FIVE-YEAR GROWTH RESPONSE IN DRAINED AND FERTILIZED BLACK SPRUCE PEATLANDS. I. PERMANENT GROWTH PLOT ANALYSIS

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ABSTRACT

A 375-ha area of black spruce (*Picea mariana* [Mill.] B.S.P.) forest on peatland in northeastern Ontario was drained with 87 km of ditches in 1984 and portions were fertilized from 1985 to 1987. Five years after drainage, trees had significantly greater diameter growth if fertilized and drained than they did without treatment. Fertilization alone was better than drainage alone. A drainage response was found in trees located close to a ditch. Responses for both drainage and fertilization were larger for OG11 and OG14 sites than for OG8 and OG12 sites. Mortality and damage were not higher in drained than in control treatments, except for trees very close to the ditches. The results to date indicate that 5 years is too short a period for a drainage response to be completed for black spruce in this site and geographical area.

RÉSUMÉ

Dans le nord-est de l'Ontario, 375 ha d'une forêt d'épinette noire (*Picea mariana* [Mill.] B.S.P.) dans une tourbière ont été drainés par 87 km de fossés en 1984, et certaines zones ont été fertilisées entre 1985 et 1987. Cinq ans après le drainage, l'accroissement du diamètre des arbres était beaucoup plus grand dans les zones fertilisées et drainées que dans celles qui ne l'étaient pas. La fertilisation seule était plus efficace que le drainage seul. Une réponse au drainage a été constatée dans les arbres près des fossés. Les réponses au drainage et à la fertilisation étaient plus grandes dans les sites OG11 et OG14 que dans les sites OG8 et OG12. La mortalité et les dommages dans les parcelles drainées ne dépassaient pas ceux des zones témoins, sauf pour les arbres situés très près des fossés. Jusqu'à maintenant, les résultats révèlent qu'une période de cinq ans n'est pas assez longue pour que la réponse au drainage soit établie chez les épinettes noires de la région.

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INTRODUCTION

Drainage to improve forest growth on wetlands, especially peatlands, is an old and well-known forest management technique in the Fenno-Scandinavian countries and in the USSR. There is a well-established literature base on different types of peatlands and the potential for improved forest growth as a result of drainage (e.g., Börjesson 1927; Malmström 1928; Karlberg 1955; P'yavchenko 1957; Heikurainen 1961, 1964, 1966; Seppälä 1969; Hånell 1984). It has been well documented that forest growth can be increased strikingly by draining in certain types of peatland: growing conditions improve when excess water is removed, the soil is better aerated and nutrients are made available.

In North America, the history of drainage on forest land is younger and, naturally, the number of reported experiments on forest drainage are fewer. Averell and McGrew (1929) classified peatland sites in Minnesota on the basis of tree growth before drainage, and described the post-drainage increase in forest production 15 years after drainage for black spruce (*Picea mariana* [Mill.] B.S.P.), tamarack (*Larix laricina* [Du Roi] K. Koch) and eastern white cedar (*Thuja occidentalis* L.). Other drainage experiments in the United states have been reported from Wisconsin (Zon and Averell 1929) and Michigan (LeBarron and Netzel 1942, Satterland and Graham 1957).

Information on forest drainage in Canada deals primarily with the effects of drainage on stands close to roads or railways, where ditches were dug in order to remove water from the constructions rather than to improve forest growth. Päivänen and Wells (1978) reported on some drainage trials in Newfoundland in which tree growth responses were mostly poor. However, they noticed that 15 years after construction, the height growth of trees 50 to 70 m from ditches was affected positively.

In Quebec, between 15,000 and 20,000 ha have been drained to improve forest production, predominantly in clearcut areas on private woodlots (Trottier 1991). When measuring the growth of tamarack at different distances from ditches, Trottier (1986) found that the post-drainage rate of wood production of tamarack within 10 m of a ditch was more than five times the pre-drainage rate. Growth of trees further from a ditch was much less, although the volume production was greater than that of trees on undrained plots.

The most important pulpwood species in Ontario is black spruce, and 50% of the forested black spruce area is on peatland (Ketcheson and Jeglum 1972). 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). Some experiments with drainage of forested peatland have been carried out in Ontario. The first forest drainage experiment in Canada was established in 1929 north of Iroquois Falls (Payandeh 1973). Although the experimental design was poor, Payandeh showed that response to drainage was more pronounced for individual trees than for stands and that the response was greater for younger trees with larger crowns growing on better sites.

Another drainage experiment in the same region in northern Ontario was reported by Stanek (1968). Five years after drainage, both diameter and height growth had increased five-fold in 11 young saplings. Younger trees and seedlings responded best to drainage, whereas older trees with short, narrow crowns showed no positive response and some even died.

As mentioned earlier, many of the reported experiments on forest drainage in Canada had poor experimental designs, as they were not originally set up for the purpose of studying forest growth. Recently, a number of better-designed forest drainage experiments have been established in Canada (Hillman 1987). One of these is the Wally Creek Area Forest Drainage Project, a cooperative project initiated by the Ontario Ministry of Natural Resources (OMNR) and Forestry Canada, Ontario Region (FCOR) (Haavisto 1984, Rosen 1986).

The purpose of the present report is to provide a preliminary analysis of the growth response of black spruce in the Wally Creek Area 5 years after drainage and fertilization.

MATERIALS AND METHODS

The Study Area

The experimental area (49°03'N, 80°40'W) is located along a provincial highway about 30 km east of Cochrane, Ontario, in the Northern Clay Section of the Boreal Forest Region (Rowe 1972) of northeastern Ontario. The experimental area has a total land base of 1,099 ha, of which 941 ha is classified as lowland black spruce forest (Rosen 1986).

The area's climate (see Appendix 1) is very favorable for peat accumulation, with a mean annual temperature of 0.6°C (–17°C in January and +17°C in July) and an annual precipitation of about 880 mm. The growing season length (mean temperatures above 5°C) is 160 days. The potential evapotranspiration in this area ranges from 400 to 450 mm per year.

The depth of the peat layer varies from less than 20 cm in the better-drained eastern part of the area up to

3.7 m in the semi-treed open spruce fen and bog areas. Peat depths are less than 1 m in approximately 50% of the area, between 1 and 2 m in about 25% of the area, and greater than 2 m in the remaining 25% of the area. The organic components of the soils are all underlain by varved heavy clays and silty clays of varying colors.

The major tree species in the area is black spruce, with minor constituents of white spruce (*Picea glauca* [Moench] Voss), tamarack, balsam fir (*Abies balsamea* [L.] Mill.), poplar (*Populus tremuloides* Michx. and *P. balsamifera* L.) and white birch (*Betula papyrifera* Marsh.). The area was classified and mapped in accordance with the Forest Ecosystem Classification (FEC) (Jones et al. 1983) in 1984, the summer before drainage, by Arnup (1985). The main FEC Operational Groups (OGs) found in the area were OG8, OG11, OG12 and OG14; OG8 is a mineral-soil type, whereas OG11 to OG14 occur on organic soils (i.e., soils with an organic layer thicker than 40 cm).

Part of the forest was harvested in about 1930 by ground cutters using horses to skid trees to the roadside. This method left much advanced growth, including saplings and small trees, and the area regenerated naturally to a fully stocked forest. As a result, the present forest is uneven-aged. Some trees were present at the time of the harvest and are therefore more than 60 years old, and others originated after the cutting and are younger. As well, the structure of the horse-logged forest is one of irregular sizes and heights, ranging from large canopy trees to smaller saplings and seedlings in the understory. Other parts of the area that had not been cut have much older trees (Jeglum 1991). The ages of 150 trees (≥ 5 cm) cut in 1985 varied between 40 and 280 years.

The Drainage Area

In the early 1970s, some preliminary work done by FCOR at Wally Creek provided a contour survey for part of the area (Silc 1973). With the use of this survey, the FEC map, aerial photos and additional field reconnaissance, the drainage was planned and implemented by a Finnish drainage expert, Ilka Koivisto, according to strict Finnish drainage standards (Haavisto 1984).

Two Finnish Lännen S–10 digging machines and their two operators were brought to Ontario (Härkönen 1986). A total of 375 ha of the study area, of which 306 ha were in the mid-rotation black spruce forest, was drained in the fall of 1984. The remaining 69 ha are located in a cutover area that has been planted. The drainage system consists of 87 km of open ditches (Fig. 1). The standard lateral ditches are mostly 90 cm deep and 1.4 m wide, but some are shallower (about 70 cm) where the peats are shallow and close to mineral-soil uplands. The collector ditches are deeper and wider to handle the water feeding in from numerous lateral ditches. They ranged in width from 1.4 to 2.0 m, and in depth from 0.9 to 1.5 m, depending on the volume of water to be handled.

As a result of drainage, the mean depth to water increased in all OGs, ranging from 1 to 48 cm, with the largest change in OG14 (Berry and Jeglum 1988). It was also found that within each OG, the mean depth to water decreased with increasing distance from a ditch and that for a given distance from a ditch, the water table became higher with increased spacing between ditches.

The drained forest area consisted primarily of OG11 sites, with some OG12; here, ditch spacings were mainly 40 to 45 m. Wider ditch spacings of 55 to 60 m were used in a predominantly upland block consisting mostly of OG8 sites with some OG5 and OG11 sites. Narrow spacings (20 to 25 m) were used on OG14 sites. For OG11 sites, the most common type, a range of ditch spacings from about 20 to 75 m were installed (Fig. 1) (Berry and Jeglum 1988).

Experimental Design and Measurements

With the objective of studying the growth response of black spruce to drainage and fertilization, 28 growth plots were established in 1985. There are four drained and two undrained (control) plots in each of the four OGs (OG8, OG11, OG12 and OG14). Four additional plots, three at different ditch spacings (20, 60 and 75 m) and one control plot in a stand of large, even-sized trees with a park-like, open understory, probably not horse-logged (11–S), were also laid out (Fig. 1). Subsequent reclassification revealed that not all the plots had been correctly classified by OG and therefore the different OGs are not evenly represented (Appendix 2).

Each of the 28 plots consists of eight smaller subplots with a size of about 400 m^2 each, reaching from one ditch to the next, in order to cover the variation in the effect of drainage from the edge of the ditch to the midpoint between ditches. This means that if the spacing between ditches was 40 m, the width of each subplot was 10 m (Fig. 2). One of the eight subplots was a "permanent growth plot" (PGP), two subplots were intended for destructive sampling (D1–D2) and the remaining five were to be fertilized (F1–F5). In the present report, the acronym PGP has been used to refer to one of the eight subplots depicted in Figure 2 even though "permanent growth plot" is also used generally to refer to the whole

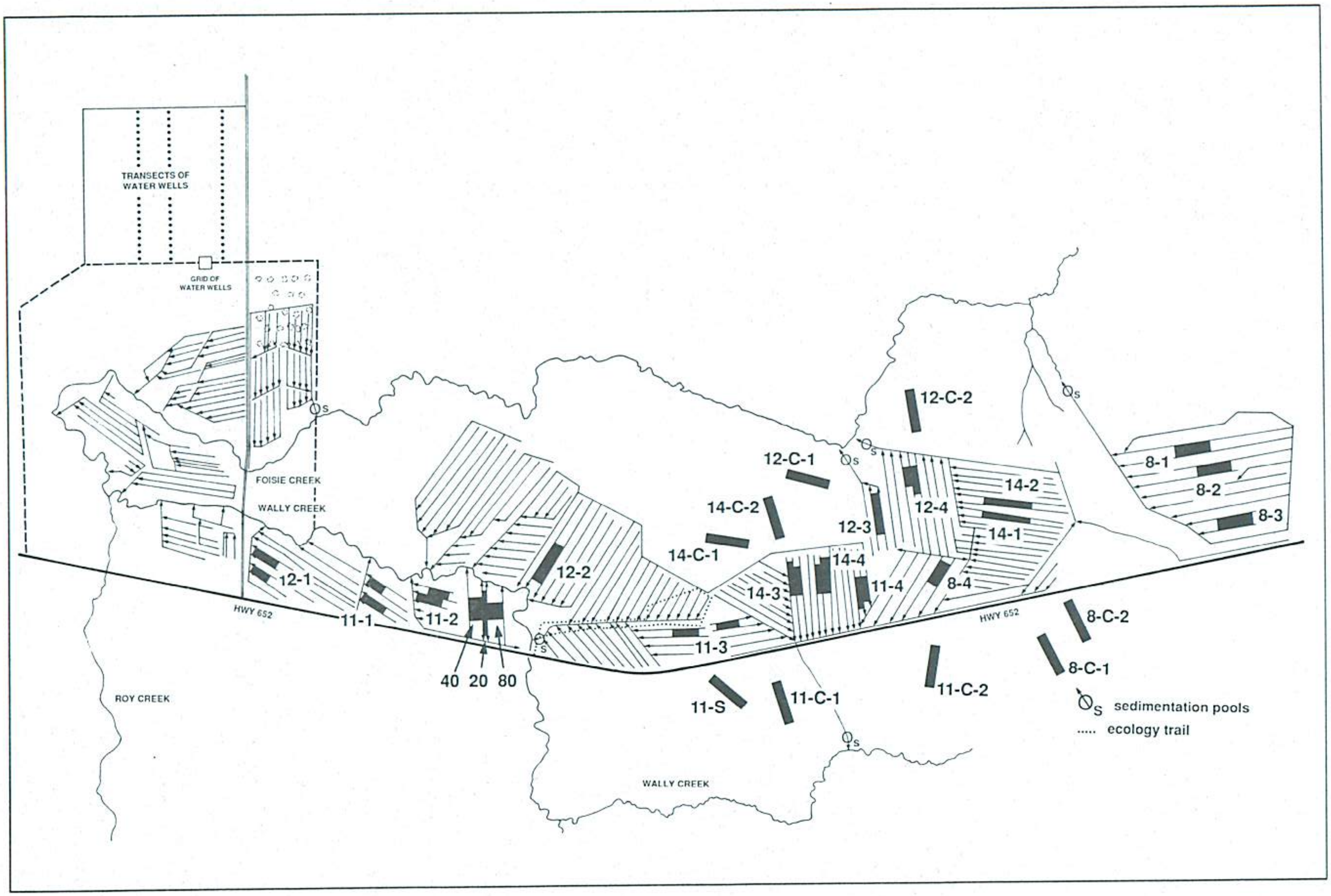

Figure 1. The drainage system and the distribution of ditches in the drainage area, with all permanent growth plots marked, in the Wally Creek area.

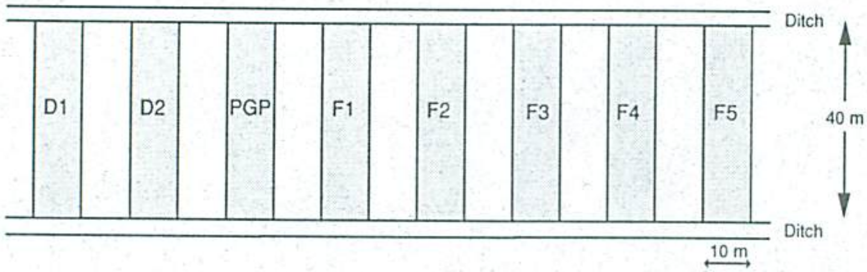

Figure 2. The design of a typical permanent growth plot and the distribution of subplots within it (D1, D2 = destructive sampling; PGP = permanent growth plot; F1–F5 = different fertilization treatments).

group of eight subplots. F1 plots were fertilized in 1985, F2 plots in 1986 and F3 plots in 1987 with a solid 150–100–100 kg/ha NPK fertilizer; F4 and F5 plots were never fertilized.

There are 56 subplots, in which the trees have been mapped with X–Y coordinates in order to identify trees at different distances from the ditches and to help locate the trees in future studies of competition effects. Nine plots were never assessed for tree dimensions; hence, the sample for this study consists of 47 subplots (Appendix 2). Of these, 35 are drained (D), 12 not drained (ND), 20 fertilized (F) and 27 not fertilized (NF), giving the following combinations: 16 D/F, 19 D/NF, 4 ND/F and 8 ND/NF. The 47 subplots cover approximately 1.7 ha. Average stocking was 2,300 trees/ha (trees ≥ 5 cm DBH), and ranged from 4,000 trees/ha in the most dense OG8 subplot to 200 trees/ha in one of the OG14 subplots. There were 3,996 trees in the 47 subplots, mostly black spruce (95%) with some balsam fir (3%) and tamarack (2%).

For all trees ≥ 5.0 cm DBH (outside bark) in 1985, a permanent numbering system was established. All trees were assessed for mortality and damage in 1985 and 1989, and four categories were used: dead, broken, leaning and blown-down trees.

Diameters for all trees in each PGP and in some of the fertilized (F1) plots were measured at 1.4-m height (ostensibly breast height) with a steel diameter tape in October 1985 and March 1990. Diameter was always recorded at the level of the numbering tag after removing the rough outer layer of bark, and the error was estimated to be ±1 mm (McLaren 1991).

Height was measured on all trees only in PGPs (not in fertilized plots) in October 1985 and March 1990. In 1985, height from the ground surface was measured with a telescoping fiberglass height pole; in 1990, when the ground was covered with snow, height was measured from the number tag to the top and then 1.4 m was added to account for the distance from the tag (ostensibly, breast height) to the ground. The accuracy of these height measurements is questionable and the error in height was estimated to be ±0.30 m (McLaren 1991). All measurements were taken by OMNR staff from Cochrane and different personnel were involved each time.

Analysis of Data

The growth response variables studied were diameter and height increment. Volume increments were estimated from diameter and height increments. The rates of mortality of and damage to black spruce after drainage were also calculated.

Analyses were carried out only on surviving undamaged black spruce trees other than those with obvious measurement errors. For certain measurements of diameter and height for which negative growth increments were obtained, rules were set to exclude these unrealistic values (see below). For each subplot, mean diameter and height increments were calculated as follows:

$$DI = \frac{Diameter\ 1989 - Diameter\ 1985}{4}$$

Where: DI is the mean annual diameter increment (mm) over 4 years. If the 4-year difference between the 1989 and 1985 diameters was <–0.1 cm or >1.1 cm, the datum was not used because it was assumed to be unrealistic. The 0.1-cm limit was chosen because this was the estimated error in diameter measurement. Height increment was calculated similarly:

$$HI = \frac{Height\ 1989 - Height\ 1985}{4}$$

Where: HI is the mean annual height increment (m) over 4 years. If a 4-year difference between the 1989 and 1985 heights was <–0.3 m or >1.3 m then it was not used in subsequent calculations because it was assumed to be unrealistic. These limits were chosen because the estimated height measurement error was ± 0.3 m.

In the present study, only trees surviving to the last measurement in 1989 and those meeting the above criteria were included in the volume estimates, described in the next section. Hence, there was no attempt to account for loss of volume as a result of blowdown and mortality.

Volume per Tree and per Unit Area

In order to calculate volume and volume growth, two different volume functions were used. One is a standard volume equation (Honer et al. 1983) for black spruce:

$$V = \frac{B1\ D^2\ (1 - 0.04365\ B2)^2}{C1 + \frac{0.3048\ C2}{H}}$$

Where: V = total tree volume inside bark (m^3), D = DBH outside bark (cm), H = total height (m), and the species-specific parameters for black spruce are $B1 = 0.004389$, $B2 = 0.164$, $C1 = 1.588$ and $C2 = 333.364$.

The second volume equation refers to merchantable volume (Honer et al. 1983) and is as follows:

$$MV = V\ (R1 + R2\ X3 + R3\ X3^2)$$

Where: MV = merchantable volume (m^3), V = total tree volume under bark (m^3), and $R1 = 0.9526$, $R2 = -0.1027$, and $R3 = -0.8199$ for black spruce. The other parameter in the equation, $X3$, is defined as follows:

$$X3 = \frac{T^2}{D^2\ (1 - 0.04365\ B2^2)} \left(1 + \frac{S}{H} \right)$$

Where: T = top diameter (7 cm), D = DBH (cm), $B2$ = 0.164, S = stump height (0.15 m), and H = total height (m).

Volumes per hectare and per plot were calculated as follows:

$$VT = N\ A\ BS\ V$$

Where: VT = volume (m^3/ha) of black spruce, N = number of trees per plot, A = 10,000 m^2/ha divided by plot area (m^2), BS = proportion of black spruce in the plot (%), and V = mean volume per tree (m^3) in a given plot.

Volumes of each of 122 trees destructively sampled in 1985 were calculated as the sum of their sectional volumes (i.e., Smalian's formula was used). The volume calculated with Honer's standard volume function was found to underestimate the actual (Smalian) volume by 6% on average for black spruce on this particular site:

$$Volume = \sum \left(\frac{A_t + A_b}{2} \right) L \quad \text{(Smalian's formula)}$$

Where: A_t = area of each section's top, A_b = area of each section's bottom, and L = length of each section.

Distance to Ditch

In order to study if growth response varied at different distances from the ditch, each subplot was divided into four distance classes, depending on distance to ditch (<3 m, 3–6 m, 6–12 m and >12 m). For each distance class and subplot, mean growth increments were calculated.

Tree Size

To determine whether trees respond differently to drainage and fertilization depending on their size, three size classes based on either diameter or height were made in each subplot. The size classes were <8 cm, 8–11 cm, and >11 cm for DBH and <7.5 m, 7.5–10 m and >10 m for height.

Mortality and Damage

The categories chosen for mortality and damage were dead, broken, leaning and blown-down trees. These categories were treated exclusively: for example, if a broken tree was also dead, it was only classified as dead. Broken, leaning and blown-down trees were all alive at the time of the assessment.

Statistical Analysis

Analysis of variance was performed using the General Linear Model (GLM) procedure of the Statistical Analysis System (Anon. 1985), which was used to test if differences in means were significant. According to the design of the experiment, analyses were made on plot means rather than on single trees.

RESULTS

Diameter Growth

Mean DBH in 1985 and 1989, mean annual diameter increment between 1985 and 1989, and relative diameter increment ([Diameter 1989 – Diameter 1985]/Diameter 1985) are shown in Figures 3–6 and Tables 1–3.

Mean diameter in 1985 for trees ≥5 cm in DBH was about 10 cm in all OGs except for OG14, for which the mean diameter was 6.41 cm (Fig. 3, Table 1). In OG14 there were no trees larger than 15 cm in diameter and 80% of the trees had a DBH of <9 cm. Trees were more evenly distributed in the other three OGs, and the highest proportion of large (>15 cm DBH) trees was found in OG12 (Fig. 3).

Five growing seasons after drainage and fertilization, the best mean annual diameter increment in all OGs was found with trees in D/F areas (Fig. 4, Table 1). The mean annual diameter increment on D/F sites was significantly greater than the diameter increments on both

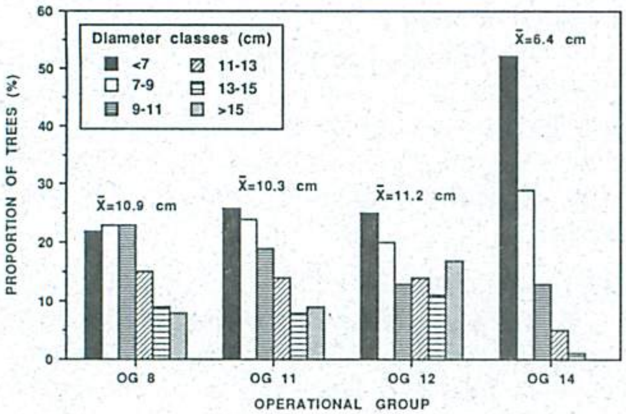

Figure 3. Diameter distribution in 1985 for different Operational Groups (OGs). Mean diameter in the different OGs is also indicated.

D/NF and ND/NF sites. The diameter increment in D/F areas was also higher, but not significantly, than the increment in ND/F areas. Fertilization without drainage (ND/F) produced a higher diameter increment than drainage alone. Trees on D/F sites grew an average of 0.5 mm/year more than trees on ND/NF sites, and the difference was significant. With no fertilization, the diameter growth was only 0.13 mm/year greater in drained than in undrained areas (Fig. 4, Table 1).

The relative diameter increment for trees in D/F areas was 5.4% over 4 years compared with 2.8% in ND/NF areas (Table 1).

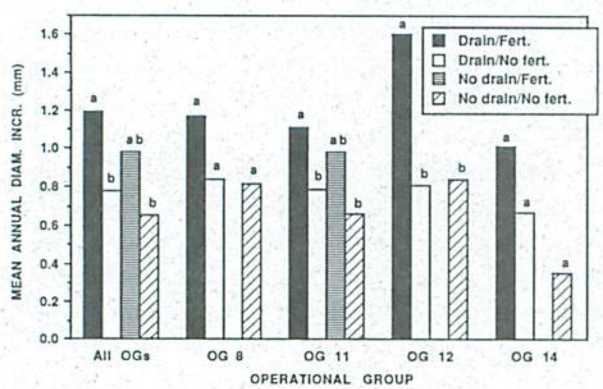

Figure 4. Mean annual diameter increment from 1985 to 1989 for different treatments. Means within different OGs followed by different letters differ significantly at the p = 0.05 level

Diameter growth response for OG11 showed the same pattern as for all OGs (Fig. 4, Table 1). Trees in D/F plots in OG11 had 68% higher diameter increment than those in ND/NF plots. Drainage without fertilization (D/NF) gave a 20% higher diameter increment than ND/NF in OG11. For the other OGs, the D/F plots consistently showed the best diameter growth (Fig. 4, Table 1). The relative diameter increment was greater in drained than in undrained areas in all OGs except OG8 (Table 1). The highest relative diameter increment (7.4%) was found in D/F plots in OG14.

Table 1. Mean diameters in 1985 and 1989, mean annual diameter increment between 1989 and 1985 and relative diameter increment (over 4 years) based on the means from 47 plots. Means marked with different letters (capital letters compare treatments and lower-case letters compare OGs) are significantly different at the p = 0.05 level.

Treatment and OG[a]	No. of plots	Diameter (cm) 1985	Diameter (cm) 1989	Mean annual diameter increment (mm)	Relative diameter increment (% over 4 years)
OG 8					
D/F	3	9.78	10.24	1.17 A	4.8
D/NF	3	10.89	11.23	0.84 A	3.1
ND/F	–	–	–	–	–
ND/NF	1	9.22	9.55	0.82 A	3.6
	7	10.04 a	10.42 a	0.96 a	3.8
OG11					
D/F	7	9.66	10.10	1.11 A	4.6
D/NF	9	9.53	9.84	0.79 B	3.3
ND/F	4	10.34	10.73	0.98 AB	3.8
ND/NF	3	9.34	9.60	0.66 B	2.8
	23	9.68 a	10.05 a	0.91 a	3.8
OG 12					
D/F	3	9.76	10.40	1.60 A	6.6
D/NF	4	10.33	10.66	0.81 B	3.1
ND/F	–	–	–	–	–
ND/NF	2	11.70	12.04	0.84 B	2.9
	9	10.73 a	11.13 a	1.00 a	3.7
OG 14					
D/F	3	5.46	5.86	1.01 A	7.4
D/NF	3	6.06	6.33	0.67 A	4.4
ND/F	–	–	–	–	–
ND/NF	2	6.89	7.03	0.35 A	2.0
	8	6.41 b	6.64 b	0.58 b	3.6
All OGs					
D/F	16	8.91	9.39	1.19 A	5.4
D/NF	19	9.36	9.68	0.78 B	3.3
ND/F	4	10.34	10.73	0.98 AB	3.8
ND/NF	8	9.30	9.56	0.65 B	2.8

[a] D = drained, ND = not drained, F = fertilized, NF = not fertilized

Since no diameters were measured in the ND/F areas in OG8, OG12 and OG14, no comparisons could be made for the effect of fertilization in these OGs.

Influence of distance to ditch

For all OGs, trees growing within 3 m of a ditch had a higher mean diameter increment than trees further from ditches (Fig. 5, Table 2). Within 3 m, diameter increment in plots with drainage alone was equal to that for drainage plus fertilization. Where fertilizer was added, trees showed no decline in diameter increment further away from the ditch; by contrast, without fertilizer there was a significant drop in diameter growth in trees 3 to 6 m from the ditch, and about the same for classes at greater distances from the ditch (Table 2).

Drained sites without fertilization (D/NF) produced better diameter growth within 3 m of a ditch than occurred on ND/F sites. Trees on drained sites had, at all distances from a ditch, better diameter growth than trees on undrained sites (Fig. 5, Table 2).

The same pattern, with greater diameter increment close to a ditch in nonfertilized areas, was true for all OGs except OG14 (Table 2). In fertilized areas in each OG, there was no greater diameter growth close to a ditch, with the exception of OG14.

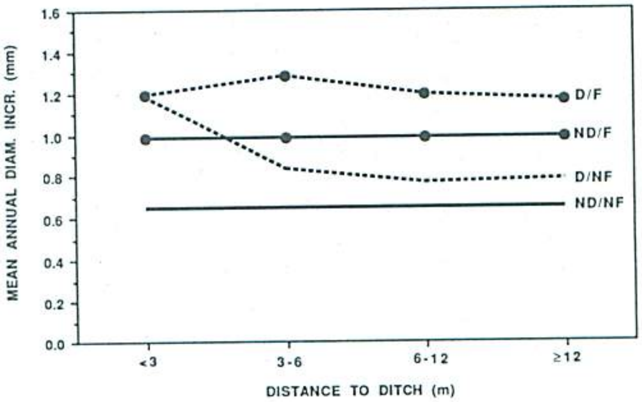

Figure 5. Mean annual diameter increment (mm) from 1985 to 1989 for trees in four distance classes from a ditch for drained (D), fertilized (F) and not fertilized (NF) areas, with all OGs combined. Diameter increments in undrained (ND) areas are shown as controls.

Table 2. Mean annual diameter increments (DI) between 1985 and 1989 for trees in drained plots at four different distances from a ditch and for undrained controls. Means marked with different letters (capital letters compare distances) are significantly different at the p = 0.05 level. (Significance tests were carried out for differences in diameter growth among different distances from a ditch rather than for undrained, control plots.)

Treatment and OG	Undrained control N	Undrained control DI (mm)	Drained, distance from ditch (m): <3 N	<3 DI (mm)	3–6 N	3–6 DI (mm)	6–12 N	6–12 DI (mm)	>12 N	>12 DI (mm)
OG 8										
Fert.	–	–	3	1.10 A	3	0.98 A	3	1.07 A	3	1.20 A
No fert.	1	0.82	2	1.92 A	2	0.82 A	3	0.88 A	3	0.79 A
	1	0.82	5	1.44 A	5	0.91 A	6	0.97 A	6	0.99 A
OG 11										
Fert.	4	0.98	7	1.17 A	7	1.23 A	7	1.10 A	7	1.11 A
No fert.	3	0.66	8	1.14 A	9	0.89 A	9	0.85 A	9	0.78 A
	7	0.84	15	1.16 A	16	1.03 A	16	0.96 A	16	0.92 A
OG 12										
Fert.	–	–	2	1.28 A	3	1.91 A	3	1.74 A	3	1.47 A
No fert.	2	0.84	4	1.05 A	4	0.84 A	4	0.64 A	4	0.83 A
	2	0.84	6	1.13 A	7	1.30 A	7	1.11 A	7	1.11 A
OG14										
Fert.	–	–	1	1.42 A	2	1.00 A	3	1.00 A	1	0.54 A
No fert.	2	0.35	1	0.50 A	3	0.67 A	2	0.51 A	3	0.73 A
	2	0.35	2	0.96 A	5	0.80 A	5	0.80 A	4	0.64 A
All OGs										
Fert.	4	0.98	13	1.19 A	15	1.28 A	16	1.19 A	14	1.16 A
No fert.	8	0.65	15	1.18 A	18	0.83 B	18	0.77 B	19	0.78 B
	12	0.76	28	1.19 A	33	1.04 AB	34	0.97 AB	33	0.94 B

Influence of tree size

The medium-sized trees (based on either DBH or height) had a greater diameter increment than either smaller or larger trees (Fig. 6, Table 3). The difference in diameter growth between trees in different size classes was similar in all treatments, which means that middle-sized trees had about 0.1 mm better annual diameter growth regardless of the treatment (Table 3). Differences in diameter growth for different size classes were, however, not significant.

Height Growth

Since height was not measured in fertilized areas, comparisons can only be made for D/NF and ND/NF plots. Mean heights in 1985 and 1989, mean annual height increments (1985–1989) and mean relative height increments (1985–1989) are shown in Figures 7 and 8 and Tables 4–6.

Mean height in 1985 was significantly lower in OG14 areas (5.02 m) than in the other OGs, where the mean height was between 8 and 9 m (Fig. 7, Table 4). In all OGs, the majority of trees were shorter than 9 m — 58% in OG8, 63% in OG11, 60% in OG12 and 98% in OG14 (Fig. 7).

The mean annual height increment in drained areas was higher than in undrained areas, but the differences were not significant (Fig. 8, Table 4). The relative height growth was 7% over 4 years in drained areas and 5.9% in undrained areas.

Mean heights and mean annual height increments in 1985 and 1989 were significantly lower in OG14 areas than in all other OGs (Table 4). The relative height increment, however, was highest in OG14 and the best relative height growth of all was found in drained plots of OG14.

Comparisons of height growth for drained and undrained areas within an OG showed no significant differences. However, there were greater height increments in drained areas in OG11 and OG14 than in comparable undrained areas. The relative height increments were higher for drained plots in all OGs except OG8 (Table 4).

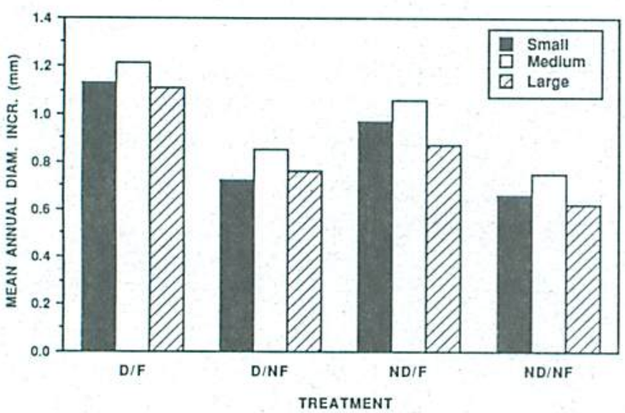

Figure 6. Mean annual diameter increment (mm) for trees of three size classes (based on DBH) in different treatments, over all OGs.

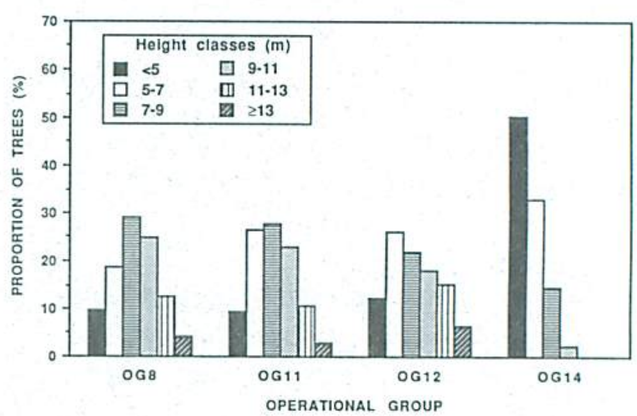

Figure 7. Height distribution in 1985 for different Operational Groups (OGs).

Table 3. Mean annual diameter increment (DI) from 1985 to 1989 for trees of different size classes (based on DBH and height); 133 subplots (N) were used for DBH and 72 for height. (No differences were significant at the p = 0.05 level.)

Treatment	Size class based on DBH (cm)						Size class based on height (m)					
	<8		8–11		>11		<7.5		7.5–10		>10	
	N	DI (mm)	N	DI (mm)	N	DI (mm)	N	DI (mm)	N	DI (mm)	N	DI (mm)
D/F	16	1.13	14	1.21	14	1.11	–	–	–	–	–	–
D/NF	19	0.72	18	0.85	17	0.76	19	0.76	17	0.80	15	0.73
ND/F	4	0.97	4	1.06	4	0.87	–	–	–	–	–	–
ND/NF	8	0.66	8	0.75	7	0.62	8	0.65	7	0.73	6	0.65

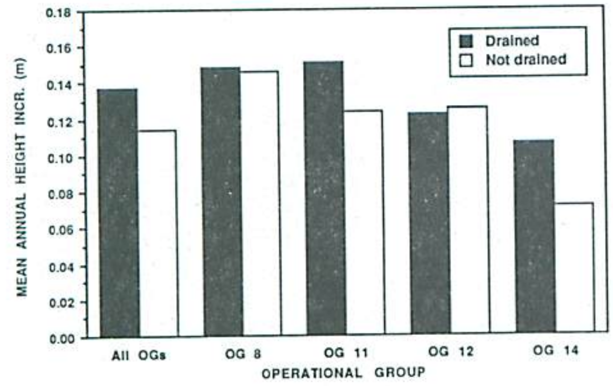

Figure 8. Mean annual height increment (m) from 1985 to 1989 for trees in drained and undrained areas in different Operational Groups (OGs). Fertilized plots were not included.

Table 4. Mean heights in 1985 and 1989, mean annual height increments between 1989 and 1985 and relative height increments (over 4 years) based on means from 27 plots (N). Means marked with different letters (capital letters compare treatments and lower-case letters compare OGs) are significantly different at the p = 0.05 level.

Treatment and OG	No. of plots	Mean height (m) 1985	Mean height (m) 1989	Mean annual height increment (m)	Mean relative height increment (% over 4 years)
OG 8					
Drained	3	9.38	9.97	0.148 A	6.3
Not drained	1	7.92	8.51	0.146 A	7.4
	4	9.02 a	9.61 a	0.147 a	6.5
OG 11					
Drained	9	8.25	8.86	0.151 A	7.3
Not drained	3	8.25	8.74	0.124 A	6.0
	12	8.25 a	8.83 a	0.144 a	7.0
OG 12					
Drained	4	8.22	8.71	0.122 A	5.9
Not drained	2	8.91	9.41	0.125 A	5.6
	6	8.45 a	8.94 a	0.123 ab	5.8
OG 14					
Drained	3	4.74	5.16	0.106 A	9.0
Not drained	2	5.44	5.72	0.071 A	5.2
	5	5.02 b	5.39 b	0.092 b	7.3
All OGs					
Drained	19	7.87	8.42	0.137 A	7.0
Not drained	8	7.67	8.12	0.114 A	5.9

Influence of distance to ditch and tree size

The mean annual height increment was highest for trees > 12 m from ditches for all OGs together (Table 5). The differences in height growth at different distances from a ditch were, however, small and not significant. For all OGs combined, height increments were higher at all distances from a ditch in drained than in undrained areas. OG11 showed a pattern of height increments similar to that of all OGs combined (Table 5). However, there were no significant differences among the different distance-to-ditch classes for any of the OGs.

Height growth was best among the largest trees in size classes based on either DBH or height (Table 6). Large trees had a greater height increment than medium-sized ones, which in turn grew better than small trees. This was the case for both drained and undrained areas, but no differences were significant.

Volume

Since the volume functions were based on both diameter and height and no heights were measured in fertilized areas, volume was only calculated for drained and undrained plots. Volumes and volume increments per tree and per hectare are shown in Figures 9–11 and Tables 7–9.

The largest average trees in 1985 were in OG12 and OG8; trees averaged somewhat smaller in OG11, and were considerably smaller in OG14. The merchantable volume was about 75% of total volume in the average tree in OG8 and OG12 areas and 60% in OG11, whereas there was no merchantable volume at all in OG14 areas (Fig. 9, Table 7).

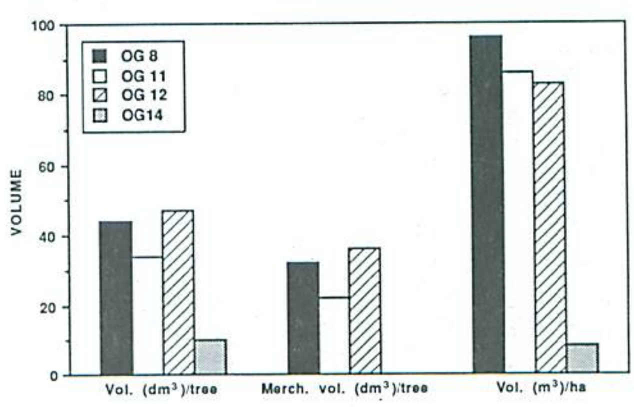

Figure 9. Mean volume and merchantable volume per tree (dm^3) and mean volume per hectare (m^3) in four different Operational Groups (OGs) in fall 1985. No fertilized plots are included.

Table 5. Mean annual height increments (HI) from 1985 to 1989 for trees in drained plots at four different distances from a ditch and for undrained controls. (No differences were significant at the p = 0.05 level.)

Operational group	Undrained control		Drained, distance from ditch (m) <3		3–6		6–12		>12	
	N	HI (m)	N	HI (m)	N	HI (m)	N	HI (m)	N	HI (m)
OG 8	1	0.146	3	0.147	3	0.168	3	0.126	3	0.158
OG 11	3	0.129	7	0.148	9	0.131	9	0.139	8	0.163
OG 12	2	0.125	4	0.117	4	0.115	4	0.128	4	0.120
OG 14	2	0.071	3	0.098	3	0.105	3	0.099	3	0.098
All OGs	8	0.114	17	0.132	19	0.129	19	0.128	18	0.141

Table 6. Mean annual height increments (HI) from 1985 to 1989 for trees in different size classes (based on DBH and height). There were 77 subplots (N) for DBH and 74 for height, and only on non-fertilized areas. (No differences were significant at the p = 0.05 level.)

Treatment	Size class, based on DBH (cm) <8		8–11		>11		Size class, based on height (m) <7.5		7.5–10		>10	
	N	HI (m)	N	HI (m)	N	HI (m)	N	HI (m)	N	HI (m)	N	HI (m)
Drained	19	0.120	17	0.138	17	0.143	19	0.128	17	0.143	16	0.149
Not drained	9	0.113	8	0.115	7	0.121	8	0.112	8	0.136	6	0.136
All	28	0.118	25	0.131	24	0.137	27	0.124	25	0.141	22	0.145

The highest volume per hectare (only black spruce) was found in OG8 areas; this was about 10 m^3 more than in OG11 and OG12 areas and 11 times more than the volume in OG14 areas. In OG14, however, the percentage of black spruce was only 50%, much lower than in other OGs (Fig. 9, Table 8).

The mean annual volume increment per tree (VI) between 1985 and 1989 was slightly but not significantly higher in drained than in undrained areas; however, the difference in relative volume increment was greater (Fig. 10, Table 7).

In each OG except OG12, the volume increment per tree was higher in drained than in undrained plots (Fig. 10, Table 7). However, the actual volume increment per tree, irrespective of treatment, was significantly lower in OG14 plots than in other OGs; in contrast, the relative increment was similar for all OGs (Table 7).

The actual volume increment per tree is always larger in large trees and therefore relative increment is a more informative value. In each OG except OG8, the relative volume increment per tree was higher in drained areas (Fig. 10, Table 7). The differences in volume increment between drained and undrained areas were small in OG8 and OG12, but both actual and relative volume increments per tree were higher in the drained areas in OG11 and OG14; however, the latter differences were not significant. Trees in OG14 plots had twice the relative volume increment in drained than in undrained plots.

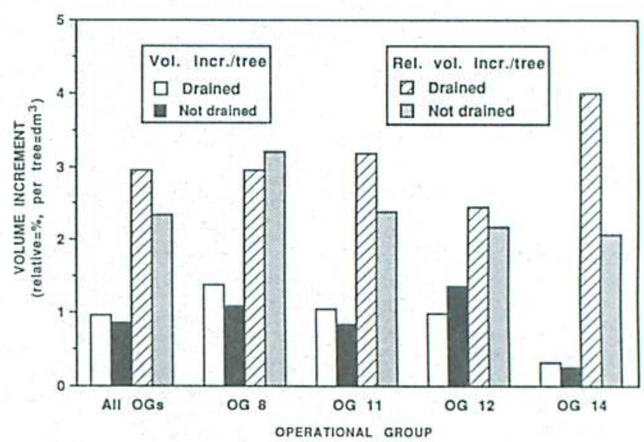

Figure 10. Mean annual volume increment per tree (dm^3) and relative volume increment per tree (%) between 1985 and 1989 for drained and undrained areas in four different Operational Groups (OGs). No fertilized plots are included.

For all OGs together, the standing volume per hectare in 1985 was higher in undrained than in drained plots but the average annual volume and relative increments per hectare were higher in drained areas (Fig. 11, Table 8). The differences were, however, not significant. Both standing volume per hectare and annual volume increment were significantly lower in OG14 because of the smaller trees and lower tree density compared with other OGs.

Undrained areas had higher standing volumes than drained areas in all OGs except OG8 (Table 8). The actual volume increment per hectare was higher in drained plots in OG8 and OG11, but lower in OG12 and OG14. The relative volume increment, on the other hand, was higher in drained areas in all OGs except OG8. The relative volume increment in drained plots was 25% higher in OG11 and almost doubled in OG14 (Fig. 11, Table 8).

The largest mean volume increment per tree was found in trees within 3 m of a ditch (Table 9). The relative volume increment was also highest close to a ditch and higher at all distances from a ditch than in the undrained control. No differences were significant.

By dividing the sample into size classes by height, it was found that small trees (<7.5 m) had higher mean volume increments and relative volume increments closer to a ditch than further away. For medium-sized and large trees, no differences were found among distances from a ditch. Medium-sized trees had the same relative growth in undrained plots as in drained plots, whereas large trees had greater relative growth in the drained plots (Table 9). Again, no differences were significant.

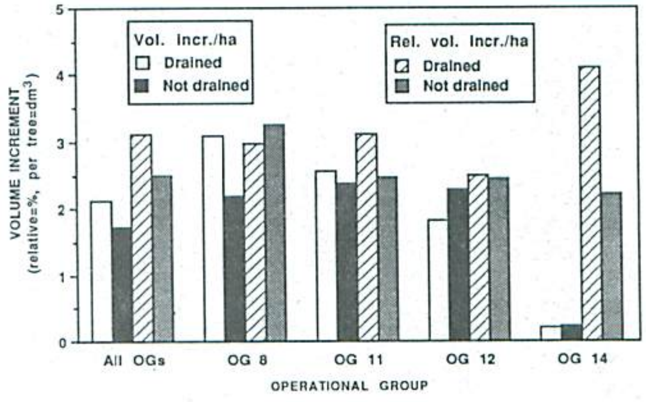

Figure 11. Mean annual volume increment per hectare (m^3) and relative volume increment per hectare (%) between 1985 and 1989 for drained and undrained areas in four different Operational Groups (OGs). No fertilized plots are included.

Mortality and Damage

The total proportion of dead and damaged (blown-down, broken and leaning) trees was about 10% in both drained and undrained areas. The lowest proportion

Table 7. Mean volumes and mean merchantable volumes per tree in 1985 and 1989, mean annual volume increments per tree from 1985 to 1989, and relative volume increments (over 4 years) for 19 drained and 8 undrained areas (no fertilized plots). Means with different letters (capital letters compare treatments and lower-case letters compare OGs) are significantly different at the p = 0.05 level.

		Mean volume (dm^3/tree)				Mean merchantable volume (dm^3/tree)			
Treatment and OG	No. of plots	1985	1989	Annual incr.	Rel. vol. incr. (%)	1985	1989	Annual incr.	Rel. vol. incr. (%)
OG 8									
Drained	3	47	53	1.39 A	2.95	36	41	1.31 A	3.63
Not drained	1	34	38	1.09 A	3.20	21	26	1.03 A	4.90
	4	44 a	49 a	1.31 a	2.98	32 a	37 a	1.24 a	4.13
OG 11									
Drained	9	33	38	1.05 A	3.18	21	26	0.98 A	4.68
Not drained	3	35	39	0.83 A	2.38	23	26	0.78 A	3.40
	12	34 a	38 a	0.99 a	2.90	22 a	26 a	0.93 a	4.23
OG12									
Drained	4	40	44	0.98 A	2.45	29	33	0.96 A	3.35
Not drained	3	62	67	1.35 A	2.18	50	55	1.32 A	2.65
	7	47 a	52 a	1.11 a	2.38	36 a	41 a	1.08 a	3.00
OG14									
Drained	3	8	10	0.32 A	4.00	–	–	–	–
Not drained	2	12	13	0.25 A	2.08	–	–	–	–
	5	10 b	11 b	0.29 b	2.90	–	–	–	–
All OGs									
Drained	19	33	37	0.97 A	2.95	21	25	0.93 A	4.43
Not drained	8	36	39	0.85 A	2.35	24	27	0.80 A	3.33

Table 8. Mean volumes per hectare in 1985 and 1989, mean volume increments per hectare from 1985 to 1989, and relative volume increments per hectare. Means are based on 19 drained and 8 undrained plots (no fertilized plots) in four Operational Groups (OGs). Means with different letters (capital letters compare treatments and lower-case letters compare OGs) are significantly different at the p = 0.05 level.

Treatment and OG	No. of plots	Volume/ha (m^3) 1985	Volume/ha (m^3) 1989	Vol. incr. (m^3/ha)	Rel. vol. incr. (%/ha)
OG8					
Drained	3	105.0	117.3	3.095 A	2.98
Not drained	1	67.0	76.0	2.181 A	3.25
	4	95.5 a	107.0 a	2.867 a	3.05
OG11					
Drained	9	80.6	90.9	2.565 A	3.10
Not drained	3	102.7	112.3	2.384 A	2.47
	12	86.1 a	96.3 a	2.520 a	2.95
OG 12					
Drained	4	73.8	79.8	1.814 A	2.48
Not drained	2	102.0	110.5	2.275 A	2.44
	6	83.2 a	90.0 a	1.968 a	2.47
OG 14					
Drained	3	7.3	8.0	0.207 A	4.11
Not drained	2	10.2	11.2	0.231 A	2.21
	5	8.4 b	9.3 b	0.217 b	3.35
All OGs					
Drained	19	71.5	79.7	2.118 A	3.11
Not drained	8	75.1	82.1	1.793 A	2.50

of dead or damaged trees was found in ND/F areas, followed by D/F areas (Table 10). Drained but not fertilized plots had the highest proportion of dead and damaged trees (12.9%).

The difference in the proportions of dead and damaged trees between drained and undrained areas was very small. There were slightly, but not significantly, higher percentages of leaning and dead trees in the drained areas. Non-fertilized areas had higher proportions of dead, broken and leaning trees, whereas fertilized areas had slightly higher percentages of blown-down trees (Table 10).

Trees close to the ditches sustained the most damage, and dead or damaged trees were particularly common within 3 m of the ditch (Fig. 12, Table 11). Further away from the ditch and in undrained plots, the proportion of damaged trees was lower and there was very little difference in the frequency of different types of damage.

The higher proportion of damage within 3 m of ditches was more pronounced in fertilized than in non-fertilized areas. In non-fertilized plots and undrained areas there were about the same proportions of damaged trees at all distances from ditches.

Small trees sustained more damage than either medium or large trees (Fig. 13, Table 12). Breakage and leaning were especially common for small trees, whereas large size classes had the highest proportion of dead trees.

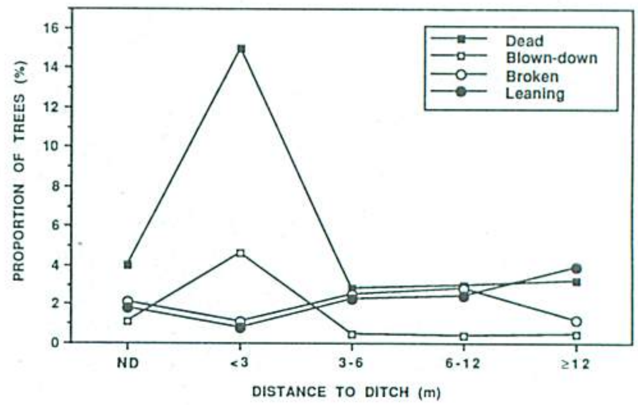

Figure 12. Frequency of different classes of damaged trees at different distances from a ditch in spring 1990. Undrained plots are indicated by ND (not drained).

Table 9. Mean volumes per tree in 1985 and 1989 for four different distances from a ditch and an undrained control, mean annual volume increments per tree, and mean relative volume increments from 1985 to 1989 for three height classes at different distances from a ditch. (No differences were significant at the p = 0.05 level.)

Tree size class	Mean volumes and volume increments (dm^3/tree): Undrained control	Distance from ditch (m) <3	3–6	6–12	>12
All sizes					
Volume 1985	36	38	34	34	30
Volume 1989	39	43	37	38	34
Volume increment	0.85	1.14	0.87	1.03	0.94
Rel. vol. incr. (%)	3.3	3.9	3.5	3.5	3.7
Height <7.5 m					
Volume increment	0.42	0.53	0.52	0.47	0.49
Rel. vol. incr. (%)	3.9	5.2	4.5	3.9	4.7
Height from 7.5 to 10 m					
Volume increment	1.00	1.08	1.01	1.11	1.23
Rel. vol. incr. (%)	3.3	3.3	3.1	3.9	3.3
Height >10 m					
Volume increment	1.78	2.08	1.59	1.87	1.82
Rel. vol. incr. (%)	1.9	2.5	2.1	2.6	2.6

Table 10. Numbers and proportions of damaged (blown-down, broken and leaning) and dead trees in plots with different treatments assessed in spring 1990.

Type of damage	Drained				Undrained			
	Fertilized		Not fertilized		Fertilized		Not fertilized	
	No.	%	No.	%	No.	%	No.	%
Dead	46	3.8	81	5.5	12	2.8	34	4.7
Blown-down	17	1.4	10	0.7	7	1.7	6	0.8
Broken	7	0.6	43	2.9	0	0.0	24	3.2
Leaning	18	1.5	57	3.9	0	0.0	21	2.9
No damage	1,1[illegible]4	92.7	1,288	87.1	400	95.5	645	88.4

Chisquare (4 treatments, df = 12) = 77.0

P (0.05, df = 12) = 21.0

	Drained		Undrained		Fertilized		Not fertilized	
	No.	%	No.	%	No.	%	No.	%
Dead	127	4.7	46	4.0	58	3.6	115	5.2
Blown-down	27	1.0	13	1.1	24	1.5	16	0.7
Broken	50	1.9	24	2.1	7	0.4	67	3.1
Leaning	75	2.8	21	1.8	18	1.1	78	3.5
No damage	2,412	89.6	1,045	91.0	1,524	93.4	1,933	87.5
Chisquare (2 treatments, df = 4)	= 4.4					= 69.5		

P (0.05, df = 4) = 9.5

Table 11. Numbers and proportions of dead and damaged (blown-down, broken and leaning) trees in plots with different treatments and at different distances from a ditch, assessed in spring 1990.

Type of damage	Undrained control		Drained, distance to ditch (m)							
			<3		3–6		6–12		>12	
	No.	%	No.	%	No.	%	No.	%	No.	%
Fertilized plots										
Dead	12	2.9	40	18.9	0	0.0	2	0.6	4	0.8
Blown-down	7	1.6	17	8.0	0	0.0	0	0.0	0	0.0
Broken	0	0.0	2	0.9	1	0.7	2	0.6	2	0.4
Leaning	0	0.0	0	0.0	3	1.9	4	1.2	11	1.2
No damage	400	95.5	153	72.2	151	97.4	330	97.6	490	96.6
Chisquare (5 distances, df = 16) = 270.3										
Nonfertilized plots										
Dead	34	4.7	16	9.9	11	4.5	23	4.7	31	5.3
Blown-down	6	0.8	0	0.0	2	0.8	3	0.6	5	0.9
Broken	24	3.3	2	1.2	9	3.7	21	4.3	11	1.9
Leaning	21	2.9	3	1.9	6	2.5	16	3.3	32	5.5
No damage	645	88.4	141	87.0	217	88.6	426	87.1	504	86.4
Chisquare (5 distances, df = 16) = 26.1										
P (0.05, df = 16) = 26.3										
All plots										
Dead	46	4.0	56	15.0	11	2.8	25	3.0	35	3.2
Blown-down	13	1.1	17	4.6	2	0.5	3	0.4	5	0.5
Broken	24	2.1	4	1.1	10	2.5	23	2.8	13	1.2
Leaning	21	1.8	3	0.8	9	2.3	20	2.4	43	3.9
No damage	1,045	90.1	294	78.6	368	91.4	756	91.4	994	91.2
Chisquare (5 distances, df = 16) = 185.0										

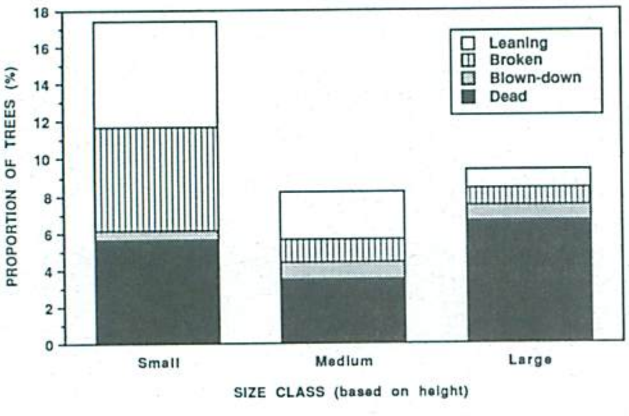

Figure 13. Frequency of different types of damaged trees according to size class (based on height: small, < 7.5 m; medium, 7.5 – 10 m; large, > 10 m).

DISCUSSION

Five years after treatment is too short a period for observing a growth response to drainage. In a drained area, lowering of the water table aerates the soil, accelerates decomposition and gradually makes nutrients available. It takes some years for the trees to adjust their root systems and take advantage of the improved conditions. Furthermore, different species of trees take different amounts of time to adjust and respond to the new conditions. It has been noted in Finland that Norway spruce (*Picea abies* [L.] Karst.) usually needs 6 to 7 years to adjust and stabilize its growth after drainage, whereas Scots pine (*Pinus sylvestris* L.) does the same in only 3 to 4 years (Seppälä 1969).

The time to adjust to drainage also varies with site quality. On poor sites similar to the Wally Creek area, some Nordic studies have reported that the trees may take several years to adjust fully to the new growing conditions (Hånell 1984). The drainage response may just start to show after 5 years, but may then increase and persist for 25 to 30 years depending on the quality of the ditches and the nutrient quality of the soil.

In contrast with drainage, fertilization provides nutrients instantly, and hence growth response is usually much faster. The response to fertilization would probably reach a maximum within 5 years of treatment and then start to fade; it would not last longer than 10 to 15 years depending on the type of fertilizer used and the amount of leaching of the added nutrients.

Response to Fertilization

The diameter growth in this study is similar to that in a study by Payandeh (1982), who found that black spruce responded to fertilization after 5 years, especially if nitrogen (N) was added. Fertilizing with phosphorus (P) alone, however, could have a depressive effect on growth. In the present experiment, NPK fertilizer was used and the mean annual diameter increments in fertilized (D/F and ND/F) areas were 25 to 80% greater than in nonfertilized (D/NF and ND/NF) areas. This is an indication that fertilization alone gave a greater short-term growth response than drainage for these sites.

In the present study, fertilization had a significant effect on diameter growth in OG11 and OG12 areas. In the other OGs, the same response occurred but was nonsignificant, partly as a result of the smaller number of measured plots.

The diameter growth response to fertilization was not larger at any specific distance from a ditch, another indication that fertilization has so far had a greater impact on the growth response than drainage. The medium-sized trees responded best to fertilization, independent of where they were located.

The increased diameter growth in fertilized areas indicates that there was a nutrient shortage on all studied sites, from OG8 to OG14. Since only one type of fertili-

Table 12. Numbers and proportions of dead and damaged (blown-down, broken or leaning) trees of different sizes, based on both diameter and height. (No fertilized plots are included in the table for height.)

Type of damage	Diameter (DBH, in cm) <8 No.	<8 %	8–11 No.	8–11 %	>11 No.	>11 %	Height (m) <7.5 No.	<7.5 %	7.5–10 No.	7.5–10 %	>10 No.	>10 %
Dead	89	5.5	40	2.9	44	5.2	54	5.6	23	3.5	38	6.6
Blown-down	19	1.2	14	1.0	7	0.8	5	0.5	6	0.9	5	0.9
Broken	56	3.5	14	1.0	4	0.5	54	5.6	8	1.2	5	0.9
Leaning	70	4.3	17	1.3	7	1.0	55	5.7	17	2.6	6	1.0
No damage	1,377	85.5	1,021	93.8	1,059	92.9	805	82.7	604	91.8	524	90.7
Chisquare (3 size classes, df = 8) = 92.8									= 72.3			
P (0.05, df = 8) = 15.5												

zer (NPK) was used in this study, it is not possible to state whether some nutrients were more deficient than others.

Unfortunately, no heights were measured in fertilized plots. Since the volume functions are based on both diameter and height, no comparisons of either height or volume increments in response to fertilization have been made, since heights were not measured in the fertilized plots and their inclusion is required in the volume functions used.

Response to Drainage

The results indicated that there is a growth response of diameter, height and volume to drainage, but the only significant response was for diameter increment in relation to distance (i.e., within 3 m of the ditch). The diameter increment for trees closer than 3 m to the ditch was 43 to 52% greater then for trees further away from the ditch. Other results indicated a drainage effect but no other differences in increments between drained and undrained areas were significant. Both diameter and height increments were about 20% higher in drained areas than in undrained ones for OG11 and OG14 areas, whereas no clear differences were found in OG8 and OG12 areas. It could be that OG12 and OG8 sites were not as constrained by high water tables as are OG11 and OG14. The water-table studies in the Wally Creek area (Berry and Jeglum 1988) have shown that OG12 and OG8 sites have deeper water tables than OG11 and OG14 sites.

The mean annual volume increment per tree for all OGs combined was 14% higher in drained than in undrained areas. The highest volume increments, both actual and relative, were found on OG11 and OG14 sites.

The stocking and standing volume per hectare varied considerably among different plots and OGs and were 8 to 10 times higher on OG8, OG11 and OG12 sites than on OG14 sites. The low volume per hectare on OG14 sites was a result of the small trees, low density and lower proportion of black spruce. The actual volume increment per hectare was higher in many undrained plots, which also had higher densities of trees. However, the relative volume increment was higher in drained areas, especially on OG14 sites. None of the volume increment increases in response to drainage were significantly higher than for the undrained controls.

Although diameter increments were significantly higher closest to a ditch, this was not the case for height increments. These were greatest at the farthest (> 12 m) distance from a ditch, though the differences were small and not significant. A reasonable explanation for this is errors in height measurement, which could have been difficult to perform in a closed, dense stand between ditches. One would expect the highest height increments closest to the ditches, as for diameter increment, since there is a significant lowering of the water table closest to ditches in response to drainage (Berry and Jeglum 1988).

The highest volume increments per tree were found closest to ditches, though there were differences in response as a result of tree sizes. Small trees had the best volume growth closest to the ditch. The largest diameter increments were found in medium-sized trees, whereas the largest trees had the best height increment. It is reasonable to expect middle-sized trees to have the best growth response, as this has been shown in other studies (e.g., Stanek 1968, Payandeh 1973). Age is one variable that would be of interest because of its possible effect on the response of individual trees, but no age information was collected in the present study. Age and crown size were, however, correlated with diameter increment in a companion study (Sundström and Jeglum 1992).

Comparisons of growth responses showed that the OG14 site type was significantly different from the other OGs. Diameter, height and volume and their respective increments were all significantly lower on OG14 sites, although the relative increments in response to drainage and fertilization were highest. Because the density of trees in these stands was very low, and because they had no merchantable volume at all, it is felt that these sites will be of little value for any drainage or fertilization operations. However, it must be noted that there was an excellent growth response of tamarack and black spruce in the "rich" OG14 type, which had some of the plant indicators of a rich fen. Personal observations of the range of variation of OG14, from ombrotrophic treed bog to rich fen, suggest there is undoubtedly a large variation in the potential growth response to drainage.

The response to drainage after 5 years was not significant, although there were some indications of a drainage response. The average difference in annual diameter increment between drained and undrained sites was only about 0.13 mm. However, the study only reported growth on a stand level, and considering the wide variation in OGs, age, size and vitality for these trees, a short-term response on a stand level may be hard to detect. Both Stanek (1968) and Payandeh (1973) were unable to show a drainage response on a stand level, even though they demonstrated very good responses to drainage by individual trees (Payandeh) or very young saplings (Stanek). A more careful investigation of individual trees could demonstrate how the size, age and vigor of trees influence the response to drainage.

Mortality and Damage

The overall proportion of dead and damaged trees in this study was about 11%. The proportions of dead and damaged trees on drained and undrained sites were almost the same, but mortality within 3 m of a ditch was higher than at all other distances.

When digging a ditch, the root systems of trees closest to the ditch will be damaged, which may cause the death of some trees. In addition, clearing lines for the ditches increases the exposure to wind, and this also increases the probability of trees blowing down near ditches. Since both the best increments and the greatest risk of damage were found close to a ditch, this may reduce the volume increment per hectare. The amount of this reduction was not studied in this report.

Limitations of the Study

When interpreting the results of this study, emphasis should be put on the OG11 sites, which contain most of the plots. Because of the small number of plots in the other OGs, the results are weaker and should be interpreted with caution.

Diameter was probably the most reliable measure of growth response to either drainage or fertilization in this study, since height was not measured in all plots and the technique used for measuring heights can be questioned.

The interpretation of growth response to drainage in this study was based on comparing the growth in undrained control plots with that in drained plots. In this study, many control plots were located in an undrained forest on the other side of a highway. The local topography in the area suggests that the highway may have cut off the water movement to these plots and they may in fact be somewhat drained. To find good control plots with unmodified, natural water regimes is always a problem in drainage experiments. This shortcoming will be overcome when the stem analysis data from before and after drainage become available, at which point it will be possible to assess, for the same plots, whether drainage improved growth for periods of time before and after the drainage. Unfortunately, 5 years after drainage is not enough time to make valid assessments, and we must wait at least for the 10-year evaluation to make a valid assessment.

Conclusions

The present study assessed responses only for trees that were living in 1989, and not broken or leaning. Also, volume per hectare was based only on these "good" trees. No attempt was made to determine net growth response by subtracting mortality and blowdown volume loss from the volume gains of remaining trees. This should be addressed in subsequent assessments. The conclusions of this study should be viewed from the perspective that 5 years is too short a period to obtain a complete response of tree growth to the new hydrological conditions, and that the results may be better after a longer period of time. Nonetheless, six general statements can be made:

1. There is a growth response of diameter increment to fertilization and the response is better if fertilization is combined with drainage. Fertilization alone is better than drainage alone, at least over the 5 years of the present study.
2. There seems to be a growth response to drainage after 5 years. Diameter, height and volume increments are all higher in drained than in undrained areas, but the differences are not significant. This response occurs most strongly on OG11 and OG14 sites, suggesting that OG12 and OG8 sites may not have been as strongly affected by high water tables.
3. The increased growth in drained areas was most obvious closest to a ditch, where the greatest lowering of the water table was found. This supports the assumption that a drainage response has begun.
4. It is not possible to predict if the drainage response will increase in coming years. Results from European studies indicate that drainage responses on poor sites similar to the ones in this study are rather slow and may take several years to become apparent. Special conditions for the Wally Creek site type, such as the underlying impermeable clay layer, may have a different impact on drainage than was reported in other studies.
5. Drainage seems to have no special effect on the extent of damage or mortality, except for the higher frequency of dead or blown-down trees close to a ditch. Fertilization seems to decrease mortality except closest to a ditch on drained sites.
6. Even though the relative growth response per tree was best on OG14 sites, no commercial drainage or fertilization operations should be carried out on this site type because the small trees, their low stocking and their negligible merchantable volume may not yield any return on the investment.

Comments and Recommendations

With the information available today, it is not possible to provide a final statement on the responses of trees and stands to drainage. However, we can say that fertilization and, to some degree, drainage have improved forest growth in the Wally Creek area. A reliable stem analysis sample from the sample plots in another 5 years will give a better idea of growth before and after drainage.

There were some problems encountered during this study that may be of interest to the reader as well as to people who are planning to set up similar projects.

When analyzing the data collected for this study, it was discovered that the measurements contained many and large errors, especially in the height measurements. In some plots, the frequency of apparently negative height increments was as high as 25 to 30%, which gives us less confidence in the reliability of the data. It was subsequently discovered that heights had been measured with different techniques at different times.

Another problem that arose during the analysis was that not all measurements were taken in all plots, which complicated the analysis and weakened the results to a great extent.

A third problem was that the measurements were taken by different people each year. The assessors were not given the same instructions, and the instructions they did receive were not very precise, which created large variations in the data that cannot be accounted for adequately in the analyses. These problems, taken together, made the results and the conclusions much weaker than they could have been.

To ensure that these problems are corrected, the following four recommendations are made:

1. Simple and well-defined instructions should be set up for how the measurements are to be taken.
2. The same techniques should be used at each assessment, and supervised carefully by an experienced technician.
3. All plots should be measured in the same assessment, and during a period of inactive growth, so as not to span different growing periods.
4. More effort should be made to improve the management and supervision necessary to achieve a high-quality, reliable body of data.

When investing a lot of money and resources in a well-designed project such as the Wally Creek study, assessments and measurements must be carried out with more care and precision. Since this experiment is the first and so far only one in Ontario that was set up for studying drainage and forest growth improvement, it should be given higher priority and managed better. This investment in research should be treated as any other investment. The research should yield a high-quality, reliable product that definitely answers a question and provides the basis for making decisions or making further analyses.

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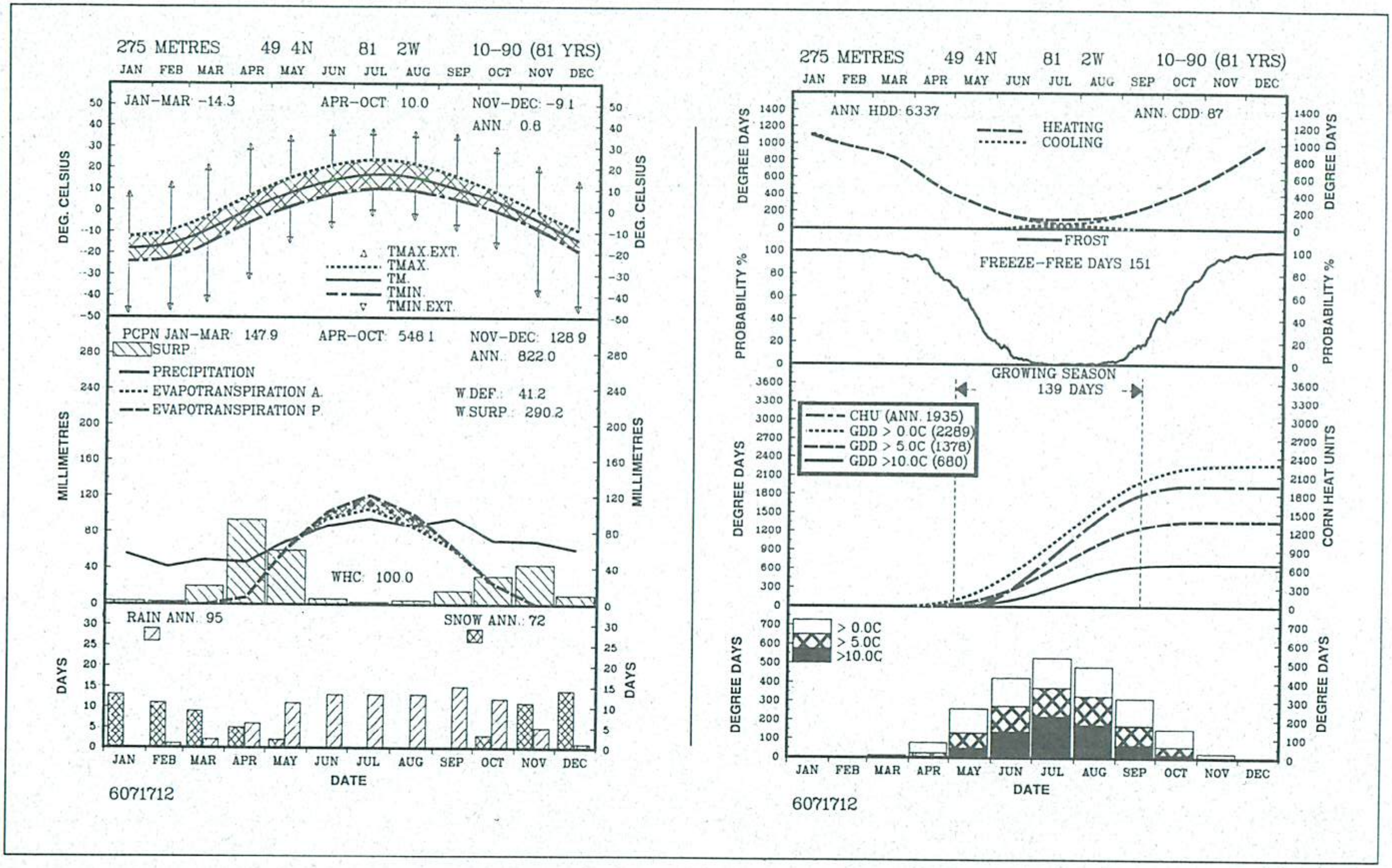
Appendix 1. Climatic data from Cochrane, Ontario.



Appendix 2a: Data from all measured subplots in the 28 growth plots: heights and diameters.

OG		No. of	%	Trees	Treat-	Diameter (cm)				Height (m)			
Orig.	Actual	trees	SB	/ha	ment	N	1985	1989	Ann. incr.	N	1985	1989	Ann. incr.
8-1	8	73	75	2086	D/NF	44	13.36	13.85	0.123	25	10.59	11.41	0.206
8-1F	8	98	89	2692	D/F	49	10.33	10.95	0.156	–	–	–	–
8-2	11	96	92	2526	D/NF	63	11.93	12.41	0.118	60	9.93	10.64	0.178
8-2F	11	113	93	3037	D/F	95	11.60	12.03	0.107	–	–	–	–
8-3	11	123	77	3060	D/NF	95	10.14	10.51	0.093	70	9.07	9.77	0.176
8-3F	11	127	95	3223	D/F	105	10.61	11.12	0.129	–	–	–	–
8-4	8	108	96	2842	D/NF	86	10.04	10.27	0.058	75	9.62	10.10	0.120
8-4F	8	141	95	2860	D/F	108	9.88	10.29	0.104	–	–	–	–
8C-1	5	103	77	2562	ND/NF	–	–	–	–	55	10.97	11.37	0.100
8C-1F	5	–	–	–	ND/F	–	–	–	–	–	–	–	–
8C-2	8	100	90	2284	ND/NF	95	9.18	9.49	0.079	90	7.87	8.44	0.143
8C-2F	8	91	81	2247	ND/F	66	10.47	11.03	0.142	–	–	–	–
11-1	8	131	100	2977	D/NF	98	8.87	9.13	0.065	60	7.75	8.30	0.137
11-1F	8	65	100	1957	D/F	51	8.84	9.25	0.103	–	–	–	–
11-2	11	123	98	3106	D/NF	96	9.42	9.82	0.101	63	9.10	9.59	0.123
11-2F	11	69	100	1830	D/F	57	11.09	11.51	0.104	–	–	–	–
11-3	11	116	99	2900	D/NF	89	8.14	8.45	0.078	105	7.10	7.58	0.121
11-3F	11	100	100	2577	D/F	66	8.63	8.99	0.089	–	–	–	–
11-4	11	96	96	2775	D/NF	71	9.38	9.68	0.075	70	7.71	8.35	0.160
11-4F	11	116	99	3195	D/F	77	8.42	8.83	0.101	–	–	–	–
11C-1	11	131	99	3275	ND/NF	116	9.42	9.76	0.083	105	8.31	8.88	0.142
11C-1F	11	126	98	3150	ND/F	102	8.82	9.33	0.127	–	–	–	–
11C-2	11	87	97	2175	ND/NF	75	8.11	8.36	0.063	76	6.83	7.38	0.135
11C-2F	11	129	99	3028	ND/F	97	8.48	8.77	0.073	–	–	–	–
11C-S	11	130	100	3250	ND/NF	85	9.84	10.03	0.047	89	9.34	9.71	0.092
11C-SF	11	93	100	2325	ND/F	53	13.24	13.44	0.048	–	–	–	–
12-1	12	77	94	2567	D/NF	51	9.33	9.69	0.092	53	7.22	7.63	0.102
12-1F	12	65	78	1641	D/F	23	8.44	9.11	0.167	–	–	–	–
12-2	11	125	93	2840	D/NF	103	8.93	9.23	0.075	90	8.07	8.65	0.147
12-2F	11	81	96	1653	D/F	–	–	–	–	–	–	–	–
12-3	12	79	100	1590	D/NF	58	10.31	10.53	0.055	58	8.65	9.15	0.125
12-3F	12	72	100	1525	D/F	45	11.82	12.39	0.142	–	–	–	–
12-4	12	53	100	1559	D/NF	43	10.06	10.38	0.080	45	7.97	8.50	0.132
12-4F	12	55	96	1662	D/F	33	9.11	9.76	0.164	–	–	–	–
12C-1	12	65	97	1625	ND/NF	50	14.67	15.05	0.096	41	10.94	11.52	0.146
12C-1F	12	59	100	1540	ND/F	–	–	–	–	–	–	–	–
12C-2	12	86	99	2150	ND/NF	78	8.57	8.86	0.072	78	6.64	7.05	0.103
12C-2F	12	95	97	2375	ND/F	–	–	–	–	–	–	–	–
14-1	14	34	32	775	D/NF	9	5.40	5.72	0.081	9	3.83	4.40	0.142
14-1F	14	7	71	196	D/F	5	5.62	5.82	0.050	–	–	–	–
14-2	14	35	54	906	D/NF	16	5.67	5.88	0.052	17	4.22	4.55	0.084
14-2F	14	13	23	399	D/F	2	3.10	3.75	0.162	–	–	–	–
14-3	11	62	100	1667	D/NF	38	7.30	7.39	0.024	50	6.34	6.90	0.141
14-3F	11	39	100	1089	D/F	26	8.20	8.66	0.115	–	–	–	–
14-4	14	40	100	1205	D/NF	31	7.47	7.66	0.047	35	6.25	6.60	0.086
14-4F	14	99	100	2115	D/F	71	7.60	7.94	0.085	–	–	–	–
14C-1	14	46	100	1192	ND/NF	43	7.12	7.27	0.040	39	5.63	6.00	0.092
14C-1F	14	28	100	700	ND/F	–	–	–	–	–	–	–	–
14C-2	14	21	100	544	ND/NF	14	6.70	6.83	0.032	16	4.98	5.19	0.053
14C-2F	14	39	100	975	ND/F	–	–	–	–	–	–	–	–
20	11	58	100	1933	D/NF	47	10.40	10.71	0.076	46	8.83	9.32	0.125
20F	11	116	99	3102	D/F	–	–	–	–	–	–	–	–
60	12	80	100	2020	D/NF	73	10.63	11.00	0.093	62	8.64	9.11	0.117
60F	12	155	97	4037	D/F	–	–	–	–	–	–	–	–
80	11	90	99	2400	D/NF	77	8.92	9.49	0.079	60	7.52	8.23	0.177
80F	11	96	99	2689	D/F	–	–	–	–	–	–	–	–

Appendix 2b: Data from all measured subplots in the 28 growth plots: volumes.

OG		No. of	%	Trees	Treat-	Volume/tree (dm^3)				Volume/ha (m^3)		
Orig.	Actual	trees	SB	/ha	ment	N	1985	1989	Ann. incr.	1985	1989	Ann. incr.
8-1	8	73	75	2086	D/NF	24	72.1	82.7	2.626	113	129	4.108
8-1	8	98	89	2692	D/F	–	–	–	–	–	–	–
8-2	11	96	92	2526	D/NF	51	59.9	68.3	2.105	139	159	4.892
8-2F	11	113	93	3037	D/F	–	–	–	–	–	–	–
8-3	11	123	77	3060	D/NF	65	36.6	41.2	1.150	86	97	2.710
8-3F	11	127	95	3223	D/F	–	–	–	–	–	–	–
8-4	8	108	96	2842	D/NF	63	45.5	49.5	0.991	124	135	2.704
8-4F	8	141	95	2860	D/F	–	–	–	–	–	–	–
8C-1	5	103	77	2562	ND/NF	–	–	–	–	–	–	–
8C-1F	5	–	–	–	ND/F	–	–	–	–	–	–	–
8C-2	8	100	90	2284	ND/NF	83	32.8	37.1	1.061	67	76	2.181
8C-2F	8	91	81	2247	ND/F	–	–	–	–	–	–	–
11-1	8	131	100	2977	D/NF	47	26.2	29.6	0.831	78	88	2.474
11-1F	8	65	100	1957	D/F	–	–	–	–	–	–	–
11-2	11	123	98	3106	D/NF	53	37.3	42.1	1.198	114	128	3.647
11-2F	11	69	100	1830	D/F	–	–	–	–	–	–	–
11-3	11	116	99	2900	D/NF	84	21.5	24.2	0.681	62	70	1.955
11-3F	11	100	100	2577	D/F	–	–	–	–	–	–	–
11-4	11	96	96	2775	D/NF	59	28.9	33.0	1.023	77	88	2.725
11-4F	11	116	99	3195	D/F	–	–	–	–	–	–	–
11C-1	11	131	99	3275	ND/NF	98	35.5	39.8	1.082	115	129	3.508
11C-1F	11	126	98	3150	ND/F	–	–	–	–	–	–	–
11C-2	11	87	97	2175	ND/NF	72	22.1	24.6	0.612	47	52	1.291
11C-2F	11	129	99	3028	ND/F	–	–	–	–	–	–	–
11C-S	11	130	100	3250	ND/NF	66	45.0	47.9	0.724	146	156	2.353
11C-SF	11	93	100	2325	ND/F	–	–	–	–	–	–	–
12-1	12	77	94	2567	D/NF	42	28.4	31.5	0.794	69	76	1.916
12-1F	12	65	78	1641	D/F	–	–	–	–	–	–	–
12-2	11	125	93	2840	D/NF	84	29.6	33.3	0.929	78	88	2.454
12-2F	11	81	96	1653	D/F	–	–	–	–	–	–	–
12-3	12	79	100	1590	D/NF	49	41.0	44.2	0.799	65	70	1.270
12-3F	12	72	100	1525	D/F	–	–	–	–	–	–	–
12-4	12	53	100	1559	D/NF	39	42.3	46.7	1.111	66	73	1.732
12-4F	12	55	96	1662	D/F	–	–	–	–	–	–	–
12C-1	12	65	97	1625	ND/NF	40	96.8	104.6	1.966	153	165	3.099
12C-1F	12	59	100	1540	ND/F	–	–	–	–	–	–	–
12C-2	12	86	99	2150	ND/NF	75	23.7	26.4	0.681	51	56	1.450
12C-2F	12	95	97	2375	ND/F	–	–	–	–	–	–	–
14-1	14	34	32	775	D/NF	9	5.5	6.8	0.329	1.4	1.7	0.082
14-1F	14	7	71	196	D/F	–	–	–	–	–	–	–
14-2	14	35	54	906	D/NF	16	6.1	7.0	0.237	3.0	3.4	0.116
14-2F	14	13	23	399	D/F	–	–	–	–	–	–	–
14-3	11	62	100	1667	D/NF	35	13.6	14.8	0.309	23	25	0.515
14-3F	11	39	100	1089	D/F	–	–	–	–	–	–	–
14-4	14	40	100	1205	D/NF	30	14.4	15.8	0.351	17	19	0.423
14-4F	14	99	100	2115	D/F	–	–	–	–	–	–	–
14C-1	14	46	100	1192	ND/NF	38	12.8	14.0	0.296	15	17	0.353
14C-1F	14	28	100	700	ND/F	–	–	–	–	–	–	–
14C-2	14	21	100	544	ND/NF	13	9.5	10.4	0.201	5.2	5.7	0.109
14C-2F	14	39	100	975	ND/F	–	–	–	–	–	–	–
20	11	58	100	1933	D/NF	42	44.2	48.3	1.032	85	93	1.995
20F	11	116	99	3102	D/F	–	–	–	–	–	–	–
60	12	80	100	2020	D/NF	60	44.8	49.4	1.157	91	100	2.337
60F	12	155	97	4037	D/F	–	–	–	–	–	–	–
80	11	90	99	2400	D/NF	54	25.9	29.6	0.921	62	70	2.188
80F	11	96	99	2689	D/F	–	–	–	–	–	–	–