groenlandica (Oeder) Fern.	7
Amelanchier spp.	22
Fragaria virginiana Duchesne	11
Rubus pubescens Raf.	11
Rosa acicularis Lindl.	41
Prunus pensylvanica L.f.	4
Polygala paucifolia Willd.	89
Viola spp.	30
Cornus canadensis L.	96
Pyrola secunda L.	4
Kalmia angustifolia L.	4
Ledum groenlandicum Oeder	26

(continued)

APPENDIX (concl'd)

Occurrence of lesser plant species prior to treatment, expressed as percentage of plots on which species occurred, based on sample of 81 m^2 quadrats.

Species	Occurrence (%)
Epigaea repens L.	78
Vaccinium angustifolium Ait.	100
Vaccinium myrtilloides Michx.	89
Trientalis borealis Raf.	7
Melampyrum lineare Desr.	7
Diervilla lonicera Mill.	56
Linnaea borealis L.	89
Solidago bicolor L.	67
Aster macrophyllus L.	11