# FIVE-YEAR GROWTH RESPONSE OF NORTHERN ONTARIO PEATLAND BLACK SPRUCE TO FERTILIZATION AND DRAINAGE

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ABSTRACT

Five-year growth response of a peatland black spruce (*Picea mariana* [Mill.] B.S.P.) stand in northern Ontario to fertilization and drainage is described. Because of constraints posed by location and numbers of existing drainage ditches, high variability in natural growth characteristics between and within stands, number of treatments, and small and unequal sample sizes among treatments, much of the variation could not be delineated. Nevertheless, the data were analyzed for annual DBH, height, BA and volume growth responses of both stands and individual trees.

Results of analysis of variance indicated highly significant differences ($P = 0.01$) among all treatments for the entire experiment and for all response variables examined. However, Tukey's test resulted in few significant differences between individual treatments for most response variables. Analysis of individual tree growth response data for the poorest site (very stagnant treed bog with $SI_{50} < 3$ m) indicated significant effects on tree growth as a result of fertilization and drainage, and of their interaction, for most response variables considered. In the case of a somewhat better site (overmature black spruce stand with $SI_{50} \sim 4$ m), however, only the effects of fertilization on DBH and/or volume growth were statistically significant.

The overall results of this study indicate that both minor thinning and application of P-fertilizer alone had depressive effects on growth, i.e., 1.6 $m^3$/ha less wood in comparison with the control over the five-year period. The best growth response observed was from the application of NPK (U TSP KC 112 kg/ha), i.e., 7 $m^3$/ha of extra wood in comparison with the control over the five-year period. Most other treatment combinations applied produced positive but nonsignificant growth responses.

# RÉSUMÉ

L'auteur décrit la réponse à la fertilisation et au drainage, pour une période de croissance de cinq ans, d'un peuplement d'épinette noire *(Picea mariana* [Mill.] B.S.P.) d'une tourbière du nord de l'Ontario. En raison de la situation et du nombre de fossés de drainage, de la grande variabilité dans les caractéristiques de la croissance naturelle dans un peuplement et d'un peuplement à l'autre, du nombre de traitements et des dimensions faibles et inégales des échantillons, une grande partie de la variation n'a pas pu être estimée. Néanmoins, l'auteur a analysé les données recueillies en mesurant à la fin de chaque année le diamètre à hauteur d'homme, la hauteur, la surface terrière et l'accroissement de volume des peuplements et des arbres.

D'après l'analyse de variance, les traitements ont donné des résultats très différents ($P = 0.01$) pour l'ensemble de l'expérience et pour toutes les variables de réponse étudiées. Toutefois, pour la plupart de ces dernières, le test de Tukey n'a montré que peu de différences importantes entre les divers traitements. Pour la station la plus défavorable (une tourbière arborée très stagnante dont l'$IS_{50}$ était inférieur à 3 m), l'analyse des mesures de la croissance des arbres individuels a montré que, pour la plupart des variables, la fertilisation et le drainage, effectués séparément ou conjointement, avaient été très efficaces. Cependant, dans le cas d'une station un peu plus favorable (un peuplement surranné d'épinette noire dont l'$IS_{50}$ était à peu près égal à 4 m), seuls les effets de la fertilisation sur le diamètre à hauteur d'homme et (ou) l'accroissement de volume, ou sur les deux à la fois, étaient statistiquement significatifs.

Dans l'ensemble, de légers travaux d'éclaircie et un engrais au phosphore seulement ont réduit la croissance: après cinq ans, le volume de bois à l'hectare a été inférieur de 1.6 $m^3$ à celui de la station témoin. C'est un amendement NPK (urée, phosphate trisodique et chlorure de potassium), à raison de 112 kg/ha, qui a donné les meilleurs résultats: l'accroissement de volume a été de 7 $m^3$/ha. La plupart des autres traitements combinés ont donné des effets positifs, mais non significatifs sur la croissance.

ACKNOWLEDGMENTS

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# INTRODUCTION

Black spruce *(Picea mariana* [Mill.] B.S.P.) is the most important pulpwood species in Ontario. With 1.2 billion $m^3$ standing volume it represents about 30% of the total growing stock of all pulpwood species (Dixon 1963). Because of its desirable pulping qualities, black spruce makes up more than 60% of the roundwood utilized by the pulp and paper industry in Ontario (Anon. 1969).

Nearly 50% of the black spruce in northern Ontario occurs on peatland sites (Ketcheson and Jeglum 1972). Because of excess water, poor aeration, inadequate nutrient availability, and adverse climatic conditions, its productivity on such sites is very low (Lebarron 1945; McEwen 1966; Payandeh 1973a). However, productivity can be improved by drainage, fertilization and/or thinning (Averell and McGrew 1929; Heinselman 1963; Stanek 1968, 1977; McEwen 1969; Payandeh 1973a,b).

Extensive areas of peatland types supporting Norway spruce *(Picea abies* L. Karst.) and Scots pine *(Pinus sylvestris* L.) have been drained and/or fertilized successfully in Finland, the USSR and several other European countries (Heikurainen 1957, 1961, 1963, 1964, 1966, 1967, 1968; P'yavchenko 1957; Anon. 1959; Huikari 1959; Päävilainen 1966, 1975; Seppälä 1969, 1972, 1976; Ivanov 1974; Gorbachev 1976; Braekke 1977; Smidle 1977; Fryk 1978; Fardmo 1979; Vomperskaya 1980; Heikurainen and Kuusela 1962; Heikurainen and Seppälä 1965; Keltikanjas and Seppälä 1968; Heikurainen and Ouni 1970; Heikurainen and Paiaven 1970; Heikurainen and Laine 1976; Seppälä and Westman 1976; Malakhouets and Babich 1978; Hukari et al. 1968; Kapustinskaite et al. 1977). The majority of the earlier articles describe the biological, hydrological and physiochemical aspects of Feno-Scandinavian and Russian peatland forestry amelioration. More recent articles deal mainly with the effects of drainage and fertilization on tree and stand growth. Few articles discuss the economic feasibility of such stand improvement efforts in relation to specific socio-economic structures.

Several small-scale forest drainage experiments have been carried out in North America (Day 1949; Satterland and Graham 1957; Walters et al. 1959; McEwen 1969; Stanek 1968, 1970, 1977, Wilton 1970; Rennie 1971; Payandeh 1973a,b; Richardson et al. 1976; Richardson 1981; Alban 1981; Alban and Watt 1981). With few exceptions, these researchers provide only a physical description of their experiments and limited casual observations on growth improvement resulting from drainage.

A detailed growth analysis of a 40-year drainage experiment in northern Ontario was provided earlier (Payandeh 1973a). It was concluded that both individual tree and stand growth responded well to draining, with younger and more vigorous trees growing on better quality sites showing the greatest response. An economic analysis of this experiment (Payandeh 1973b) indicated that the annual rate of return [due to drainage] increased by 2.0%-3.4% as a result of drainage, depending on the site quality.

Stanek (1977) compared peatland types in northern Ontario and tree growth on undrained and artificially drained sites. Growth improvement of 3 m and 2 m in terms of site index, i.e., height at 50 years, was predicted on drained bog and fen-marsh types, respectively. Total nutrient count of peat was suggested as a means of predicting the potential of peatland for post-drainage tree growth.

Richardson et al. (1976) and Richardson (1981) described a peatland drainage and fertilization experiment in central Newfoundland to develop an optimum drainage system for the afforestation of bog and fen. Three- and seven-year remeasurements following drainage indicated that draining had a pronounced effect on the growth of tree seedlings. Annual height increment on the drained area was consistently higher than on the undrained area. Average annual height increments for black spruce and larch *(Larix laricina* [Du Roi] K. Koch) on the drained area were 7.5 cm and 13.0 cm in comparison with 3.1 cm and 4.2 cm, respectively, on the undrained area. Fertilization on drained areas brought about an even greater increase in growth than did draining alone. Annual height increments following fertilization were two to three times as great on fertilized as on unfertilized sites.

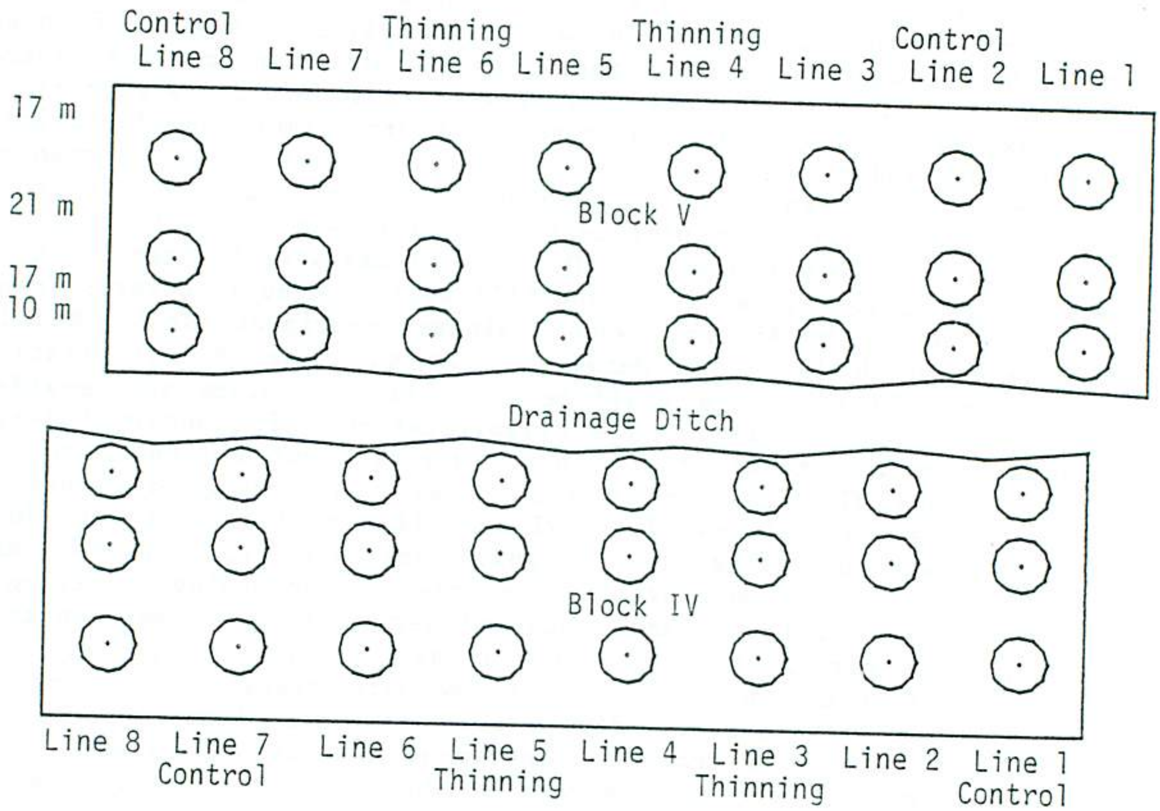
Alban and Watt (1981) described the results of a fertilization experiment on a peatland black spruce stand in northern Minnesota. They reported that various rates of nitrogen and phosphorus increased height and diameter growth from two to four times. The growth response declined with time but was still apparent 16 years after fertilization. Shrub biomass and coverage, and nutrient levels of spruce foliage were strongly affected by fertilization.

The purpose of the present paper is to give a preliminary report on the growth response of northern Ontario peatland black spruce to drainage and fertilization. This is part of a growth and yield study established in 1969. The objectives of the study were to provide a basis for sound management of northern Ontario peatland black spruce by developing and refining methods of predicting individual tree and stand volume and value growth as influenced by drainage and fertilization.

# MATERIALS AND METHODS

From 1969 to 1973, 425 permanent growth plots were established in the Cochrane district of northern Ontario. Of these, 132 plots, located in nine blocks, were fertilized. Two of the blocks contained 24 plots each and the remaining seven blocks contained 12 plots each. Plot arrangement within blocks was constant. Each line consisted of three plots with plot centres located approx. 10, 17 and 50 m from the centre of the drainage ditch. The distance between rows of plots within block was approx. 30 m. Figure 1 illustrates plot arrangement and fertilizer treatments applied to plots in blocks IV and V; Figure 2 shows permanent growth and a fertilization plot combined. A fertilization plot consisted of a .04 ha circular plot centred on a growth plot with a buffer zone of about 1 m wide around it. The nine blocks were located in three separate locations. Blocks I, II and XIII were located in Edwards Township, the site of the Abitibi swamp drainage experiment established in 1929 (see Payandeh 1973a for details). At the time of fertilization treatment in 1970 this site could be classified as black spruce-alder according to Jeglum's (1975) site classification. It contained semi-merchantable mature stands of pure black spruce about 110 years of age with an average $SI_{50}$ of 5 m or site class 3 according to Plonski's (1974) site classes. Blocks IV, V, VI and VII were located in St. John and Hanna townships alongside a highway drainage ditch dug in mid 1940s. This site could be classified as treed bog according to Jeglum's (1975) site classification, and contained very stagnant unmerchantable black spruce averaging about 95 years of age. Average $SI_{50}$ for this area was about 3 m, which is well below site class 3 according to Plonski's (1974) site classes. Blocks XI and XII were located in Leitch Township, the site of a drainage experiment established in 1962 (see Stanek 1968 for details). At the time of the fertilization experiment, this site could be classified as black spruce-alder according to Jeglum's (1975) site classification. Existing stands in this area were considered overmature: they averaged about 118 years of age and had a $SI_{50}$ of 4 m, which is below that of Plonski's (1974) site class 3.

Within all blocks each row of three plots was randomly selected and subjected to fertilization treatment. Fertilizers were hand broadcast in each plot as uniformly as possible at various levels (level refers to fertilizer, not element). Treatments applied to blocks IV and V were replicated twice since these two blocks each contained 24 plots (in eight rows of three plots each). In other blocks containing four rows of plots, each row was subjected to a separate treatment without replication. Fertilization plots were established in mid-June over a 3-year period, starting in 1970.



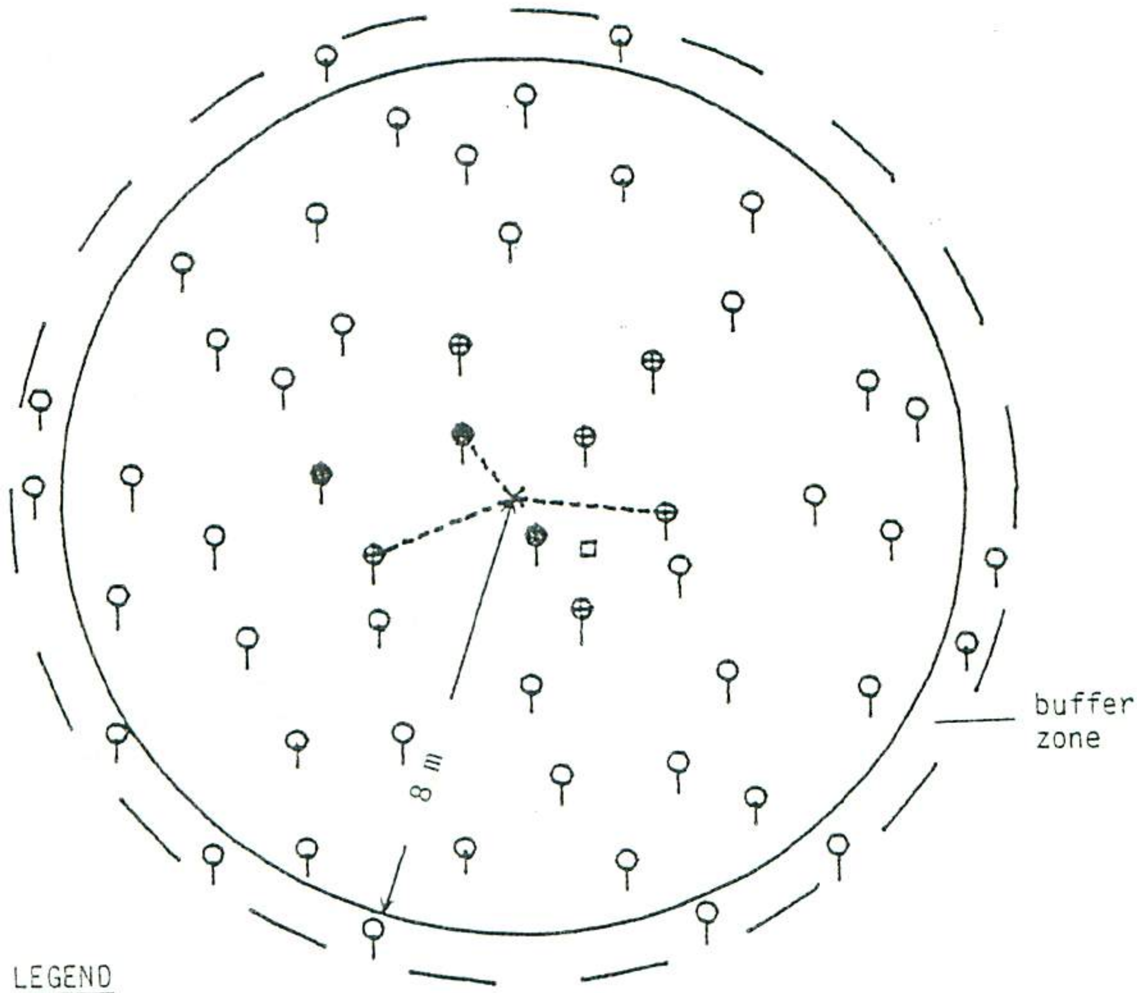

Lines 1 and 5--AN 84 kg/ha, TSP 84 kg/ha, KC 42 kg/ha

Lines 2 and 6--AN 112 kg/ha, TSP 112 kg/ha, KC 66 kg/ha

Lines 3 and 7--AN 168 kg/ha, TSP 168 kg/ha, KC 84 kg/ha

Lines 4 and 8--AN 224 kg/ha, TSP 224 kg/ha, KC 112 kg/ha

Figure 1. Plot arrangement and fertilization treatments applied to plots within Blocks IV and V, located in St. John and Hanna townships south of Cochrane, Ontario.




LEGEND

× aluminum stake - plot centre

fertilized tree only

fertilized "in" tree within PGP

fertilized "in" tree with additional measurement

"in" tree with measured azimuth and distance to plot centre

□ peat sample

Fertilization plot radius 8 m (.02 ha) + buffer 9 m

Figure 2. Combination of permanent growth and fertilization plot: Growth and yield of peatland black spruce in northern Ontario.

On each plot, all trees with DBH >1.5 cm were marked and tagged at breast height. Species, DBH and height were measured and recorded for all trees. Tree diameters were measured to the nearest 0.025 cm with a diameter tape. Trees taller than 10 m were measured with a Spiegal Reloskop and others were measured with sectional tree height measuring poles to the nearest 30 cm. In addition, detailed individual tree data such as tree age, crown class, crown condition, distance to the ditch, distance to the nearest tree, etc., were recorded for three or four dominant and codominant trees as part of the permanent growth plot located at the centre of each fertilization plot (see Fig. 2). Peat and foliage[1] samples were collected from each plot and chemically analyzed before fertilization and annually thereafter.

Seventy-two of the fertilized plots which were located in blocks IV, V, VI and VII were remeasured two and five years after treatment. All other plots were remeasured five years after treatment. During the five-year remeasurement about 60 dominant and codominant trees located at various distances from the drainage ditches were felled and sectioned for detailed analysis of individual tree growth response to drainage and fertilization.[2] All data were collected and measurements were taken in English units, but these were converted to SI units during preliminary analysis. Calculation of total and merchantable tree volumes was based on standard tree volume equations (Honer 1967). All growth remeasurements were based on surviving trees only.

## ANALYSIS AND RESULTS

Owing to constraints imposed on this study by the number and location of existing experimental and/or highway drainage ditches, heterogeneity of stands involved, small sample size, and the number of treatments applied, a replicated and experimentally efficient design was not possible. Therefore, much of the variation in results can not be partitioned or delineated. Nevertheless, the data were analyzed to provide as much insight as possible.

Two- and five-year measurements were taken, and annual stand growth variables were calculated (Table A1). Five-year annual growth

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[1]Analysis of peat and foliage samples is given elsewhere (Payandeh, B. and Haavisto, V.F. Nutrient status of poorly drained peatland black spruce in northern Ontario. Manuscript in preparation).

[2]Analysis of sectional tree data is given elsewhere (Payandeh, B. Growth response of peatland black spruce trees to drainage and fertilization. Manuscript in preparation).

figures were consistently higher than two-year figures for all stand variables, and this suggests a time lag in growth response to fertilization treatment.

Table A2 summarizes average annual stand diameter, height, BA and volume growth over the five-year period for the various fertilization treatments. The number of plots per treatment varied from 3 to 33. Weighted averages for various growth figures are given for comparison. Various annual stand growth responses are presented graphically in Figures A1-A4.

Five-year growth response data were subjected to analysis of variance, which indicated highly significant (at the 1% level) differences among various treatments as well as for annual DBH, height, BA and volume growth. However, Tukey's test indicated (Table A3) only a few significant differences among individual treatments. This is perhaps due mainly to constraints posed on the experimental design mentioned above.

To remove variability among the three experimental areas and to reduce the number of treatments, five-year periodic growth responses for blocks I, II and XIII located in Edwards Township, blocks IV and V located in St. John and Hanna townships, and blocks XI and XII located in Leitch Township, are summarized separately in Tables 1-3. No statistical tests were carried out on these tables; nevertheless, they give the magnitude of various growth responses which were due to treatment effects within each experimental area.

To eliminate the source of variability among experimental areas and between blocks within each area, and also to examine the effects of fertilization, drainage and their interaction on growth, the data were analyzed on the basis of growth responses of the 12 largest trees per plot within blocks IV, V, XI and XII.

Table 4 provides the summary of analysis of variance on tree diameter, height and volume growth responses to fertilization and drainage for the four blocks. In the case of Block V, highly significant (at the 1% level) differences due to fertilization, drainage and their interaction (with the exception of the effect of drainage on height growth) were observed. In the case of Block IV, there were significant differences due to the effect of drainage on diameter, height and volume growth. There were no significant differences due to fertilization or the interaction of drainage and fertilization except in the case of volume growth. Table 4 also indicates that, in the case of blocks XI

Table 1. Summary of five-year periodic growth response of peatland black spruce to fertilizer treatments in blocks I, II and XIII, located in Edwards Township, the site of the Abitibi drainage experiment.

| Block No. | Treatment | DBH growth (cm) | Basal area growth ($m^2/ha$) | Merchantable volume growth ($m^3/ha$) |
|---|---|---|---|---|
| I | Control | 0.503 | 2.30 | 10.87 |
| | TSP224 | 0.635 | 2.32 | 7.56 |
| | AN112, TSP112, KC112 | 0.568 | 2.49 | 14.42 |
| | TSP112, KC112 | 0.558 | 2.31 | 17.30 |
| II | Control | 0.463 | 1.32 | 12.84 |
| | TSP112 | 0.687 | 1.74 | 11.26 |
| | AN112, TSP112, KC112 | 0.717 | 2.12 | 17.78 |
| | TSP112, KC112 | 0.572 | 1.69 | 15.79 |
| XIII | Control | 0.903 | 1.61 | 14.96 |
| | TSP224 | 0.838 | 1.73 | 15.44 |
| | AN112, TSP112, KC112 | 0.793 | 1.38 | 11.18 |
| | TSP112, KC112 | 0.810 | 1.53 | 12.66 |
| Average | Control | 0.623 | 1.74 | 12.89 |
| | TSP112 | 0.720 | 1.93 | 11.42 |
| | AN112, TSP112, KC112 | 0.629 | 2.00 | 14.46 |
| | TSP112, KC112 | 0.647 | 1.84 | 15.25 |

Table 2. Summary of five-year periodic growth response of peatland black spruce to fertilizer treatments in blocks IV and V, located in St. John and Hanna townships, the site of a highway drainage ditch south of Cochrane, Ontario.

| Block No. | Treatment | DBH growth (cm) | Basal area growth ($m^2$/ha) | Merchantable volume growth ($m^3$/ha) |
|---|---|---|---|---|
| IV | Control | 0.521 | 1.53 | 6.83 |
| | Thinning | 0.469 | 1.51 | 4.39 |
| | AN112, TSP112, KC66 | 0.546 | 2.26 | 8.51 |
| | AN224, TSP224, KC112 | 0.608 | 2.04 | 4.76 |
| V | Control | 0.432 | 1.15 | 1.46 |
| | Thinning | 0.443 | 0.89 | 0.72 |
| | AN84, TSP84, KC42 | 0.610 | 1.53 | 3.27 |
| | AN168, TSP168, KC84 | 0.621 | 1.68 | 0.78 |
| Average IV and V | Control | 0.477 | 1.34 | 4.15 |
| | Thinning | 0.456 | 1.20 | 2.55 |

Table 3. Summary of five-year periodic growth response of peatland black spruce to fertilizer treatments in blocks XI and XII, located in Leitch Township, Cochrane District, the site of an experimental drainage system.

| Block No. | Treatment | DBH growth (cm) | Basal area growth ($m^2$/ha) | Merchantable volume growth ($m^3$/ha) |
|---|---|---|---|---|
| XI | Control | 0.782 | 1.73 | 7.98 |
| | TSP224 | 0.750 | 1.99 | 9.17 |
| | U112, TSP112, KC112 | 0.847 | 2.15 | 14.57 |
| | U112, TSP112, KC168 | 0.880 | 2.35 | 14.97 |
| XII | Control | 0.605 | 1.20 | 1.52 |
| | TSP224 | 0.585 | 1.46 | 1.98 |
| | TSP112, KC112 | 0.795 | 1.56 | 3.10 |
| | U112, TSP112, KC112 | 1.075 | 2.55 | 8.43 |
| Average XI and XII | Control | 0.693 | 1.47 | 4.75 |
| | TSP224 | 0.667 | 1.73 | 5.58 |
| | U112, TSP112, KC112 | 0.961 | 2.35 | 11.50 |

Table 4. Summary of analysis of variance of individual tree growth in response to fertilization and drainage for three response variables in blocks IV, V, XI and XII[a].

| Source of variation | D.F. | Response variable | F-Ratio IV | V | XI | XII |
|---|---|---|---|---|---|---|
| Treatment | 11 | Annual diameter growth | 5.31** | 6.31** | 2.21* | 1.98 |
| Fertilization | 3 | | 0.85 | 4.38** | 2.83* | 5.05** |
| Drainage | 2 | | 21.74** | 10.61** | 2.04 | 0.47 |
| Interaction | 6 | | 2.06 | 5.84** | 1.96 | 0.77 |
| Treatment | 11 | Annual height growth | 2.20* | 4.48** | 0.74 | 0.69 |
| Fertilization | 3 | | 1.40 | 6.80** | 0.42 | 1.19 |
| Drainage | 2 | | 7.07** | 1.12 | 0.72 | 0.65 |
| Interaction | 6 | | 0.98 | 6.28** | 0.91 | 0.46 |
| Treatment | 11 | Annual volume growth | 8.73** | 10.53** | 2.10* | 0.69 |
| Fertilization | 3 | | 4.85** | 10.47** | 5.43** | 1.19 |
| Drainage | 2 | | 36.89** | 11.44** | 0.69 | 0.65 |
| Interaction | 6 | | 1.29 | 10.27** | 0.91 | 0.46 |

[a]Analysis based on the 12 largest trees per plot in each treatment
* and ** indicate significance at 5% and 1% levels, respectively

and XII, only the effects of fertilization on diameter and volume growth were significant. None of the other factors, singly or in combination, were statistically significant.

## SUMMARY AND DISCUSSION

The results of this study are significantly affected by the experimental constraints posed upon it by the location and numbers of existing experimental and/or highway drainage ditches, high variability of natural growth characteristics among the stands examined, and relatively large numbers of unreplicated treatments applied. Nevertheless, many of the results are in general agreement with those from similar experiments on peatland sites conducted in the Scandinavian countries and Russia (cf. Päävilainen 1975; Seppälä 1976; Braekke 1977; Smidle 1977; Fardmo 1979; Heikurainen and Laine 1976; and others). The results are also in relative agreement with those from similar studies carried out on upland black spruce in Canada (cf. Weetman 1968, 1975; Van Nostrand and Bhure 1973; Morrison and Foster 1979; Krause 1981 and others). Highlights of the results of the present study may be summarized as follows:

a) Table A2 and figures A1-A4 indicate that growth response to several of the treatments was less than that of the overall control for the entire experiment. However, Table A3 indicates that most of the observed differences were not statistically significant and might be due to variability of natural growth characteristics between experimental areas (blocks) or within stands. Nevertheless, Table 2 indicates that on average, minor thinning in blocks IV and V had a depressing effect on diameter, BA and volume growth in comparison with the control plots. The adverse effects of thinning on growth may be a result of reduction in crown cover and consequently reduction in the rate of photosynthesis and evapotranspiration.

b) Tables A2 and A3 and figures A1-A4 also indicate that the four levels of phosphorus fertilizers applied had depressive effects on growth in most cases. Here again, some of the observed differences could be due to variability in natural growth characteristics between experimental areas and stands within blocks.

c) The two treatments containing urea gave the best and the statistically most significant growth response over the control for most response variables examined. All other treatment combinations resulted in modest but statistically nonsignificant response.

d) Analysis of individual tree growth response to fertilization and drainage (Table 4) indicates that only in the case of block V were there definite and statistically significant effects on growth response to fertilization, drainage and/or their interaction for the three response variables examined. In the case of block IV, the effects of drainage on growth response were also statistically significant, but the effects of fertilization and of the interaction of fertilization and drainage were nonsignificant. For blocks XI and XII, however, no significant effects due to drainage or the interaction of drainage and fertilization were detected.

In general, growth response of mature peatland black spruce stands (treed bogs) to fertilization, drainage and minor thinning was highly variable, as were the stand characteristics examined in this study. In view of the slow-growing nature of the stands, such responses varied from very good to poor. The best growth response to fertilizer treatment was obtained from U TSP KC at the rate of 112 kg/ha of each fertilizer. This treatment resulted in about 7 $m^3$/ha of extra wood in comparison with the control over the five-year period. On the other hand, the application of TSP alone resulted in a growth reduction of about 1.5 $m^3$/ha. Minor thinning also had a depressive effect on growth, i.e., about 1.6 $m^3$/ha of volume loss in comparison with the control during the five-year period. For the main experiment, four of the treatments applied resulted in a reduction in volume growth. These consisted of application of TSP at the rates of 112, 336 and 448 kg/ha and minor thinning.

The depressive effects of phosphorus fertilizer on the growth of spruce stands have been reported elsewhere. Morrison and Foster (1979), for example, reported such depressive effects in two out of 12 treatment combinations applied to a 65-year-old upland black spruce stand and also in eight out of 12 treatment combinations applied to spruce-fir stands located at Black Sturgeon Lake, Ontario. Application of 100 kg/ha of P fertilizer caused the loss of about 4 $m^3$/ha in total volume growth for the black spruce stand. In the case of the spruce-fir stand, the reduction in total volume growth ranged from 1 to 15 $m^3$/ha over the five-year period. Weetman et al. (1976, 1978, 1979) have also reported actual growth suppression as the result of applying NP fertilizer in four out of 18 treatment combinations involving upland black spruce stands within the Inter-provincial Forest Fertilization Program. Therefore, the depressive effects on the growth of peatland black spruce as a result of the application of P-fertilizer in this study seem to be in general agreement with those of the studies mentioned above.

## CONCLUSIONS AND RECOMMENDATIONS

Owing to experimental constraints imposed on this study, no definite conclusion can be reached from the results. Nevertheless, many of the results are in agreement with those of previous fertilization experiments involving upland and peatland black spruce in Ontario, Newfoundland and Minnesota. In general, the following tentative statements can be made on the basis of this study:

a) Minor thinning of mature peatland black spruce stands may have a depressive effect on the growth of residual stands following treatments, perhaps because of the reduction in crown cover and the rate of photosynthesis and evapotranspiration.

b) Application of P-fertilizer alone, especially at a high rate, may also have a depressive effect on the natural growth of peatland black spruce stands, perhaps because it increases the acidity of the soil.

c) Moderate application of NPK fertilizer may have a positive and significant effect on the growth of mature peatland black spruce stands.

d) Despite several sources of variation, the results of this study indicate, in part at least, that drainage has a positive and significant effect on the growth of individual trees and stands of peatland black spruce. Depending on site, stand characteristics and fertilization treatments there may also be a significant growth response as a result of the interaction between fertilizer treatment and drainage.

Numerous drainage and/or fertilization experiments in swamps conducted in Finland, Sweden, Russia and other European countries have proven that such treatments can improve growth and yield of peatland forest stands significantly. The large-scale application of such treatments has also proven both practical and economical under the socio-economic conditions of Finland and Russia. Consequently, large areas of swampy forests are being drained and/or fertilized annually in both countries.

In the case of Canadian peatland forests in general and black spruce stands in northern Ontario in particular, no concrete recommendations can be made with respect to the magnitude of growth and yield improvement as a result of drainage and/or fertilization, mainly because of a lack of sufficient information. Only a few small-scale forest drainage and/or fertilization experiments have been conducted in Canada to date. Unless a series of long-term, well designed, and well replicated experiments is carried out to determine the effects of such treatments on growth and yield of peatland black spruce, no definite recommendation can be made with respect to the practicality and economic feasibility of such stand improvements under Canadian economic conditions. Nevertheless, it is perhaps safe to say that, unless economic conditions in general and the wood supply situation in particular change dramatically in the near future, the application of such silvicultural treatments to peatland black spruce stands may not be economically justified.

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# APPENDIX I

Table A1. Statistical summary of annual growth of peatland black spruce two[a] and five years[b] following fertilization.

| Growth characteristic | Min. | Max. | Range | Mean | Std. Dev. | Coeff. of var. (%) |
|---|---|---|---|---|---|---|
| Avg DBH growth (cm) | [a]0.07<br>[b]0.05 | 0.27<br>0.28 | 0.20<br>0.23 | 0.11<br>0.12 | 0.03<br>0.04 | 29.67<br>33.79 |
| Total BA growth ($m^2$/ha) | [a]0.01<br>[b]0.02 | 0.36<br>0.42 | 0.35<br>0.40 | 0.17<br>0.22 | 0.13<br>0.14 | 76.47<br>63.64 |
| Merchantable vol growth ($m^3$/ha) | [a]0.00<br>[b]0.00 | 4.56<br>5.71 | 4.56<br>5.71 | 1.26<br>1.32 | 1.16<br>1.29 | 90.16<br>97.73 |

[a]Two-year annual growth based on remeasurement of 72 plots.

[b]Five-year annual growth based on remeasurement of 132 plots.

APPENDIX II

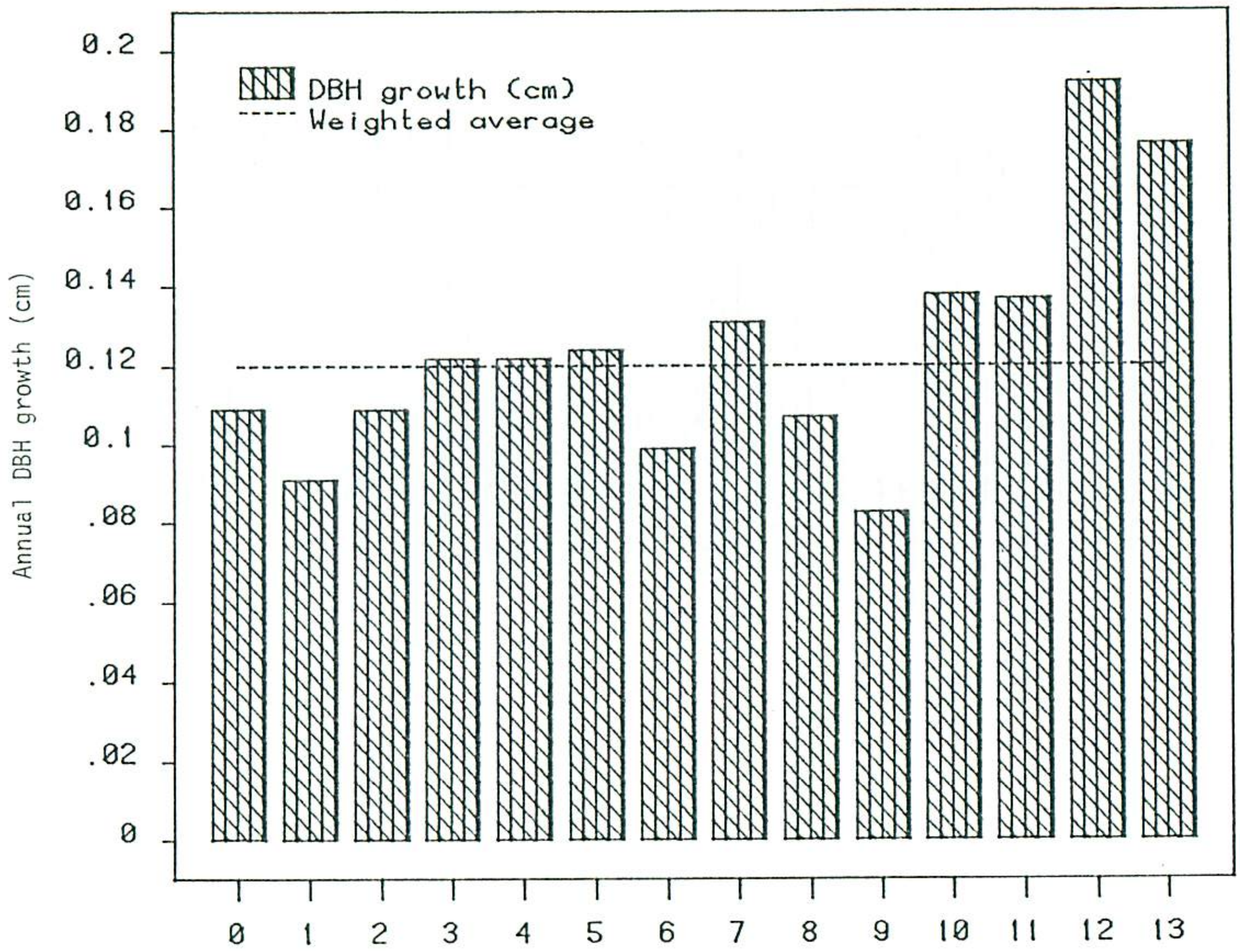


Figure A1. Five-year annual stand DBH growth of peatland black spruce under various fertilization treatments.

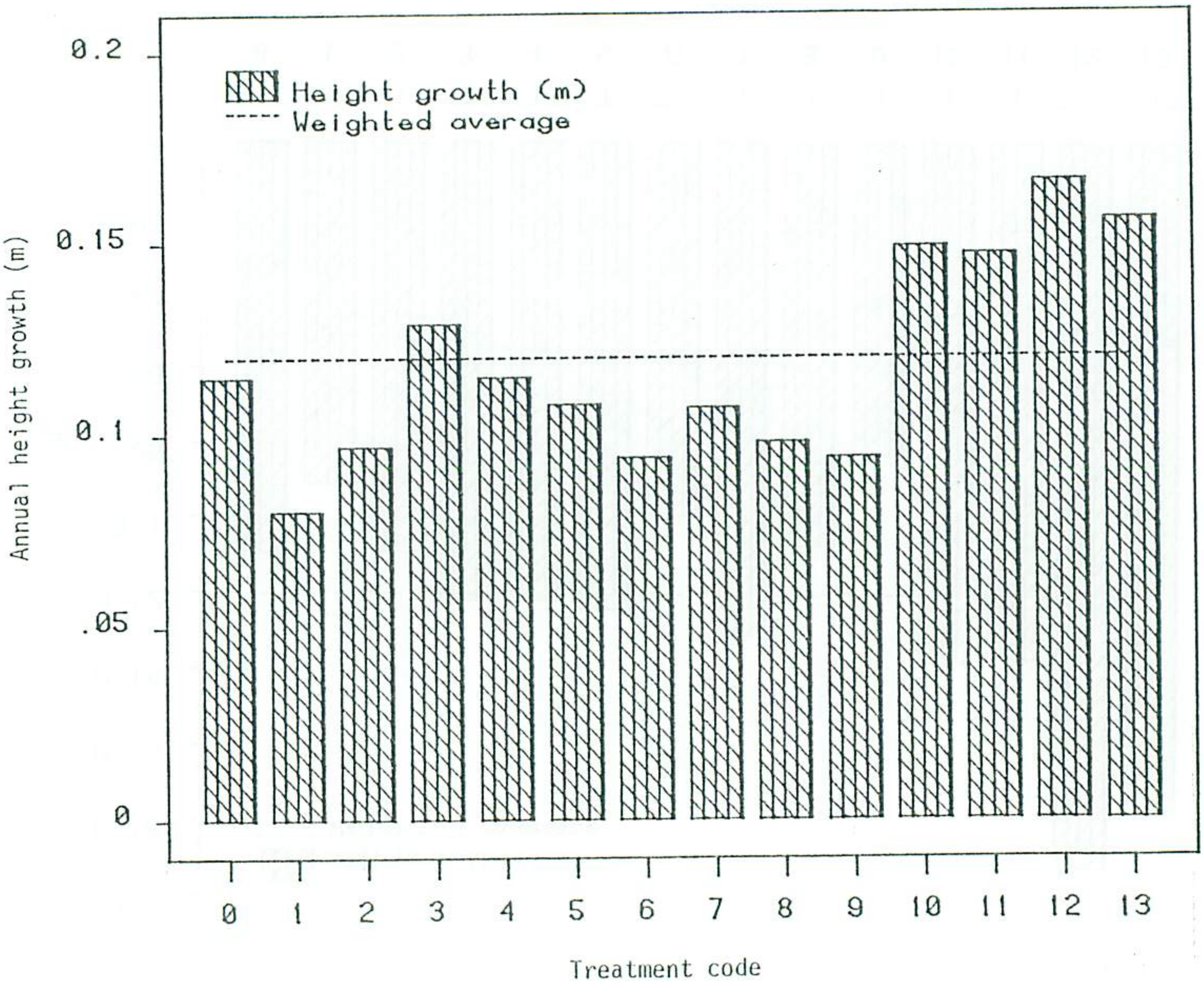


Figure A2. Five-year annual stand height growth of peatland black spruce under various fertilization treatments.

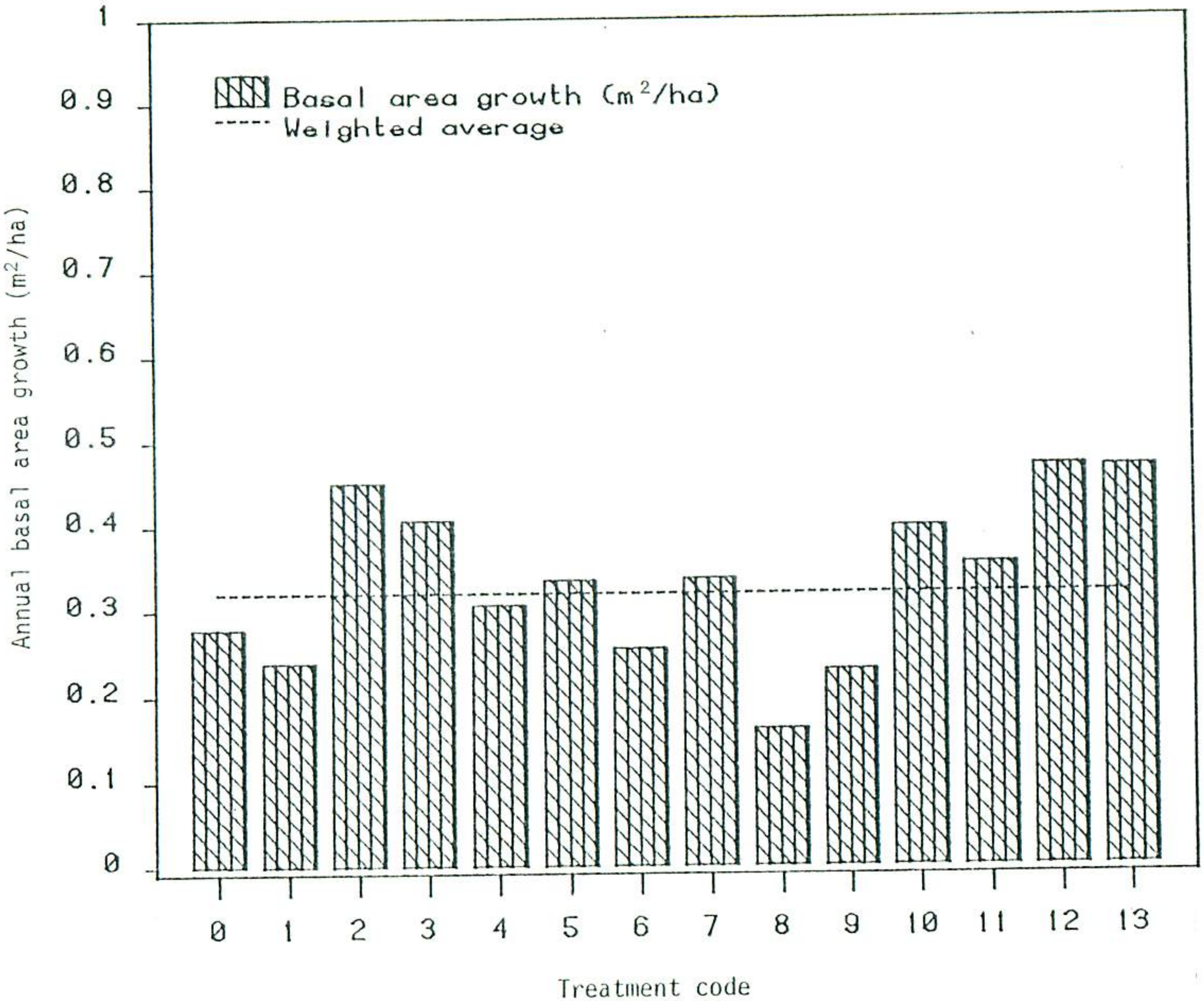


Figure A3. Five-year annual stand basal area growth of black spruce under various fertilization treatments.

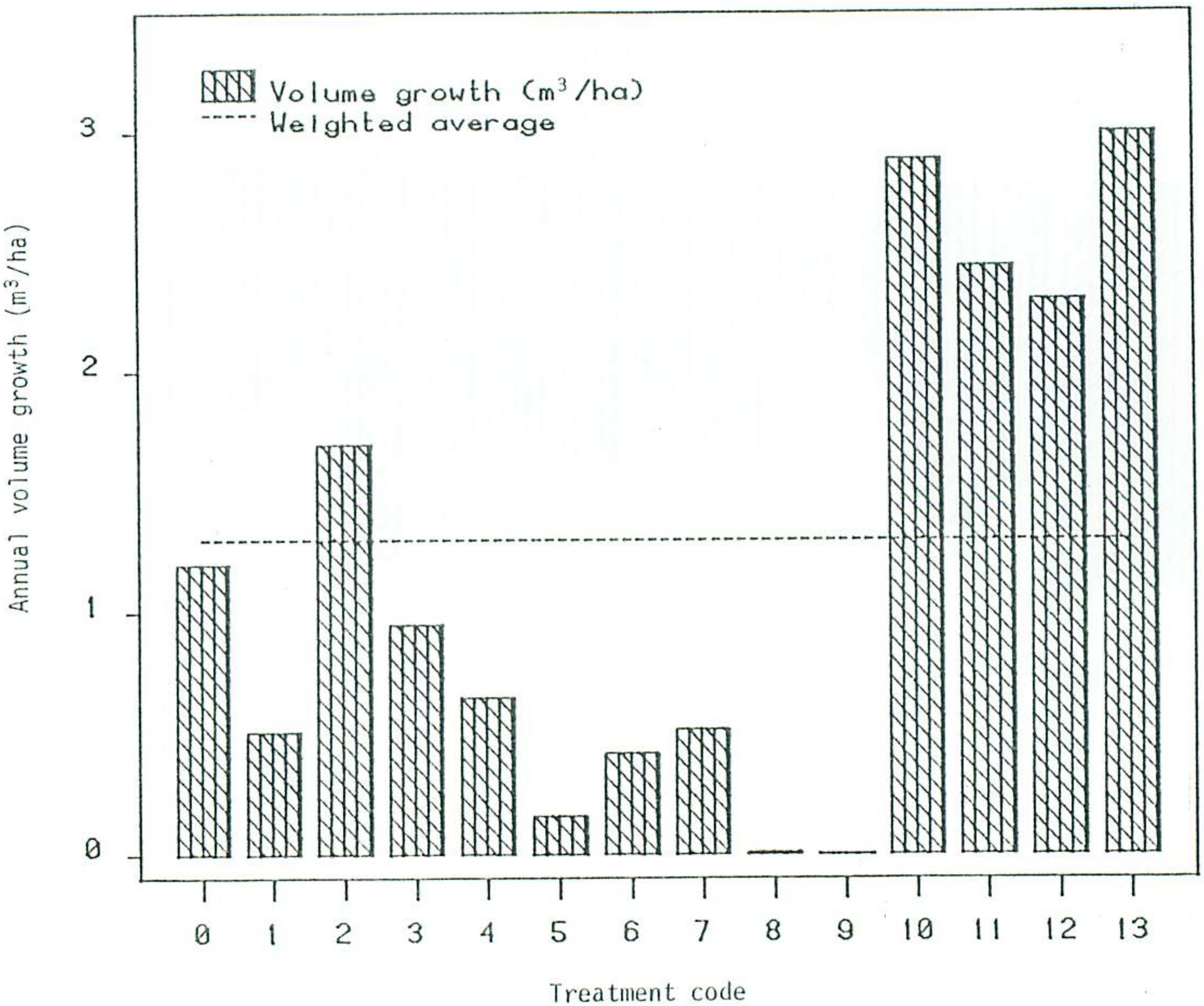


Figure A4. Five-year annual stand volume growth of black spruce under various fertilization treatments.

# APPENDIX III

Table A2. Summary of average annual growth response of peatland black spruce to fertilizer treatments over five-year growth period.

| Treatment | Code | No. of plots | DBH (cm) | Height (m) | Total basal area ($m^2$/ha) | Merchantable vol. ($m^3$/ha) |
|---|---|---|---|---|---|---|
| Control | (0) | 33 | .109 | .115 | .279 | 1.198 |
| Thinning[a] | (1) | 12 | .091 | .080 | .240 | 0.511 |
| AN112, TSP112, KC66 | (2) | 6 | .109 | .097 | .451 | 1.702 |
| AN224, TSP224, KC112 | (3) | 6 | .122 | .129 | .407 | 0.952 |
| AN84, TSP84, KC42 | (4) | 6 | .122 | .115 | .307 | 0.653 |
| AN168, TSP168, KC84 | (5) | 6 | .124 | .108 | .336 | 0.156 |
| TSP112 | (6) | 6 | .099 | .094 | .256 | 0.424 |
| TSP224 | (7) | 18 | .131 | .107 | .338 | 1.518 |
| TSP336 | (8) | 6 | .107 | .098 | .231 | 0.009 |
| TSP448 | (9) | 3 | .083 | .094 | .162 | 0.006 |
| AN112, TSP112, KC112 | (10) | 9 | .138 | .149 | .399 | 2.392 |
| TSP112, KC112 | (11) | 12 | .137 | .147 | .355 | 2.442 |
| U112, TSP112, KC112 | (12) | 6 | .192 | .166 | .470 | 2.300 |
| U112, TSP112, KC168 | (13) | 3 | .176 | .156 | .469 | 2.993 |
| Weighted average | | | .121 | .117 | .322 | 1.321 |

[a]Low thinning by removing 10-15% of intermediate and suppressed trees

Table A3. Summary of Tukey's test on peatland black spruce response to fertilization treatments for various response variables

| Diameter growth (cm) | | Height growth (m) | |
|---|---|---|---|
| Treatment | Ranked Mean | Treatment | Ranked Mean |
| U112, TSP112, KC112 | 0.192 | U112, TSP112, KC112 | 0.166 |
| U112, TSP112, KC168 | 0.176 | U112, TSP112, KC168 | 0.156 |
| AN112, TSP112, KC112 | 0.139 | AN112, TSP112, KC112 | 0.149 |
| TSP112, KC112 | 0.134 | TSP112, KC112 | 0.147 |
| TSP224 | 0.131 | AN224, TSP224, KC112 | 0.129 |
| AN168, TSP168, KC84 | 0.124 | Control | 0.115 |
| AN84, TSP84, KC42 | 0.122 | AN84, TSP84, KC42 | 0.115 |
| AN224, TSP224, KC112 | 0.122 | AN168, TSP168, KC84 | 0.108 |
| AN112, TSP112, KC66 | 0.109 | TSP224 | 0.107 |
| Control | 0.109 | TSP336 | 0.098 |
| TSP336 | 0.107 | AN112, TSP112, KC66 | 0.097 |
| TSP112 | 0.099 | TSP112 | 0.094 |
| Thinning | 0.092 | TSP448 | 0.094 |
| TSP448 | 0.084 | Thinning | 0.080 |
| Basal area growth ($m^2/ha$) | | Volume growth ($m^3/ha$) | |
| U112, TSP112, KC112 | 0.470 | U112, TSP112, KC168 | 3.000 |
| U112, TSP112, KC168 | 0.469 | AN112, TSP112, KC112 | 2.892 |
| AN112, TSP112, KC168 | 0.451 | TSP112, KC112 | 2.442 |
| AN224, TSP224, KC112 | 0.407 | U112, TSP112, KC112 | 2.300 |
| AN112, TSP112, KC112 | 0.399 | AN112, TSP112, KC66 | 1.702 |
| TSP112, KC112 | 0.355 | TSP224 | 1.518 |
| TSP224 | 0.338 | Control | 1.198 |
| AN168, TSP168, KC84 | 0.336 | AN224, TSP224, KC112 | 0.952 |
| AN84, TSP84, KC42 | 0.307 | AN84, TSP84, KC42 | 0.653 |
| Control | 0.279 | Thinning | 0.511 |
| TSP112 | 0.256 | TSP112 | 0.424 |
| Thinning | 0.240 | AN168, TSP168, KC84 | 0.156 |
| TSP336 | 0.231 | TSP336 | 0.009 |
| TSP448 | 0.162 | TSP448 | 0.006 |

Connecting arrows indicate that the largest treatment mean is significantly (at the 5% level) greater than other treatment means not included within the same connecting arrows.