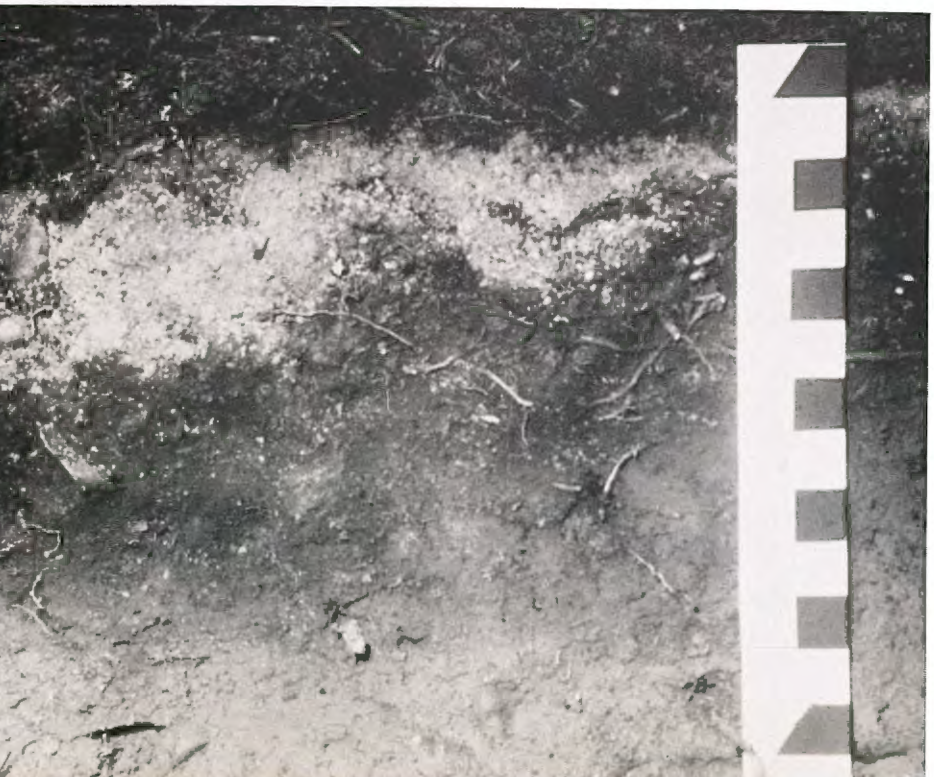

M-X-123
ISSN 0704-769X

FACTORIAL EXPERIMENTS WITH NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZERS IN SPRUCE AND FIR STANDS OF NEW BRUNSWICK: 10-YEAR RESULTS

by
H. H. KRAUSE

MARITIMES
CANADIAN FORESTRY SERVICE

MARITIMES FOREST RESEARCH CENTRE

The Maritimes Forest Research Centre (MFRC) is one of six regional establishments of the Canadian Forestry Service, within Environment Canada. The Centre conducts a program of work directed toward the solution of major forestry problems and the development of more effective forest management techniques for use in the Maritime Provinces.

The program consists of two major elements - research and development, and technical and information services. Most research and development work is undertaken in direct response to the needs of forest management agencies, with the aim of improving the protection, growth, and value of the region's forest resource for a variety of consumptive and non-consumptive uses; studies are often carried out jointly with provincial governments and industry. The Centre's technical and information services are designed to bring research results to the attention of potential users, to demonstrate new and improved forest managment techniques, to assist management agencies in solving day-to-day problems, and to keep the public fully informed on the work of the Maritimes Forest Research Centre.

COVER PHOTOS

Top: Balsam fir, Green River, Experiment E.

Bottom: Soil profile, Nashwaak, Experiment C.

FACTORIAL EXPERIMENTS WITH NITROGEN, PHOSPHORUS, AND POTASSIUM FERTILIZERS IN SPRUCE AND FIR STANDS OF NEW BRUNSWICK: 10-YEAR RESULTS

by

H.H. Krause

Department of Forest Resources
University of New Brunswick
Fredericton, New Brunswick

Information Report M-X-123

Maritime Forest Research Centre
Canadian Forestry Service
Department of the Environment
P.O. Box 4000, Fredericton, N.B. E3B 5P7

1981

CONTENTS

ABSTRACT

The effects of nitrogen, phosphorus and potassium on tree growth were tested at two levels (residual and residual plus fertilizer supplement) in natural stands of black spruce (*Picea mariana* (Mill.) B.S.P.), mixed red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.) and pure balsam fir at five different locations in New Brunswick. Nitrogen was applied at the rate of 168 kg ha^{-1} as urea, phosphorus at the rate of 112 kg ha^{-1} as triple superphosphate, and potassium at the rate of 112 kg ha^{-1} as potassium sulphate. Trees were measured at the time of treatment and remeasured after 5 and 10 full growing seasons. Treatments were evaluated on the basis of total volume gross and net periodic increments.

All stands showed significantly increased gross periodic increments with nitrogen fertilization. This treatment effect was strongest in the first 5-year period. Separate nitrogen application yielded a maximum 10-year growth response of 12.5 m^3 ha^{-1} total volume, approximately 20% of the gross periodic increment without treatment, in a mixed red spruce-balsam fir stand on well drained, loamy soil. The two black spruce stands showed best growth with combined nitrogen and phosphorus treatment. However, there were no statistically significant phosphorus main effects nor nitrogen x phosphorus interactions. There also was no convincing evidence that potassium benefited tree growth in these experiments.

All stands showed high tree mortality in the second 5-year period of the experiments. Volume losses exceeded fertilization gains in most instances and resulted more often than not in negative net periodic increments.

RESUME

Les effets de l'azote, du phosphore et du potassium sur la croissance des arbres ont été testés à deux niveaux (résiduel et résiduel plus supplément par engrais) dans des peuplements naturels d'Épinette noire (*Picea mariana* (Mill.) B.S.P.), d'Épinette rouge (*Picea rubens* Sarg.) et de Sapin baumier (*Abies balsamea* (L.) Mill.) et des peuplements purs de Sapin baumier en cinq endroits différents au Nouveau-Brunswick. L'azote a été administré sous forme d'urée à raison de 168 kg ha^{-1}, le phosphore sous forme de superphosphate triple à raison de 112 kg ha^{-1} et le potassium sous forme de sulfate de potassium à raison de 112 kg ha^{-1}. Les arbres ont été mesurés au moment des traitements et remesurés au bout de 5 et 10 saisons plénières de croissance. Les traitements ont été évalués sur la base des accroissements périodiques en volume total brut et net.

Tous les peuplements ont accusé des accroissements périodiques bruts significativement plus grands avec la fertilisation à l'azote. L'effet de ce traitement s'est avéré le plus puissant dans la première période de 5 années. L'épandage d'azote a produit en 10 ans une réaction de croissance maximale de 12,5 m^3/ha^{-1} en volume total, soit près de 20% de l'accoissement périodique brut sans traitement, dans un peuplement mélangé d'Épinette rouge et de Sapin baumier venant sur un sol limoneux bien drainé. Les deux peuplements d'Épinette noire ont manifesté la meilleure croissance avec le traitement combiné à l'azote et au phosphore. Cependant, le phosphore n'a pas eu d'effets principaux statistiquement significatifs et il n'y a pas eu non plus d'interactions de l'azote et du phosphore. Il n'y a pas eu également de preuve convaincante que

Use of fertilizers in naturally regenerated and unmanaged spruce and fir stands of the region is not recommended because of the potentially high and uncontrolled tree mortality and because of generally low stumpage values. However, fertilization may hold a certain potential if preceded by spacing and thinning to control stocking and to improve the value of the stands.

le potassium ait favorisé le croissance des arbres dans ces expériences.

Tous les peuplements ont accusé une forte mortalité des arbres au cours de la seconde période quinquennale des expériences. Les pertes en volume ont dépassé les gains par fertilisation dans la plupart des cas et se sont soldées plus souvent qu'autrement en des accroissements périodiques nets négatifs. L'usage d'engrais n'est pas recommandé dans les peuplements d'Épinette et de Sapin de la région régénérés naturellement ou non aménagés, à cause de la mortalité potentiellement forte et incontrôlée des arbres avant que ces peuplements n'atteignent l'âge de gros bois fort ainsi que des valeurs généralement faibles des bois sur pied. Toutefois, la fertilisation peut avoir un certain potentiel si elle est précédée d'un espacement et d'une éclaircie à l'effet de contrôler le matériel sur pied et relatif et améliorer la valeur des peuplements.

ACKNOWLEDGEMENTS

The installation of experiments and early stand measurements were accomplished with the valuable help of Messrs. R.M. Day, R.D. Mercer, R.H.A. Leduc, D.N.F. Chai and F. Gatundu who worked as student assistants on this project. A major portion of the field work was carried out by Mr. D.J. Beggs who was employed as a technician by the Faculty of Forestry. Mr. T.J. Mullin tested the various approaches for quantifying the height/diameter relationships, remeasured the stands, and computed the 5-year growth responses. The 10-year remeasurements and computations were done by Mr. T.A. Erdle.

This project received financial support from the Canadian Forestry Service in the form of extramural research grants, research subventions and contracts. Throughout these fertilization studies Dr. M.K. Mahendrappa acted as the liaison officer and scientific authority for the Maritimes Forest Research Centre.

INTRODUCTION

By the mid-1960's, many studies had indicated that tree growth in the northern coniferous forest is commonly limited by nutrient shortage, particularly nitrogen (N). It was logical to assume that such shortages would intensify with stand age because of the accumulation of nutrients in the tree biomass and forest floor. An example of early awareness for the need of supplementary N by stands in the pole-size and timber stages is the study of Weinkauff (1941). He had calculated that Norway spruce (Picea abies (L.) Karst.) and Scots pine (Pinus sylvestris L.) between the ages of 40 and 100 years required annual N supplements from 1.2 to 22.6 kg ha^{-1} to maintain satisfactory growth. Considerable attention had also been given to excessive raw humus formation which would seriously diminish the rate of biogeochemical nutrient cycling and further aggravate N shortages in coniferous stands of older age classes (Wittich 1952, Weetman 1961).

Convincing proof of N deficiency in pole-size and timber stage stands had been obtained first by simple fertilization trials in central and northern Europe during the 1930's and 40's (Hesselman 1937, Fabricius 1940, Berg 1952). Continued field experimentation in Sweden had revealed that yield and quality of Norway spruce and Scots pine stands could be improved substantially by N fertilization, but that responses to phosphorus (P) and potassium (K) additions would be small if present at all (Tamm and Carbonnier 1961).

The silvicultural potential of forest fertilization was recognized by Scandinavian foresters in the early 1960's. Both industry and governments mounted fertilization programs which have grown steadily through the 1960's and most of the 70's (Hagner 1967, Holmes 1977).

Canadian forest industries had experienced rapid expansion during the 1950's and 60's. Forest fertilization, as practiced in Scandinavian countries, had a special appeal for improving the vanishing wood supplies in the vicinity of production centres. Field experiments sponsored by industries, governments, and universities were therefore initiated in most provinces during the late sixties and early seventies.

This report gives the results of a series of identical fertilization experiments carried out in pole-size and early timber-stage spruce and fir stands at various locations in New Brunswick between 1968 and 1979. Since no quantitative information was available on nutrient availability in forest soils of New Brunswick and the immediate Atlantic region at initiation of this study, the experiments were designed to determine main effects and interactions of N, P, and K when present at two levels (residual and fertilizer amended). Follow-up experiments were planned to ascertain optimum application rates and response surfaces where proven that shortages of more than one of the three elements limited tree growth.

MATERIALS AND METHODS

Experimental Sites

Experiments of identical design were established at six locations in New Brunswick (Fig. 1). These represent some of the important growing regions in the Province. One of these experiments (Canaan) was terminated early because of heavy damage by an ice storm. It is, therefore, not reported here.

Experiment A (Bathurst)

The experimental site is located on level terrain about 120 m above sea level. The proximity of the ocean has moderated the climate to some degree (Appendix I). Precipitation is less than average for New Brunswick.

The soils, being derived from sand and siltstones (Pennsylvanian age), have sandy loam texture. The substrate is severely compacted which has led to impeded drainage and shallow rooting. The soils are classified as Gleyed Humo-Ferric Podzols (Canada Soil Survey Committee 1978). They are further characterized by high acidity, low contents of total N, available P, and exchangeable calcium (Ca) (Appendix II).

The forest stand is composed mainly of black spruce (Picea mariana (Mill.) B.S.P.) with an average age of 60 years[1]. Balsam fir (Abies balsamea (L.) Mill.) is present in small numbers contributing about 10% to the basal area. White pine (Pinus strobus L.) and white birch (Betula papyrifera Marsh.) are of sporadic occurrence (Appendix III). With a standing total volume of about 200 m^3 ha^{-1} and a net mean annual increment of about 3.3 m^3 ha^{-1}, it was the least productive stand in the series.

Experiment B (Piskahegan)

The experimental area lies about 140 m above sea level and slopes very gently towards the Piskahegan River. The climate differs from that of the other sites by the long frost-free period and high number of growing-degree days (Appendix I).

The soils are imperfectly and poorly drained sandy loams with profile characteristics of Gleyed Humo-Ferric Podzols and Orthic Gleysols. They have developed in till from red and grey sandstones (Pennsylvanian and Mississippian eras), silicic and mafic volcanic flows, tuffs, and related instrusive rocks. The presence of mafic materials in the till is reflected by a somewhat lower soil acidity than found at the Bathurst site, and high concentrations of exchangeable Ca and magnesium (Mg) in the surface horizons. Appendix II gives texture and nutrient contents of an imperfectly drained variant of these soils.

The forest stand is also dominated by black spruce (Appendix III). This stand was younger and revealed a somewhat greater past productivity than the Bathurst stand. Its net mean annual increment was about 3.8 m^3 ha^{-1} as compared to 3.3 m^3 ha^{-1} at the Bathurst site.

Experiment C (Nashwaak)

This experiment is located between 290 and 310 m above sea level on a gently undulating area near the Nashwaak River. The climate is more humid and the growing season is considerably shorter than at the two black spruce sites (Appendix I).

Soils have developed in till of diverse origin. Its coarse fraction is made up of granite, granodiorite, quartz monzonite, sandstone, greywacke and conglomerate fragments. The soils have sandy loam texture, are well drained and classified as Orthic Ferro-Humic Podzols. They are strongly acidic throughout the profile, but concentrations of available P show a noticeable increase with depth (Appendix II).

The forest stand is variable in composition. Balsam fir and red spruce (Picea rubens Sarg.) are present in about equal numbers, but red spruce comprises more than 50% of the basal area (Appendix III). The stand is the most productive one in the series. It exhibited a total volume of about 350 m^3 ha^{-1} at the average age of 48 years, indicating a net mean annual increment of about 7.2 m^3 ha^{-1}.

[1] Age at breast height plus 5 years.

Experiment D (Sevogle)

The experiment was carried out on undulating terrain near the South Sevogle River at the eastern side of the New Brunswick Highlands. The climate is characterized by a low mean annual temperature, high summer precipitation, short frost-free period, and a low number of growing-degree days (Appendix I).

The bedrock of this area includes formations of micaceous schist, gneiss and phyllites. These have given rise to till and soils with large silt and very fine sand fractions. Soils are further characterized by high porosity throughout the solum. Other features of interest are the moderately high concentrations of exchangeable K, Ca, and Mg in the surface horizon. Available P showed a marked increase in the C horizon (Appendix II). These soils were well-drained and exhibited the profile characteristics of an Orthic Ferro-Humic Podzol. The total stand volume at the time of treatment indicates a somewhat lower past productivity than shown for the Nashwaak site (Appendix III).

Experiment E (Green River)

The experimental area is gently sloping and located at about 500 m above sea level on the Northwestern Plateau of New Brunswick. Climatic conditions are among the least favourable in the Province with a frost-free period of 80 days and a low number of growing-degree days (Appendix I).

Till deposits in which soils have developed, are derived from slate, argillite, Greywacke, conglomerates and sandstones. The soil texture varies from sandy loam to loam. The soils are well drained and well structured and also exhibit the profile characteristics of an Orthic Ferro-Humic Podzol. Fertility is comparable or slightly higher than in the well-drained loams of the previous two experiments (Appendix II).

The stand is formed by balsam fir with an average age of 44 years. White spruce (Picea glauca (Moench) Voss), the remnants of the previous stand, and white birch are sporadically mixed with balsam fir (Apprendix III). This stand exhibited moderately high productivity. The standing total volume was 266 m^3 ha^{-1} at the time of treatment which corresponds to a net mean annual increment of about 6 m^3 ha^{-1}.

Experimental Design

Nitrogen, P, and K were tested at two levels in factorial combination. The levels were residual fertility and residual fertility plus 168 kg ha^{-1} (150 lb/acre) of N as urea and/or 112 kg ha^{-1} (100 lb/acre) of P as triple superphosphate and/or 112 kg ha^{-1} of K as sulphate of potash. The 8 treatments were replicated 5 times. The Piskahegan experiment included only 4 replicates because of limited stand size. The third order interaction was confounded in order to achieve a higher precision for main effects and second order interactions (Cox 1958). For this purpose, the 8 treatments were distributed in two blocks which formed one superblock or one replication (Fig. 2).

Circular or rectangular, 0.04-ha (0.1 acre) experimental plots were established. Rectangular plots were used where stand and terrain exhibited an acceptable degree of uniformity. Circular plots were found more convenient where such uniformity was lacking. It was aimed to space plots at a minimum distance of 10 m but a few plots lay closer together because of insufficient space or excessive variability of stand and terrain.

A 0.027-ha (0.067 acre) area was concentrically located in each plot (Fig. 2). Fertilizers were applied to the 0.04-ha plot, but growth measurements were limited to all trees on the inner plot. This provided a buffer zone about 2 m wide around each plot of measured trees. Fertilizers were applied during the first half of the 1968 growing season to plots of the Bathurst, Nashwaak, Sevogle, and Green River experiments, and early in the growing season of 1969 to plots of the Piskahegan experiment.

Stand Mensuration

All living trees with a diameter at breast height[1] (dbh) equal to or greater than 7.6 cm (3.0 inches) were numbered and the location of measurement on the stem was permanently marked. Breast height diameters were recorded to the nearest 0.025 cm (0.01 inch) with a steel tape before or at the time of treatment. Trees of the Bathurst, Nashwaak, Sevogle, and Green River experiments were remeasured after completion of the 1968, 1973, and 1978 growing seasons. Trees of the Piskahegan experiment were originally measured before fertilizer addition early in the growing season of 1969, and remeasured after completion of the 1973 and 1978 growing seasons. At each remeasurement, the number of dead trees was recorded on the tally sheets.

In the summer of 1973, the heights of 7 - 9 trees were measured on each plot of the Bathurst and Green River experiments. Equations proposed by Bennet (1966), Hendricksen (1950), Stoffels and van Soest (1953), and Trorey (1932) were used for quantifying the height/diameter relationship by treatments for the major species at each experimental site. The equation giving the best fit for an individual data set was selected. The standard error of the estimate was used as criterion for best fit.

Comparison of height/diameter relationships of different treatments did not reveal statistically significant differences. This was not entirely unexpected since the error of tree height measurements by the Suunto hypsometer has been found to vary between 2 and 4% (Fitje 1967). One height/diameter relationship was therefore determined for each experiment. For this purpose, the heights of 80 trees, randomly selected from all plots of an experiment, were measured after completion of leader growth in 1973 and again early in the season of 1979. Measurements of dbh were used to compute the basal area (BA) per plot and treatment. Total volumes (TV) were computed for each living tree and summed to obtain plot TV and treatment mean TV. This was accomplished by obtaining the height for each tree of given dbh from the previously established height/diameter relationship and by substituting both values into Honer's (1967) volume equations. The TV of dead trees was also determined. From the TV of surviving trees, 5-year gross periodic increments (PI) were computed. Net PI were obtained by subtracting the volume of all dead trees from the volume increment of survivor trees for the period in question.

Merchantable volumes (MV) were computed by assuming a stump height of 15 cm (0.5 feet) and a merchantable top diameter of 6.7 cm (3.0 inches).

Treatment means were tested statistically by covariance analysis using the model for a confounded 2^3 factorial experiment (Cox 1958). Initial total BA, TV, or MV were used as covariates.

RESULTS

Fertilization effects are evaluated in terms of TV. Mean BA and MV increments are given by treatment and experiment in Appendix IV.

---

[1] Measured at 1.37 m (4.5 feet) above ground level.

Gross Periodic Increment and Fertilization Response

Bathurst

The black spruce stand grew at an intermediate rate during the first 5-year period, but stagnated during the second 5-year period. The periodic annual increment (PAI) for total volume, without fertilizer treatment, was 5.3, 1.5 and 3.4 m^3 ha^{-1} for the first and second 5-year periods and for the 10-year period, respectively. Exact reasons for the decline in growth are not known, but it is conceivable that stand productivity decreased because of age and low level budworm (Choristoneura fumiferana (Clem.)) infestation.

The black spruce stand responded signficantly to N addition (Table 1). The total volume was increased by 8.3 m^3 ha^{-1} over the 10-year period (Table 2). About 60% of the total response was realized during the first 5-year period. The stand showed a maximum response to the combination N+P treatment. However, P main effect and NxP interaction were not statistically significant. Potassium seems to have interacted negatively with N. Application of N, N+K and N+P produced relative total volume growth responses of 24, 18.5, and 34.4% over the 10-year period (Fig. 3A).

Piskahegan

Black spruce at this location showed generally low PAI over the 10-year observation period (Table 2). Extensive tree mortality indicated early deterioration of this stand. This is probably the result of wet soil condition.

Nitrogen application significantly affected tree growth (Table 1). With the separate N application, the TV increment was improved by 4.7 m^3 ha^{-1} (Table 2) or 17.3% (Fig. 3B). The response was limited to the first 5-year period. With the combination N+P treatment, a 10-year PI of 8.4 m^3 ha^{-1} or 31% was recorded. However, P main effects and NxP interaction were not statistically significant.

Potassium addition failed to improve growth significantly. It seems to have interacted negatively with N or P or both in the N+P+K treatment.

Nashwaak

The mixed stand of spruce and fir showed moderately high productivity without fertility supplements (Table 3). The corresponding PAI were 5.3 and 7.7 m^3 ha^{-1} for the first and second 5-year periods, respectively. The slower growth at first is most likely due to a budworm infestation which was controlled later by the provincial insecticide spray program.

The spruce-fir stand responded strongly to the N treatment during the first 5-year period. The response continued through the second 5-year period so that the TV increment for the 10-year observation period was increased by 12.5 m^3 ha^{-1} or 19.2% (Fig. 3C). There were no significant P and K effects, but N and P interacted negatively and P and K showed a significant positive interaction (Table 1) during the second 5-year period.

Sevogle

The mixed fir-spruce stand suffered from budworm infestation throughout the entire study period. This is probably the main reason that the 10-year PI of this stand was considerably below that of the similar Nashwaak stand.

Nitrogen application resulted in a modest, but statistically significant growth response during the first 5-year period (Tables 1 and 3). However, in the second 5-year period, the N treated plots showed a lower TV increment than the control plots so that the N effect became insignificant for the 10-year period. Combination of N and K resulted in the highest periodic increments for the first 5-year period and the 10-year period, but the statistical analysis did not indicate significant K nor P effects.

A noticeable feature of this experiment is the decline of the mean PI for treated plots below the mean PI of control plots during the second 5-year period. This may indicate an unfavourable interaction of fertilizer treatments and budworm damage in trees.

Green River

The nearly pure balsam fir stand showed a moderately high productivity at indigenous soil fertility. The rate of growth was increased by 4.6 m^3 ha^{-1} (Table 3) or 13.6% (Fig. 3E) on the N fertilized plots during the first 5-year period. The N response had faded to 1.9 m^3 ha^{-1} or 6.8% during the second 5-year period. Although tree growth was best on plots with N+P+K treatment, the statistical analysis of data did not indicate significant P and K effects. During the second half of the experiment, P and K seemed to influence tree growth negatively. The 10-year data show clearly that no further benefit beyond the N effect was obtainable with P and/or K fertilizers at this site.

Tree Mortality, Net PI, and Fertilization Response

In the previous section, fertilization responses were based on the PI of survivor trees. Biologically, this appears to be the most appropriate approach, but in the overall context of forest management, the net gain in TV and value of the fertilized stands must be considered as overriding criteria. This cannot be done without accounting for volume losses due to tree mortality.

Tree mortality varied with experimental stand and time. Volume losses were generally much higher in the second than the first 5-year period. This may simply reflect the pattern of stand development. The natural stands, without density control, apparently begin to deteriorate at age 55 years or earlier. The presence of the spruce budworm undoubtedly accelerated this process in at least two of the experimental stands.

On the control plots of the Bathurst experiment, tree mortality reduced the TV increment by 13.5% in the first 5-year period and nearly cancelled the volume gain shown by survivor trees in the second 5-year period (Table 4). Although not proven statistically, mortality appeared to be increased by P and K treatments and it remained at a similar rate as on control plots with N-only and combined N+P and N+K treatments. As a result, fertilization responses based on net PI were actually negative for K and P treatments without N. For separate N addition and two element combinations including N, the responses were similar regardless whether based on gross or net PI.

The second black spruce stand at the Piskahegan River showed considerably greater mortality than the Bathurst stand. It was pointed out previously that stand deterioration at this site may have been hastened by the presence of excess water throughout portions of the growing season. As in the Bathurst experiment, volume losses were much larger in the second than in the first 5-year period (Table 4). Fertilizer treatments seemed to lower tree mortality. Fertilization responses based on net PI differed strongly from those obtained by considering survivor trees only. However, tree mortality showed a strong plot to plot variation, and the differences in volume loss by treatment were not statistically significant.

In the Nashwaak experimental stand volume losses were also larger during the second than the first 5-year period (Table 5). In the untreated stand, tree mortality reduced the PI of survivor trees by 33% during the first 5-year period and by 75% over the 10-year period. Fertilizer treatments did not impart an apparent pattern on tree mortality although losses were notably lower on P+K treated plots and increased by the 3-element treatment. The high N response of the surviving stand is also evident when net PI is considered.

The Sevogle spruce-balsam fir stand suffered high tree mortality during the second term of the experiment due to budworm infestation. As a result, the net gain in total volume over the 10-year period was negative for all treatments. Balsam fir was more strongly affected than red spruce. Table 5 suggests a small fertilization response in total volume net gain with N+K treatment.

The Green River balsam fir stand had the lowest rate of tree mortality. Of special interest are the large increases in the net PI with the N-only and the 3-element treatments (Table 5). However, as pointed out previously, fertilization responses based on net PI lack reliability since treatment means for tree mortality were not significant at the 5% level of probability.

DISCUSSION

The results from the five experiments are generally in agreement with those of other studies. However, responses to N tended to be lower in all but one of the five experiments than reported for other trials carried out under similar conditions. This could probably be attributed to differences in physical site. Also, the low stand vitality at several sites during the second half of this study may have affected adversely the response to fertilizer treatments.

Responses to Nitrogen

The two black spruce stands of this study showed increased annual growth of 0.8 and 0.5 $m^3 ha^{-1}$ over the 10-year observation period with addition of 168 kg N ha^{-1}. For comparison, van Nostrand (1979) reported increases in the PAI of 2.3 and 2.6 $m^3 ha^{-1}$ for a 9-year period following N fertilization at two black spruce sites in Newfoundland. The N application rate used by van Nostrand was only 1.3 times higher than in the present experiment, but the fertilizer was added in split applications, at the beginning of the experiment and two years later.

In a combination thinning and fertilization experiment in Quebec (Weetman 1975), N applied to unthinned stands at rates of 112 and 448 kg ha^{-1} increased the 10-year PAI by 0.9 and 2.1 $m^3 ha^{-1}$ (approx.). The fertilization response tended to be higher in thinned stands. The response shown with the low application rate was slightly higher than the best response obtained in the New Brunswick black spruce stands with 168 kg of N ha^{-1}.

Also of interest to the present study are the results of the interprovincial forest fertilization program (Weetman <u>et al.</u> 1981). In the three black spruce trials with significant treatment effects, the PAI was increased by 0.6, 0.9 and 2.0 $m^3 ha^{-1}$ in the first 5 years following application of 224 kg of N ha^{-1}. The corresponding values for our two black spruce experiments with the lower N application rate were both close to 1.0 $m^3 ha^{-1}$. Morrison and Foster (1979) reported a similar low

N response for a black spruce stand in northwestern Ontario.

Balsam fir in the nearly pure stand at the Green River experiment showed the same reaction to N addition as reported previously for a similar stand by Hoyt (1973). In both cases, the PAI was increased by 0.9 m^3 ha^{-1} over the first five years with 168 kg of N ha^{-1}. The Interprovincial Forest Fertilization Program included 14 balsam fir trials, three of which showed significant treatment effects (Weetman et al. 1981). In these trials, N addition at the rate of 224 kg ha^{-1} stimulated the PAI by 1.7, 2.1 and 3.1 m^3 ha^{-1}. These responses are far superior to the N effects on balsam fir in the New Brunswick experiments, even if adjustment is made for the differences in application rates. Larger fertilization gains than shown for balsam fir in the present study were also reported by Gagnon et al. (1979).

The Nashwaak experimental stand which showed a moderately high N response, consisted mainly of red spruce. Information on fertilization response by this species is very limited. A predominantly red spruce stand in Nova Scotia, being part of the Interprovincial Fertilization Program, showed an annual growth improvement of 1.2 m^3 ha^{-1} during the first 5 years following addition of 224 kg of N ha^{-1} of N (Weetman et al. 1981). In the Nashwaak experiment, the PAI was increased by 1.8 m^3 ha^{-1} during the same period with a considerably lower N application rate. White spruce, a somewhat more demanding species than red spruce in terms of nutrients, has shown increases in the PAI of 2.4 m^3 ha^{-1} during the first five years in Alberta trials of the Interprovincial Forest Fertilization Program (Weetman et al. 1981).

It is also of interest to compare the fertilization responses by spruce and fir from this study with responses of jack pine (Pinus banksiana Lamb.). Hoyt (1973) applied identical treatments as used in this study, to two semimature jack pine stands in New Brunswick. Addition of N only improved the PAI of the first 5 years by about 1.5 m^3 ha^{-1}. An only slightly lower response by jack pine to N addition was reported by Kingston et al. (1978). It seems that the N fertilizer has been more efficient in the jack pine stands than in the spruce and fir stands of the province, excepting the Nashwaak experimental stand.

Swedish foresters have established the average amounts of N required to produce 1 m^3 of wood. Values varied not only with species, but also with application rate and duration of response period (Jansson 1977). This information, reproduced in part in Fig. 4, represents useful reference points for rating the efficiency of the applied N. Accordingly, the N treatment of the two black spruce stands was lacking in efficiency because more than 20 kg of N were required to produce 1 m^3 of wood. With the same application rate of urea to a Norway spruce stand in Sweden, 18 kg of N would have been sufficient to produce 1 m^3 of wood over 10 years (Fig. 4). Nitrogen treatments were particularly inefficient in the pure balsam fir stand of the Green River experiment and the mixed fir-spruce stand of the Sevogle experiment. In contrast, moderately high efficiency was shown in the Nashwaak stand. The amount of N required to produce 1 m^3 of wood in this experiment was only two-thirds of the average amount required by Norway spruce to accomplish the same under Swedish conditions (Fig. 4).

What are valid reasons to explain the low efficiency of N treatments in all but one of the present experiments? Foliar analysis after completion of the first growing season showed substantial increases in N content of current-year needles from each of the experimental stands[1]. However, the duration of increased foliar N levels was short especially in the black spruce stands. This suggests that the increase of available N in the soil was short-lived and that the recovery of the added N by the trees was low. It has, in fact, been shown in other studies that fertilizer N disappeared rapidly from the mineral pool of the forest floor during the first few months after application, and more slowly thereafter (Mahendrappa 1978, Morrison and Foster 1977). After three years, the fertilization effect on the mineral N pool was mild or non-detectable, depending on site and application rate. With the disappearance of N from the mineral pool, increases in the organic pool were observed (Mahendrappa 1978, Morrison and Foster 1977, Roberge and Knowles 1965).

Immobilization of fertilizer N presumably was an important factor in the present study, especially in the black spruce experiments. In the words of Themlitz (1954), raw humus is N starved. Perhaps several intermediate rate fertilizer applications may be required to normalize the N nutrition of many middle-age and older coniferous stands in New Brunswick.

Another explanation for the low N responses in our study is the possibility that other mineral deficiencies limited growth.

[1] H.H. Krause, unpublished data.

Effects of Potassium and Phosphorus

The statistical analysis has not shown significant P or K main effects or positive interactions of these elements with N.

A lack of response to K addition was not unexpected as New Brunswick soils contain appreciable quantities of only partially weathered, K-bearing, primary layer silicates (Kodoma and Brydon 1968). These minerals are capable of sustaining an adequate labile K pool. Furthermore, K is being recycled efficiently in forest ecosystems after canopy closure (Cole et al. 1976, Foster and Morrison 1976, Switzer and Nelson 1972). It is therefore unlikely that a deficiency of K existed at the five sites with the possible exception of the Sevogle area. However, there is a possibility that the small effects shown for separate K application in Experiments A, B, C, and D (Tables 2 and 3) are real, and are due to enhanced mineralization of indigenous N in the presence of the K salt. Such salt effects have been discussed earlier by Broadbent and Nakashima (1971).

Although not statistically significant, P addition has shown small positive main effects and interactions in the two black spruce experiments, (Table 2). It would not be unreasonable to expect that P was deficient at these sites which are characterized by impeded drainage and low contents of available P in the mineral soil (Appendix II) and forest floor (Maftoun and Krause 1977). It is also possible that P effects, if in existence, were indirect insofar as the presence of calcium monophosphate reduced the loss of added urea N by volatilization (Mahendrappa and Ogden 1973) which, in turn, would have increased the recovery of added fertilizer N by trees. Also, the salt effect on the mineralization of indigenous N described previously in connection with K additions, may be applicable to P treatments.

Salt effect and reduced volatilization losses may also be the explanation for a possible growth improvement with a separate P application in the Nashwaak experiment. Combined application of N and P considerably increased growth beyond that obtained with a separate N treatment in a jack pine stand at a location not far removed from the Sevogle experiment (Kingston et al. 1978). However, there was no doubt that P addition failed to benefit the growth of the predominantly balsam fir stand of the Sevogle experiment and the pure balsam fir stand of the Green River experiment.

Inconclusive results with respect to P and K treatments were also reported by Weetman et al. (1981) for trials in the Interprovincial Forest Fertilization Program.

Implications to Forest Management

A logical question following the performance of field experiments is whether or not the tested treatments are operationally feasible. The answer has to include a certain form of cost/benefit analysis. What follows is not intended to be a comprehensive economic evaluation of forest fertilization under the local conditions, but a simple discussion of some relevant information.

Fertilization is feasible if the revenue from additional wood produced exceeds the total cost of fertilization. Cost usually includes the purchase price of fertilizers, their application, and interest charges. Owners of large forests may be in a position to disregard interest charges by invoking the "allowable cut effect", i.e., they may increase the allowable cut in the year of treatment by an amount that equals the expected gain in forest growth.

Determining the benefits from fertilizer treatments is more difficult as this depends not only on the quantity but also on the quality of the additional wood produced by the treatments as well as a number of other factors (Tucker 1974). Hence opposing answers may be obtained for a given response at different locations and different times.

Diameter distribution is an important parameter as it determines the value of extra wood produced and the cost of tree harvesting. Miller and Fight (1979) determined a negative present net worth of Douglas fir wood if it were produced at the rate of 200 cu. ft. (5.66 m^3) per 200 lb. (224 kg) of N applied, and if the mean dbh were 8 inches (20.3 cm). However, the present net worth turned positive as the mean dbh changed from 8 inches to 20 inches (50.8 cm). This diameter constraint existed despite the high stumpage values for Douglas fir in the Pacific Northwest of the United States and even though the allowable cut effect had been applied.

If the guidelines of this Douglas fir case study were applied to the results of the present study and general forest conditions in New Brunswick, fertilization would not appear to be a promising alternative for improving the wood supply in the Province. Even with responses as high as in the Nashwaak experiment, the economic threshold beyond which treatments are justified, may just be approached, provided stumpage prices were raised considerably above the present level.

The above comparison leads to the question whether or not the efficiency of added N can be improved sufficiently so that fertilization may be considered in forests of the north Atlantic region. One possible way may be to use fertilizer N at high enough rates to induce an amelioration effect on the accumulated raw humus (Wittich 1952, Themlitz 1954). The long-lasting response of a black spruce stand to urea application supplying 448 kg ha^{-1} of N in Quebec is seen to be due to favourable changes in the raw humus layer, including enhanced release of indigenous organic N and improved nutrient cycling (Weetman et al. 1980).

Source of N and time of fertilizer application may also affect the efficiency of the added N. However, a factor of primary importance is the vitality of the stands to be treated. The present experiments have shown that unmanaged coniferous stands in New Brunswick, 45 years old or older, are prone to high tree mortality. In fact, volume losses due to tree mortality were more often than not greater than fertilization responses, and the net PI for the 10-year observation period was negative in two of the five experiments. Operational fertilization would be irrational under these conditions. Such unmanaged stands which lack density and stocking control would probably show maximum productivity if harvested before they reach the age of 50 years.

Could fertilizers be used advantageously in naturally regenerated unmanaged stands harvested in short rotation? In the north Atlantic region, naturally regenerated conifer stands are usually very dense and characterized by a low mean dbh at age 45 or 50 years. Diameters would not change much if the total stand volume were increased by one or several N applications between ages 30 and 40 years. According to present standards, the major portion of wood from such stands would be directed to pulp mills and only a small portion would attain sawmilling quality. Under these conditions, stumpage values would be low, even if they represented fair market value, and use of fertilizers would not be warranted.

Another view on fertilizer use would probably emerge if stands, naturally or artificially established, were subjected to some degree of management, involving density and stocking control. For example, the Nashwaak experimental stand with a BA of about 52 m^2 ha^{-1} and a standing TV of about 350 m^3 ha^{-1}, at the time of treatment, was overstocked according to the Nova Scotia yield tables (Hawboldt and Kostjukovits 1961). Reduction of the BA by one-third, using especially adapted equipment, might have resulted in an economically viable pulpwood operation and would have left an improved stand capable of producing, with the help of appropriate amounts of N fertilizer, quality saw timber. Unfortunately, stands that merit such treatment are not abundant in the Province today.

SUMMARY AND CONCLUSIONS

1. Naturally regenerated and unmanaged black spruce, balsam fir, and mixed red spruce-balsam fir stands responded consistently to N fertilization.

2. In black spruce stands on imperfectly to poorly drained soils, small gains in tree growth were observed with P and combined N+P additions. However, the statistical analysis did not show significant P main effects or NxP interactions.

3. Potassium applied separately and in combination with N did not significantly affect tree growth. Positive and statistically significant P x K interactions occurred in two experiments, but no practical significance could be attributed to this observation.

4. The experimental stands showed high tree mortality in the second 5-year period of the study. This

resulted in negative net PI for most treatments at all experimental sites. In two experiments, net PI were negative for the entire 10-year period of the experiments.

5. Use of fertilizers in the unmanaged spruce and fir stands of the north Atlantic region is unlikely to yield benefits as shown by fertilization in the coastal forests of British Columbia or many other parts of the world because of high tree mortality, the tendency of stands to deteriorate early and low stumpage values. However, fertilization may offer a potential for improving the supplies of quality wood in this region if combined with other silvicultural activities such as the control of species and stand density.

6. Even in the latter case, the efficiency of added fertilizer N needs to be improved above levels shown in this study. At sites with pronounced raw humus formation, high-rate or repeated N applications may be necessary to achieve practically significant growth improvements. At sites with impeded drainage, efficient use of N may require simultaneous addition of P. Both N application rate and timing, and the need for P require further study.

REFERENCES

Bennett, F.A. 1966. Construction and use of volume and yield tables. In: Fifteenth Annual Forest Symposium: Measuring the southern forest. Keister, T.D. ed. La. State Univ. Press, Baton Rouge, La., p. 17-29.

Berg, E. 1952. Gödsling av Skog. Vaxt Narings-Nytt 8:62.

Broadbent, F.E. and T. Nakashima. 1971. Effect of added salts on nitrogen mineralization in three California soils. Soil Sci. Soc. Am. Proc. 35:457-460.

Canada Soil Survey Committee. 1978. The Canadian System of Soil Classification. Publ. No. 1646, Can. Dep. Agric., Ottawa, Ont.

Cole, D.W., J. Turner and S.P. Gessel. 1976. Elemental cycling in Douglas fir ecosystems of the Pacific northwest: a comparative examination - Paper presented at 12th Inter. Bot. Congr., Leningrad. USSR 12 pp.

Cox, D.R. 1958. Planning of Experiments. John Wiley and Sons.

Fabricius. 1940. Ein 10-jähriger N-Düngungsversuch. Forstw. Centralblatt 62:76-89.

Fifje, A. 1967. Errors in the height measurement of individual trees. Medd. Norske Skogforsoksv. 22:103-137. (In Norwegian).

Foster, N.W. and I.K. Morrison. 1976. Distribution and cycling of nutrients in a natural Pinus banksiana ecosystem. Ecology 57:110-120.

Gagnon, J.D., M. Roberge, Truong dinh Phu, et H.S.D. Swan. 1979. Effets de la fertilisation, après 10 ans, sur la croissance et le milieu d'une sapinière naturelle de 60 ans au nord-est du Québec. Can. Cent. Rech. For. Laurentides, Ste-Foy, Qué. Rapp. Inf. LAU-X-36.

Hagner, S. 1967. Fertilization as a production factor in industrial forestry. U.B.C. MacMillan Lecture in Forestry, Mar. 1967.

Hawboldt, L.S. and S.N. Kostjukovits. 1961. Forest regulation for Nova Scotia. Part I. Site quality normal yield tables for softwoods. N.S. Lands For., Bull. No. 20.

Hendricksen, H.A. 1950. Height/diameter curve with logarithmic diameter. Dansk Skovforen. Tidsskr. 35:193-202. (In Danish).

Hesselman, H. 1937. Om humustäckets beroende av bestandes oller och sammansättnig i den nordsika granskogen av blabärsrik Vacciniumtyp och des anverkan pa skogends förnyngring och tillväxt. Medd. Skogförsöksanst. 30:529- 716.

Holmen, H. 1977. Forest fertilization in Sweden 1976. Kungl. Skogs och Lantbr.-akad. Tidsskr. 6:1-8 (In Swedish with English Summary).

Honer, T.G. 1967. Standard volume tables and merchantable conversion factors for the commercial tree species of central and eastern Canada. Can. Dep. For. Rural Dev., For. Br. Inf. Rep. FMR-X-5.

Hoyt, J.S. 1973. Growth increases after fertilization in mature jack pine and balsam fir stands. Dep. Nat. Res.: For. Br. Tech. Rep. TR3-73. 81p.

Jansson, S. 1977. Results from the 10-year-old series of trials with high doses of nitrogen fertilization. (In Swedish with English summary). Föreningen Skogsträdsförädling och Institute för Skogsförbättring. Arsbok 1977, p. 79--128.

Kingston, D.G.O., M.K, Mahendrappa, and P.O. Salonius. 1978. Stand and soil changes after fertilization of semimature jack pine in northern New Brunswick. Can. For. Serv., Marit. For. Res. Cent. Inf. Rep. M-X-91. 7 p.

Kodama, H. and J.E. Brydon. 1968. A study of clay minerals in podzol soils in New Brunswick, Eastern Canada. Clay Min. 7:295-309.

Maftoun, M. and Krause, H.H. 1977. Phosphate solubility in dried forest floor samples from New Brunswick Soils. Can. J. Soil Sci. 57:457-463.

Mahendrappa, M.K. and E.D. Ogden. 1973. Patterns of ammonia volatilization from a forest soil. Plant Soil 38:257-265.

Mahendrappa, M.K. 1978. Changes in the organic layers under a black spruce stand fertilized with urea and triple superphosphate. Can. J. For. Res. 8:237-242.

Miller, R.E. and R.D. Fight. 1979. Analyzing forest fertilization; study evaluates cost, benefits. For. Ind. 106:60-62.

Morrison, I.K. and N.W. Foster. 1977. Fate of urea fertilizer added to a boreal forest <u>Pinus banksiana</u> Lamb stand, Soil Sci. Soc. Am. J. 41:441-448.

Morrison, I.K. and N.W. Foster. 1979. Five-year growth in two nitrogen-phosphorus fertilization experiments in spruce and spruce - fir upland forest in northern Ontario. Can. For. Serv., Great Lakes For. Res. Cent. Inf. Rep. O-X-299. 15 p.

Roberge, M.R. and R. Knowles. 1965. Available nitrogen in a black spruce humus fertilized with urea. Pulp Pap. Res. Inst. Can., Woodl. Res. Index 172.

Stoffels, A. and J. van Soest. 1953. The main problem in sample plots. 3. Height regression. Ned. Boschb.-Tijdschr. 25:190-199. (In Dutch).

Switzer, G.L., and L.E. Nelson. 1972. Nutrient accumulation and cycling in loblolly pine (Pinus taeda L.) plantation ecosystem: The first twenty years. Soil Sci. Soc. Am. Proc. 36:143-147.

Tamm, C.O. and C. Carbonnier. 1961. Växt näringen som skoglig produktion-faktor [Plant nutrients and forest yield] Statens Skogs forskningsinstitut. Uppsatser-Nr. 82, p. 95-124.

Themlitz, R. 1954. Die Anwendung von Kalkstickstoff zur Rohhumusumwandlung und Ertragssteigerung in Walde. Zeitschrift f. Pflanzenernährung, Düngung und Bodenkunde, 64:54-66.

Trorey, L.G. 1932. A mathematical method for the construction of diameter height curves based on site. For. Chron. 8:121-132.

Tucker, T.L. 1974. What is it worth. An economic evaluation of fertilizer trials in jack pine at Dryden, Ontario. Proc. Workshop on Forest Fertilization in Canada, p. 39-45. Can. For. Serv., Great Lakes Res. Cent. Sault Ste. Marie, Ont.

van Nostrand, R.S. 1979. Growth response of black spruce in Newfoundland to N, P and K fertilization. For. Chron. 55:189-193.

Weetman, G.F. 1961. The nitrogen cycle in temperate forest stands. Pulp Pap. Res. Inst. Can., Woodl. Res. Index 126.

Weetman, G.F. 1975. Ten-year growth response of black spruce to thinning and fertilization treatments. Can. J. For. Res. 5:302-309.

Weetman, G.F., H.H. Krause, E. Koller, and J.-M. Veilleux. 1981. Interprovincial forest fertilization program: Results of five- year growth remeasurements. Can. For. Serv. Tech. Rep. (In press).

Weetman, G.F., M.R. Roberge, and C.H. Meng. 1980. Black spruce thinning and fertilization: 15-year growth and humus microbiological response. Can. J. For. Res. 10:502-509.

Weinkauff. 1941. The Fortentwicklung der Forstwirtschaft durch N-Düngung. Forstw. Central-blatt. 60:243-255.

Wittich, W. 1952. Der heutige Stand unseres Wissens vom Humus und neue Wege zur Lösung des Rohhumus Problems in Walde. Schriftenreihe der Forstl. Fakultät d. Universität Göttingen, Bd. 4. Sauerläander Verl. Frankfurt a. M.

Table 1. Statistical significance of treatment effects as determined by covariance analysis of 10-year total volume data.

Experiment		Main effects			Interactions		
		N	P	K	NP	NK	PK
Bathurst	1968/73	**	n.s.	n.s.	n.s.	n.s.	n.s.
	1974/78	**	n.s.	n.s.	n.s.	n.s.	n.s.
	1968/78	**	n.s.	n.s.	n.s.	n.s.	n.s.
Piskahegan	1968/73	**	n.s.	n.s.	n.s.	n.s.	n.s.
	1974/78	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
	1968/78	*	n.s.	n.s.	n.s.	n.s.	n.s.
Nashwaak	1968/73	**	n.s.	n.s.	n.s.	n.s.	n.s.
	1974/78	n.s	n.s.	n.s.	**	n.s.	*
	1968/78	**	n.s.	n.s.	*	n.s.	n.s.
Sevogle	1968/73	**	n.s.	n.s.	n.s.	n.s.	n.s.
	1974/78	n.s.	*	n.s.	n.s.	n.s.	n.s.
	1968/78	n.s.	*	n.s.	n.s.	n.s.	n.s.
Green River	1968/73	**	n.s.	n.s.	n.s.	n.s.	n.s.
	1974/78	n.s.	n.s.	n.s.	n.s.	n.s.	**
	1968/78	*	n.s.	n.s.	n.s.	n.s.	*

* significant at P = 0.05.
** significant at P = 0.01.
n.s. not significant.

Table 2. Gross periodic total volume increments and fertilization responses in two black spruce stands

	Gross periodic increment			Response		
	1969-73	1974-78	1969-78	1969-73	1974-78	1969-78
	m³/ha					
			Bathurst experiment (A)			
Control	26.7	7.3	34.0	--	--	--
K	27.2	9.0	36.2	0.5	1.7	2.2
P	26.5	9.7	36.2	-0.2	2.4	2.2
PK	25.7	8.4	34.1	-1.0	1.1	0.1
N	31.6	10.7	42.3	4.9	3.4	8.3
NK	30.9	9.4	40.3	4.2	2.1	6.3
NP	34.2	11.5	45.7	7.5	4.2	11.7
NPK	32.3	11.8	44.1	5.6	4.5	11.1
			Piskahegan experiment (B)			
Control	16.1	11.0	27.1	--	--	--
K	17.3	12.5	29.8	1.2	1.5	2.7
P	17.6	11.3	28.9	1.5	0.3	1.8
PK	17.8	11.4	29.2	1.7	0.4	2.1
N	20.8	11.0	31.8	4.7	0.0	4.7
NK	20.7	11.7	32.4	4.6	0.7	5.3
NP	22.8	12.7	35.5	6.7	1.7	8.4
NPK	20.2	13.0	33.2	4.1	2.0	6.1

Table 3. Gross periodic total volume increments and fertilization responses in two mixed stands of red spruce and balsam fir and a pure balsam fir stand

	Gross periodic increment			Response		
	1969-73	1974-78	1969-78	1969-73	1974-78	1969-78
			m^3/ha			
			Nashwaak experiment (C)			
Control	26.5	38.6	65.1	--	--	--
K	29.2	38.4	67.6	2.7	-0.2	2.5
P	29.2	40.8	70.7	3.4	2.2	5.6
PK	31.4	42.5	73.9	4.9	3.9	8.8
N	35.4	42.2	77.6	8.9	3.6	12.5
NK	32.7	42.6	75.3	6.2	4.0	10.2
NP	31.8	37.1	68.9	5.3	-1.5	3.8
NPK	35.3	43.0	78.3	8.8	4.4	13.2
			Sevogle experiment (D)			
Control	24.2	29.0	53.2	--	--	--
K	25.3	28.3	53.6	1.1	-0.7	0.4
P	22.2	25.4	47.6	-2.0	-3.5	-5.6
PK	23.4	25.8	49.2	-0.8	-3.3	-4.0
N	26.9	26.7	53.6	2.7	-2.3	0.4
NK	30.2	25.6	55.8	6.0	-3.4	2.6
NP	27.7	25.5	53.0	3.5	-3.6	0.0
NPK	27.6	25.2	52.8	3.4	-3.8	-0.4
			Green River experiment (E)			
Control	33.9	27.6	61.5	--	--	--
K	33.3	25.1	58.4	-0.7	-2.5	-3.1
P	35.5	24.7	60.2	1.5	-2.9	-1.3
PK	35.9	25.7	61.6	2.0	-1.9	0.1
N	38.6	29.5	68.5	4.6	1.9	6.6
NK	36.3	25.0	61.3	2.4	-2.6	-0.2
NP	37.3	24.1	61.4	3.4	-3.5	-0.1
NPK	40.1	27.9	68.0	6.1	0.3	6.5

Table 4. Volume losses due to tree mortality, net periodic increments (PI) and fertilization response in two black spruce stands

	1st 5-year period			2nd 5-year period			10-year period		
	Mortality	Net PI†	Response	Mortality	Net PI†	Response	Mortality	Net PI†	Response
	m³/ha								
Bathurst									
Control	3.6	23.1	--	6.4	0.9	--	10.0	24.0	--
K	8.6	18.6	-4.5	11.8	-2.8	-3.7	20.4	15.8	-8.2
P	10.7	15.8	-7.3	11.0	-1.3	-2.2	21.7	14.5	-9.5
PK	12.1	13.6	-9.5	7.9	0.5	-0.4	20.0	14.1	-9.9
N	4.6	27.0	3.9	5.2	5.5	4.6	9.8	32.5	8.5
NK	3.3	27.6	4.5	7.4	2.0	1.1	10.7	29.6	5.6
NP	5.6	28.6	5.5	6.9	4.6	3.7	12.5	33.2	9.2
NPK	5.9	26.4	3.3	19.8	-8.0	-8.9	25.7	18.4	-5.6
Piskahegan									
Control	21.7	-5.6	--	41.0	-30.0	--	62.7	-35.6	--
K	8.6	8.7	14.3	54.3	-41.8	-11.8	62.9	-33.1	2.5
P	17.0	0.6	6.2	36.5	-25.2	4.8	53.5	-24.6	11.0
PK	10.7	7.1	12.7	25.9	-14.5	15.5	36.6	-7.4	28.2
N	13.6	7.2	12.8	36.6	-25.6	4.4	50.2	-18.4	17.2
NK	7.4	13.3	18.9	50.4	-38.7	-8.7	57.8	-25.4	10.2
NP	17.0	5.8	11.4	46.3	-33.6	-3.3	63.3	-27.8	7.8
NPK	13.1	7.1	12.7	45.2	-32.2	-2.2	58.3	-25.7	10.5

† Net PI = Gross PI (PI increments shown in Table 2) — mortality.

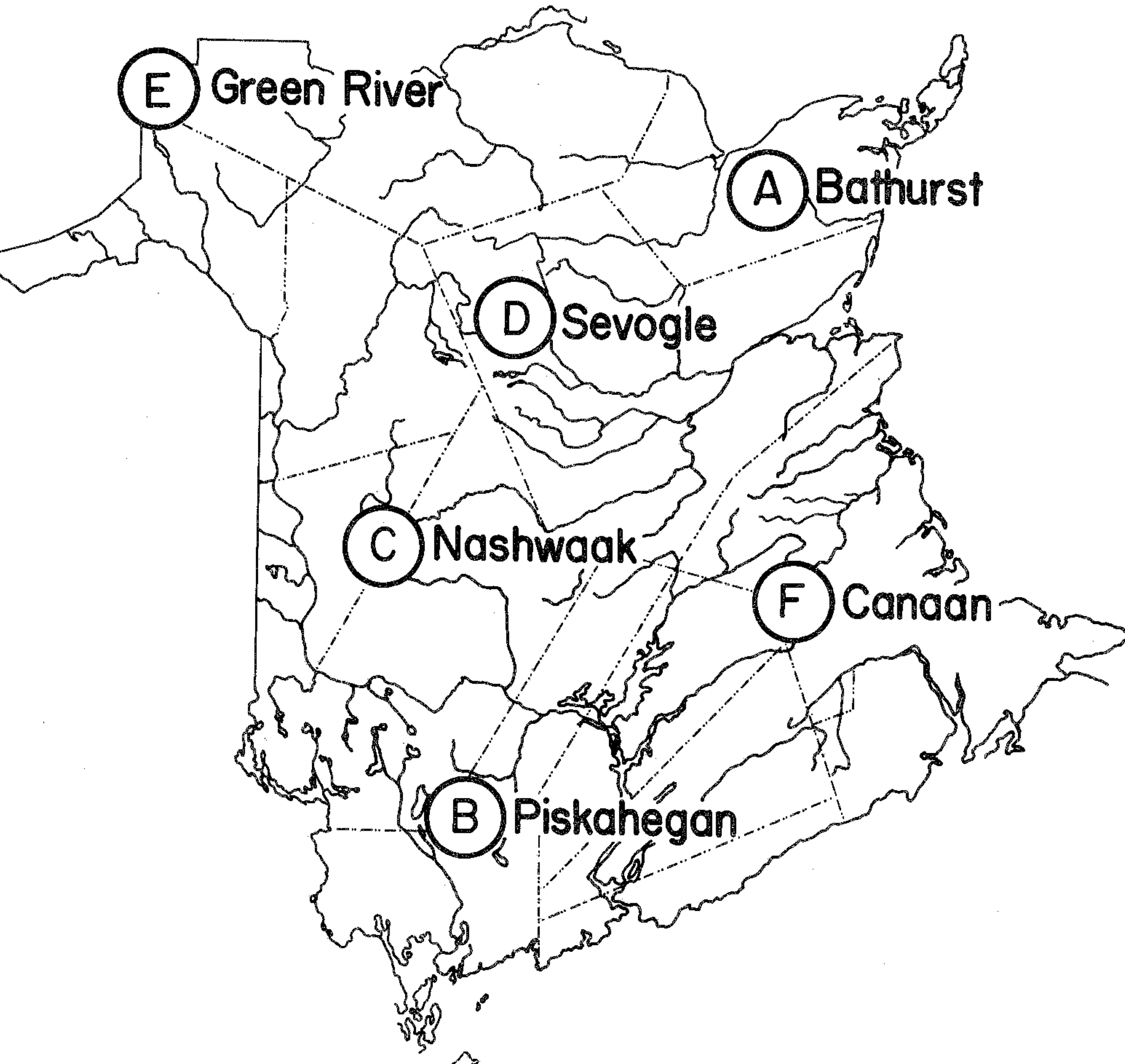

Fig. 1. Map of New Brunswick showing general location of experiments.

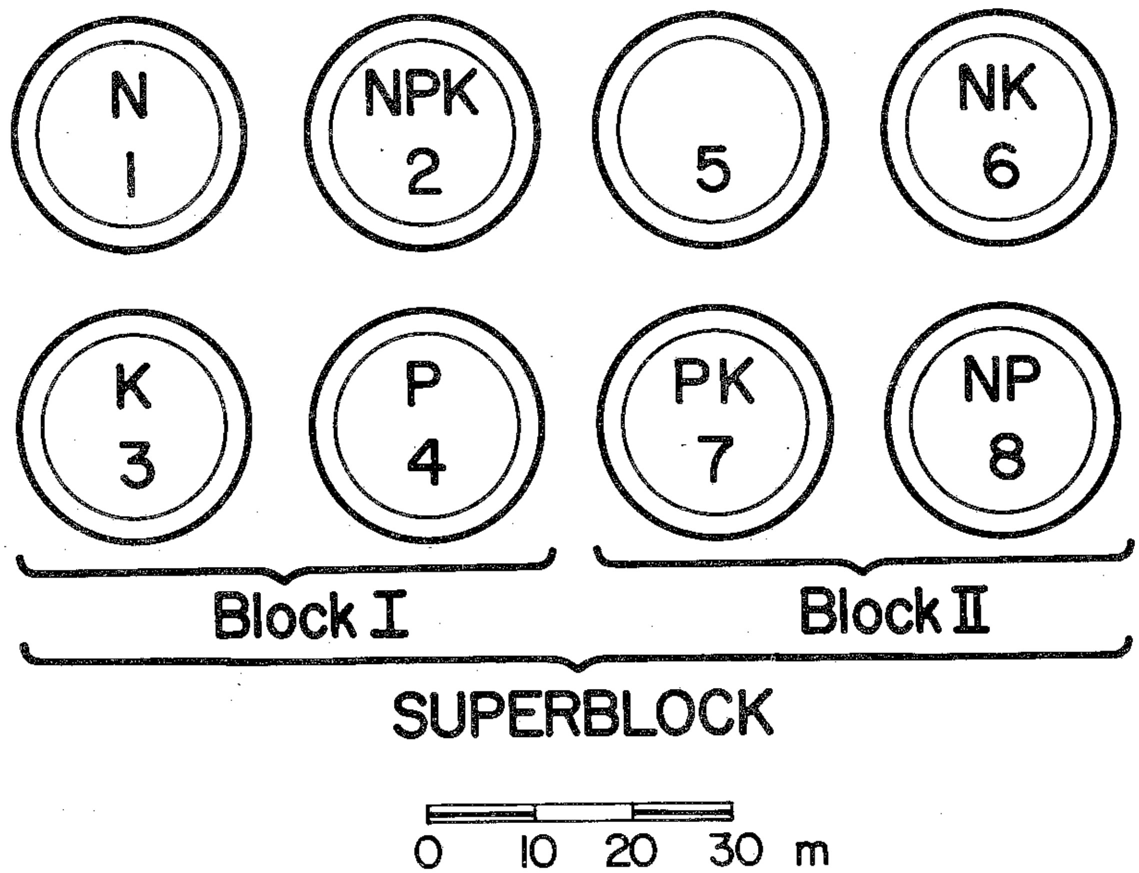

Fig. 2. Schematic diagram of a replication of treatments in two incomplete blocks. Tree measurements were limited to the concentric inner plot. Capital letter notation indicates treatments.

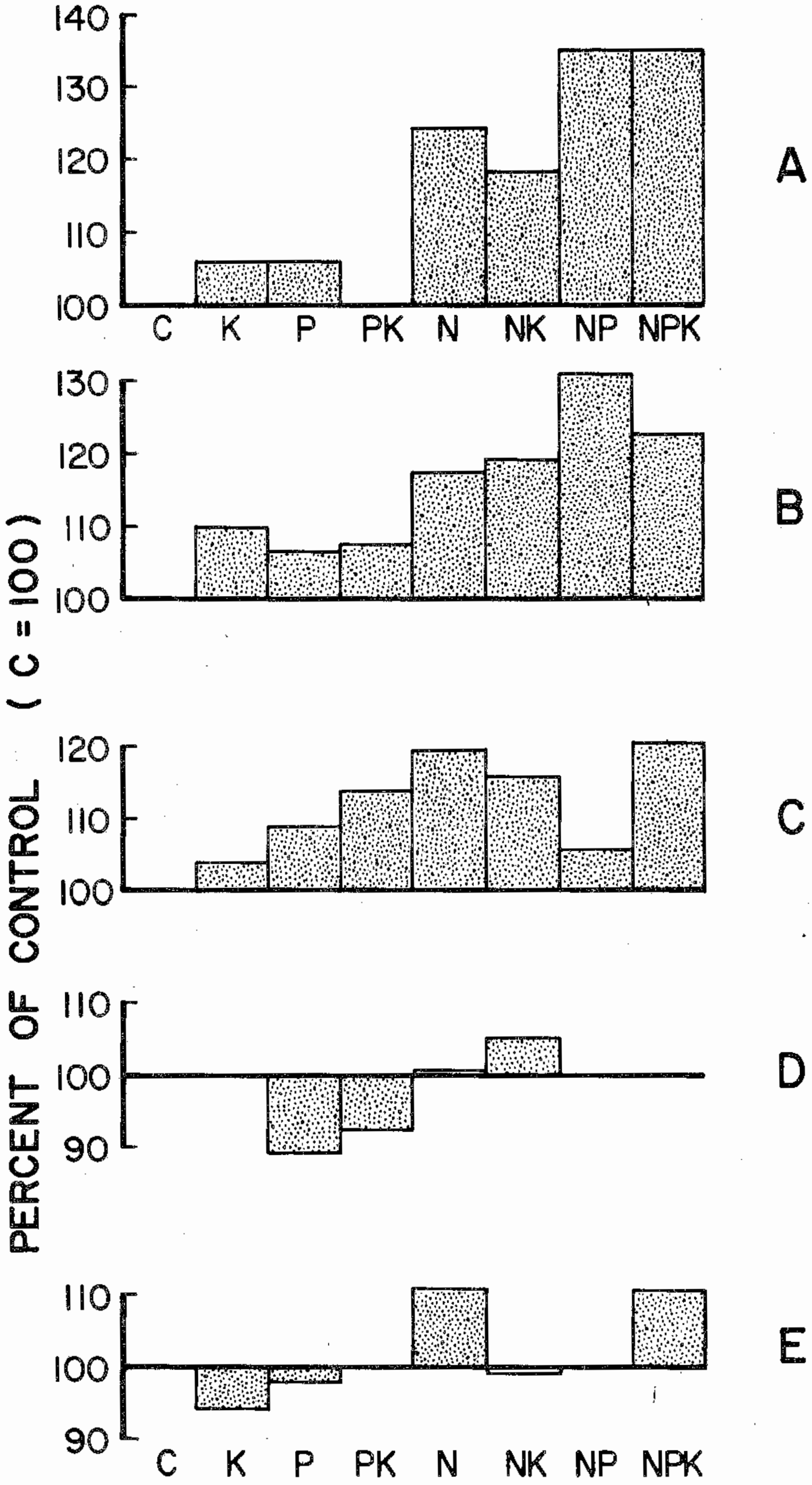

Fig. 3. Relative fertilization response in two black spruce stands (A and B), two mixed stands of red spruce and balsam fir (C and D), and a pure balsam fir stand, based on 10-year gross periodic increments in total volume, adjusted by covariance analysis.

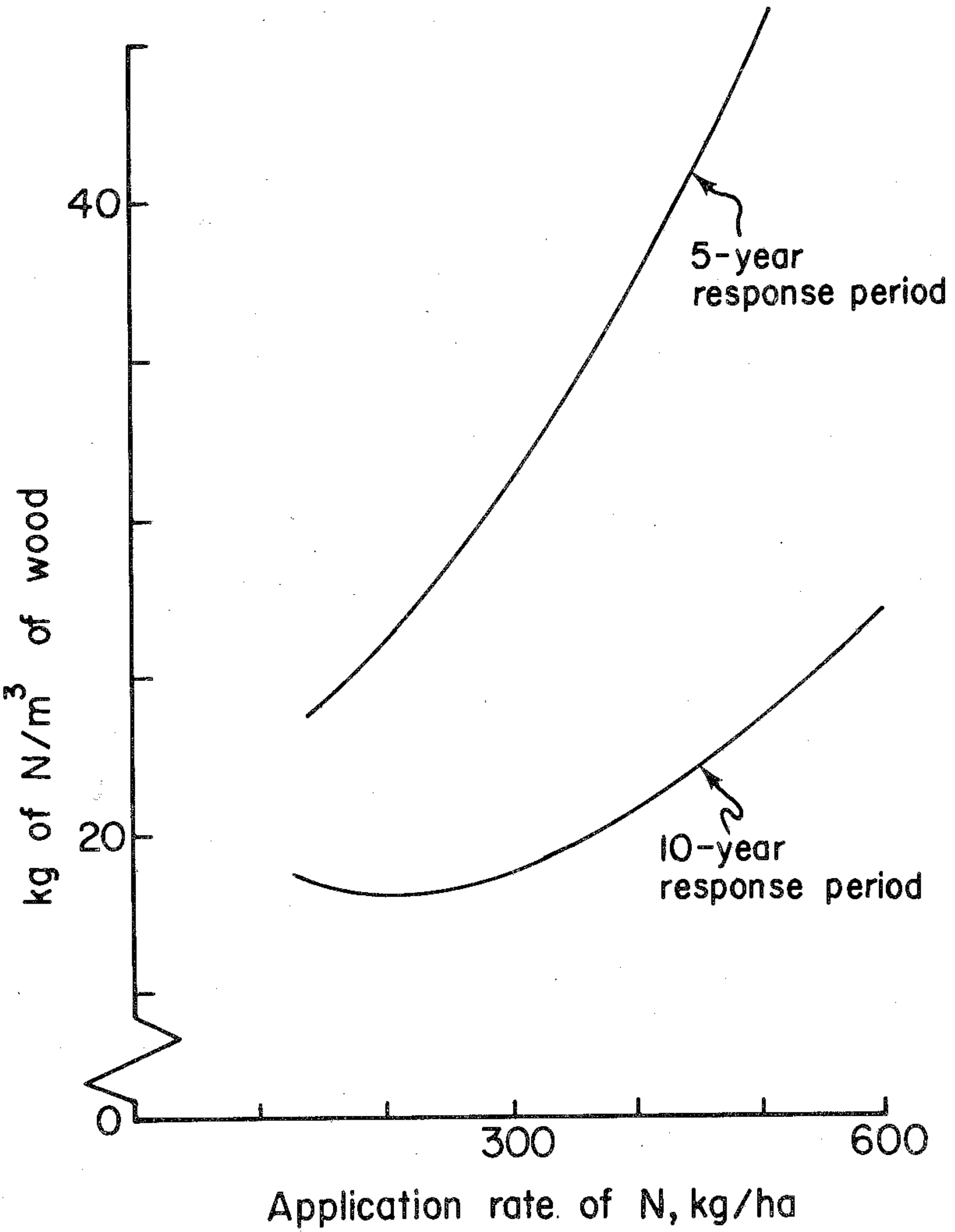

Fig. 4. Average amount of urea nitrogen required to produce one m^3 of wood (total volume) by Norway spruce as a function of application rate (reproduced from Jansson 1977).

Appendix I. Location and some climatological data of experimental sites.

Exper- iment	Physiographic region	Geographic Coordinates	Elevation a.s.l. m	Mean precipitation (mm) annual	May-Sep	Mean temperature, degree Celsius annual	July	Jan	Frost-free days	Growing degree days
A	Eastern Lowland†	47°35' Lat. 65°24' Long.	120	889	406	4	19	-11	108	2550
B	Central Lowland	45°32' Lat. 66°50' Long.	140	1067	406	5	19	-9	115	2750
C	Central Highland	46°25' Lat. 67°10' Long.	300	1143	533	3	18	-11	84	2350
D	York Plateau	47°05' Lat. 66°18' Long.	330	1118	584	3	18	-13	74	2200
E	Northwestern Plateau	47°50' Lat. 68°20' Long.	500	965	508	2	17	-14	80	2100

† As defined by Putnam, D.F. 1954. Canadian Regions. A geography of Canada. J.M. Dent and Sons (Canada) Ltd. Toronto, 2nd. edition, 1954. 601 pp.

Appendix II. Texture, pH and nutrient contents of a typical pedons at each of the experimental sites.

Horizon	Depth	Sand	Texture Silt	Clay	pH	Exchangeable K	CA	Mg	Total N	Avail P
	cm		%				ppm		%	ppm
					Bathurst					
LF	7- 4				n.d.*	n.d.	n.d.	n.d.	1.325	n.d.
H	4- 0				3.2	336	235	223	1.247	n.d.
Ae	0-10	97.7	18.1	2.2	3.5	113	1	3	0.039	3.2
Bf_1	10-15	60.0	18.9	21.1	3.9	127	39	11	0.168	3.2
Bf_2	15-23	63.5	21.5	15.0	4.7	25	51	4	0.124	3.7
Bfg	23-33	59.2	27.4	13.4	5.1	34	12	1	0.059	2.8
Cg_1	33-46	66.2	22.9	10.9	4.8	21	11	1	0.036	4.6
Cg_2	46+	60.6	23.8	15.6	4.8	31	10	3	0.029	1.9
					Piskahegan					
LF	4- 1				n.d.	n.d.	n.d.	n.d.	1.771	n.d.
H	1- 0				4.8	582	2663	280	1.236	n.d.
Ae_1	0- 5	57.1	40.3	2.6	4.5	30	84	39	0.056	4.2
Ae_2	5-12	n.d.	n.d.	n.d.	4.5	27	41	26	0.046	14.7
Bf_1	12-18	51.2	42.4	6.4	5.4	40	28	17	0.025	n.d.
Bf_2	18-28	48.8	34.5	16.7	5.7	26	7	4	0.143	17.8
Bfg	28-38	50.8	41.0	8.2	5.7	19	8	2	0.075	18.8
Cg_1	38-48	51.0	39.2	9.8	5.9	31	8	3	0.081	10.9
Cg_2	48+	53.3	38.9	7.8	5.9	27	8	4	0.048	8.8
					Nashwaak					
LF	4- 1				n.d.	n.d.	n.d.	n.d.	1.846	n.d.
H	1- 0				3.5	538	364	138	1.728	n.d.
Ae	0- 8	60.4	31.5	8.1	3.4	24	8	6	0.077	3.1
Bhf_1	8-13	74.3	21.5	4.2	4.4	82	4	2	0.626	n.d.
Bhf_2	13-25	70.4	20.0	9.6	4.9	23	2	4	0.320	1.4
Bf_1	25-38	75.7	18.4	5.9	5.0	18	1	2	0.195	3.0
Bf_2	38-51	72.1	24.2	3.7	4.9	13	3	1	0.101	19.3
C	51+	69.2	28.0	2.8	4.8	12	2	1	0.070	25.2
					Sevogle					
LF	5- 1				n.d.	n.d.	n.d.	n.d.	1.661	n.d.
H	1- 0				n.d.	600	2350	177	1.448	n.d.
Ae	0- 5	50.6	45.8	3.6	3.6	25	58	16	0.072	5.3
Bhf_1	5- 8	63.7	30.2	6.1	3.4	47	12	13	0.360	5.0
Bhf_2	8-23	57.4	39.0	3.6	4.3	21	8	3	0.288	3.0
Bf_1	23-30	50.6	45.0	4.4	4.7	20	5	1	0.170	2.0
Bf_2	30-46	55.5	37.9	6.6	5.1	22	3	1	0.56	5.0
C	46+	56.2	37.8	6.0	5.1	30	3	1	0.37	13.4

Appendix II continued.

Horizon	Depth	Texture Sand	Texture Silt	Texture Clay	pH	Exchangeable K	Exchangeable CA	Exchangeable Mg	Total N	Avail P
		%				ppm			%	ppm
					Green River					
LF	4- 1				n.d.	n.d.	n.d.	n.d.	1.850	n.d.
H	1- 0				3.4	736	725	225	1.590	n.d.
Ae	0- 3	n.d.	n.d.	n.d.	3.5	25	13	26	0.171	11.8
Bhf_1	3- 8	64.6	23.9	11.3	3.9	26	3	33	0.416	2.5
Bhf_2	8-18	48.6	36.1	15.3	4.6	21	2	7	0.306	4.0
Bf_1	18-23	55.9	33.8	10.3	4.8	17	1	2	0.176	4.0
Bf_2	23-38	55.8	29.4	10.8	5.0	9	2	1	0.109	5.4
C	38+	n.d.	n.d.	n.d.	5.2	10	2	1	0.098	16.1

* n.d. = not determined.

Appendix III Stand characteristics. Measurements were made before treatments were applied.

Species	Average Age (Years)	Number of trees per ha	Average diameter cm*	Basal area m^2ha	Total Volume m^3/ha	Merch. Volume m^3/ha	** SI_{50}
			Experiment A, Bathurst				
Black spruce	60	1674	15.6	31.8			14.6
Balsam fir		398	11.9	4.4			
Red maple		54	11.9	0.6			
White pine		56	14.3	0.9			
All species		2182	14.8	37.7	202	170	
			Experiment B, Piskahegan				
Black spruce	55	1963	14.8	33.7			15.8
Balsam fir		87	10.1	0.7			
Both species		2050	14.6	34.4	207	177	
			Experiment C, Nashwaak				
Red spruce	48	1593	15.4	29.8			16.8
Balsam fir		1561	13.0	20.8			
White birch		95	14.2	1.5			
All species		3249	14.3	52.1	348	289	
			Experiment D, Sevogle				
Balsam fir	47	1758	14.0	27.0			16.5
Red spruce	47	593	17.0	13.5			
White birch		17	17.3	0.4			
Red maple		24	12.6	0.3			
All species		2392	14.8	41.2	256	219	
			Experiment E, Green River				
Balsam fir	44	3047	13.4	42.8			16.8
White spruce		45	16.8	1.0			
White birch		145	10.3	1.2			
All species		3237	13.3	45.0	266	218	

* Average diameter = diameter of tree of average basal area.
** SI_{50} = Average dominant height in metres at age 50 years; from height/age curves given in Hawboldt and Kostjukovits (1961).

Appendix IV Ten-year basal area, total volume and merchantable volume increments by experiment and treatment (unadjusted).

Mean	CONTROL	K	P	PK	N	NK	NP	NPK
				Treatment				
Experiment A, Bathurst								
Basal area, m^2/ha	5.01	4.71	5.16	4.85	6.03	5.57	5.99	6.28
Total volume, m^3/ha	34.10	32.64	36.98	34.69	43.46	38.68	42.87	45.30
Merch. volume, m^3/ha	34.14	32.54	36.49	34.28	42.74	38.06	42.12	44.70
Experiment B, Piskahegan								
Basal area, m^2/ha	2.80	2.94	3.47	3.20	3.78	3.30	3.96	3.66
Total volume, m^3/ha	23.17	24.21	29.00	26.42	31.36	27.54	33.11	30.40
Merch. volume, m^3/ha	22.01	23.29	28.18	25.37	29.57	26.58	32.00	29.49
Experiment C, Nashwaak								
Basal area, m^2/ha	5.58	6.01	6.56	6.68	7.14	6.86	6.41	7.36
Total volume, m^3/ha	60.14	66.24	73.12	69.86	78.51	73.01	68.02	78.99
Merch. volume, m^3/ha	57.26	63.07	69.42	65.93	74.72	69.53	65.02	75.00
Experiment D, Sevogle								
Basal area, m^2/ha	5.03	4.56	3.91	4.37	4.49	5.55	5.32	4.55
Totl volume, m^3/ha	50.52	48.58	43.15	45.80	46.61	57.01	55.19	48.39
Merch. volume, m^3/ha	48.32	46.53	41.16	43.82	44.66	54.77	52.97	46.37
Experiment E, Green River								
Basal area, m^2/ha	7.42	7.01	7.20	7.64	8.20	7.42	7.46	8.31
Total volume, m^3/ha	60.50	57.72	58.81	62.42	66.45	60.38	61.00	67.59
Merch. volume, m^3/ha	58.83	56.21	57.45	60.90	64.77	58.86	59.39	66.15