Scientific and Technical Articles/ Articles scientifiques et techniques

Growth of Black Spruce Trees Following Fertilization on Drained Peatland

by

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Abstract

Stem analysis of 67 peatland black spruce trees from previously drained experimental areas in northeastern Ontario that had been fertilized was used to examine effects on growth of individual trees. Stepwise multiple linear regression analysis was used to express pre- and post-fertilization diameter and volume growth as a function of site, stand and individual tree characteristics and amelioration treatments.

Results indicated that, on average, diameter growth increased by 4% after fertilization. Standard volume equations, in comparison with sectional volume summation, underestimated both inside- and outside-bark tree volumes by about 3%.

Résumé

L'analyse des tiges de 67 épinettes noires poussant en sol tourbeux dans des stations expérimentales antérieurement asséchées puis fertilisées du nord-est de l'Ontario a permis d'examiner l'effet de ces facteurs sur l'accroissement individuel. Pour exprimer le diamètre avant et après la fertilisation ainsi que l'accroissement en volume en fonction de la station, du peuplement et des caractéristiques de chaque arbre de même qu'en fonction des traitements d'amélioration, on s'est servi de régressions linéaires multiples pas à pas.

Les résultats montrent que, en moyenne, l'accroissement en diamètre augmente de 4% après la fertilisation. Les équations ordinaires du volume sous-estimaient d'environ 3% le volume des arbres sous l'écorce et sur l'écorce, comparativement à la sommation des volumes de sections de tige.

Introduction

Black spruce (*Picea mariana* [Mill.] B.S.P.) is the most important pulpwood species in Ontario. About 50% of black spruce in northern Ontario occurs on peatland sites (Ketcheson and Jeglum 1972). Because of excess water, poor aeration, low nutrient availability and adverse climatic conditions, its growth on such sites is usually very slow (Payandeh 1973). Productivity can be improved by drainage and fertilization (Stanek 1968, 1977; Payandeh 1973, 1982).

Extensive peatland site amelioration has been carried out in Finland, the USSR and elsewhere in Europe (Heikurainen 1982, Payandeh 1982). Only a few small-scale experimental

forest drainage and fertilization trials have been carried out in North America (cf Stanek 1968, 1977; Jeglum et al. 1983).

A 5-year growth response of northern Ontario peatland black spruce to fertilization and drainage was reported earlier (Payandeh 1982). Figure 1 shows the study area; blocks I to XIII indicate the locations of the fertilization experiments. The experimental design was very much constrained because it was bound to the existing experimental and/or highway drainage ditches (see Payandeh 1982, Stanek 1968). Despite high variability and constraints imposed on the experimental areas, results indicated that 5-year growth response to drainage and fertilization could result in as much as 7 m³/ha of additional wood in comparison with the control. The purpose of this note is to report on growth of black spruce trees after fertilization in the same study area.

Materials and Methods

In all, 67 dominant and codominant trees located at various distances from drainage ditches were felled and sectioned for detailed growth analysis. For each tree the following measurements were made and/or recorded (Please note that field measurements were made in English units, but converted to SI units for analysis):

- a) TC — treatment code, assigned as TC1, TC2, ... TC14 to 14 treatment combinations²

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²Treatments and their respective codes were: control = 1; minor thinning = 2; AN112, TSP112, and KC66 = 3; AN224, TSP224, and KC112 = 4; AN 84, TSP84, and KC42 = 5; AN168, TSP168, and KC84 = 6; TSP112 = 7; TSP224 = 8; TSP336 = 9; TSP448 = 10; AN112, TSP112, and KC112 = 11; TSP112 and KC112 = 12; U112, TSP112, and KC112 = 13; and U112, TSP112 and KC168 = 14, where: AN112 = 112 kg/ha of ammonium nitrate, TSP224 = 224 kg/ha of triple super phosphate, KC84 = 84 kg/ha of potash, and U112 = 112 kg of urea.

Treatment codes rather than dummy variables were used in the analysis for: a) low and unequal frequency with respect to treatments, b) commonality of elements, i.e., N, P and K among treatments, and c) relatively small sample size. For regression analysis on an individual tree basis, allocating 14 out of 65 degrees of freedom to treatments represented by dummy variables would not be justified.

BLACK SPRUCE POP'S COCHRANE AND VICINITY

Figure 1. Map of Cochrane and vicinity indicating the location of permanent growth sample plots and blocks containing fertilization plots near the experimental or highway drainage ditches.

- b) DBH — diameter at breast height, measured to nearest 0.025 cm
- c) H — tree height, measured to nearest 30 cm
- d) DD — distance to ditch, measured to nearest 30 cm
- e) DN — distance to nearest tree, measured to nearest 2.5 cm
- f) CC — tree crown class designated by two dummy variables:
Dominant — [CC1] = 1 and [CC2] = 0
Codominant — [CC1] = 0 and [CC2] = 1
Intermediate — [CC1] = 0 and [CC2] = 0
- g) CN — crown condition designated by two dummy variables:
Good — [CN1] = 1 and [CN2] = 0
Medium — [CN1] = 0 and [CN2] = 1
Poor — [CN1] = 0 and [CN2] = 0
- h) HC — height to live crown, measured to nearest 30 cm
- i) CD — crown diameter, measured to nearest 30 cm

Starting at stump height (30 cm) on each of the 67 trees, a disc was removed at intervals of 1.22 m. The following measurements were subsequently made with an Addo-X Tree Ring Measuring Instrument, and recorded for each:

- a) DOB — diameter outside bark (mm)
DIB — diameter inside bark (mm)
DBT — double bark thickness (mm)
- b) Age — years
- c) 5-year diameter growth, measured to nearest 0.01 mm.

The following preliminary growth calculations were made on each sectional disc:

- 1) Average Annual Diameter Growth (AADG)
- 2) Post-fertilization Average Annual Diameter Growth, i.e., the most recent 5-year diameter growth divided by 5 as calculated above (PAADG)
- 3) Post-fertilization Annual Average Diameter Growth as a percentage of Average Annual Diameter Growth, i.e., PAADG/AADG*100
- 4) Post-fertilization Average Diameter Growth as a percentage of diameter growth immediately prior to fertilization, i.e., PADGP2 = (PAADG divided by average annual diameter growth five years before fertilization)*100

Tree volume (inside and outside bark, before and after fertilization) and tree volume growth were calculated as follows:

- a) Tree volume as the sum of the sectional volumes (Smalian formula) as:

$$\text{Tree volume} = \sum \left(\frac{r_{i+1} + r_i}{2} \right) \times L$$

where: r_i = section area at H_i height
 r_{i+1} = section area at H_{i+1} height
 K = number of 1.22 m for each tree
 L = section length = 1.22 m

- a1) Tree volume outside bark after fertilization (VOLA1), using DOBi and DOB_{i+1} for calculating lower and upper sectional surface area, respectively.
- a2) Tree volume inside bark after fertilization (VOLA2), using DIBi and DIB_{i+1} for calculating lower and upper sectional surface area, respectively.
- a3) Tree volume outside bark before fertilization (VOLA3), using (DOBi - RADGi*5) and (DOB_{i+1} - RADG_{i+1}*5) for calculating lower and upper surface areas.
- a4) Tree volume inside bark before fertilization (VOLA4), using (DIBi - RADGi*5) and (DIB_{i+1} - RADG_{i+1}*5) for calculating lower and upper diameter, respectively.
- b) Pre- and post-fertilization volumes calculated by standard tree volume (Honer et al. 1983) equation for black spruce as follows:

$$V = [B_1 \cdot D \cdot D^2 \cdot (1 - 0.04365 \cdot B_2) \cdot H] / (C_1 + 0.3048 \cdot C_2 / H)$$

where: V = total tree volume in m³
 D = outside bark diameter at breast height in cm
 H = total tree height in m
 B_1 = 0.004389
 B_2 = 0.164
 C_1 = 1.588
 C_2 = 333.364

Table 1. Statistical summary from measurements on cross sections of peatland black spruce. (data for all discs from 67 trees)

Variable ^a	Mean	Range	Coefficient of variation (%)
DBH (cm) ^b	12.93	12.3	26
H (m) ^b	11.21	9.6	22
DO (m) ^b	25.10	52.5	60
DN (m) ^b	0.11	0.3	64
HC (m) ^b	4.23	10.4	47
CO (m) ^b	1.77	2.1	30
DOB (cm) ^c	8.91	22.5	48
DBT (cm) ^c	0.84	2.6	39
DIB (cm) ^c	8.06	20.1	50
Age (years) ^c	52.9	197.0	74
AADG (cm) ^c	0.19	0.4	47
PAADG (cm) ^c	0.18	0.6	61
PADGP	90.4	346	44
PADGP2	104.2	454	35

^aVariables as defined in text.^bBased on 67 trees.^cBased on 587 sectional discs.

- b1) Tree volume after fertilization (VOLB1) using the post-fertilization tree DBH and total height in the above formula.
- b2) Tree volume before fertilization (VOLB2) using pre-fertilization tree DBH and total height in the above formula.
- c) Individual tree volume growth was calculated as follows:
- c1) Tree volume growth outside bark (VOLC1) and its percentage volume growth (PBOLC1) were calculated as $(a1-a3)/a3 \times 100$ of section a) above, respectively.
- c2) Tree volume growth inside bark (VOLC2), and its percentage volume growth (PVOLC2) were calculated as $(a2-a4)/a4 \times 100$ section a) above, respectively.
- c3) Total tree volume growth (VOLC3) and percentage total tree volume growth (PVOLC3) were calculated as: $(b1-b2)/b2 \times 100$ of section b) above, respectively.

Stepwise multiple regression analysis with mixed models³ (i.e., containing both continuous and discrete variables) was used to express tree volume and diameter growth as a function of tree, stand, site and fertilization treatment factors.

Results and Discussion

Table 1 provides a statistical summary of tree growth data used in this study. Table 2 gives a similar summary for individual tree volume and volume growth and for pre- and post-fertilization treatment. Tree volume and volume growth were calculated by both sectional summation (i.e., Smalian formula) and standard volume equation to detect possible significant

Table 2. Statistical summary of peatland black spruce tree volume and volume growth for pre- and post-fertilization treatments^a.

Variable ^a	Mean	Range	Coefficient of variation (%)
VOLA1 (m ³) ^b	0.071	0.182	68
VOLA2 (m ³)	0.059	0.152	69
VOLA3 (m ³)	0.070	0.181	68
VOLA4 (m ³)	0.058	0.151	69
VOLB1 (m ³)	0.069	0.190	70
VOLB2 (m ³)	0.068	0.189	70
VOLC1 (m ³)	0.001	0.003	75
VOLC2 (m ³)	0.001	0.003	76
VOLC3 (m ³)	0.001	0.002	78
PVOLC1	1.731	5.800	61
PVOLC2	1.890	6.500	62
PVOLC3	1.194	4.540	87

^aBased on 67 trees.^bVariable names as defined in the text; in VOLA or B, A indicates after fertilization, B indicates before fertilization.

volume increment in the upper stems that was due to treatment that would not be detected by the standard volume equations.

Table 1 shows that post-fertilization average annual diameter growth (PAADG) was slightly less than the average annual diameter growth (AADG), an indication that diameter growth rate had been declining for some time prior to treatment, perhaps owing to tree age and site conditions. Similarly, post-fertilization annual diameter growth (PADGP) as a percentage of average diameter growth is less than 100% for the same reason mentioned above. On the other hand, post-fertilization annual diameter growth as a percentage of diameter growth 5 years immediately prior to treatment is 104.2%. Therefore, post-fertilization growth increased by 4.2% in comparison with 5 years immediately prior to treatment.

Table 2 indicates that tree volume calculated by the standard volume equation underestimated volume by about 3% for both pre- and post-fertilization treatments (i.e., VOLB2/VOLA3 or $0.068/0.070 = 0.971$; VOLB1/VOLA1 or $0.069/0.071 = 0.971$). Such a difference does not affect the volume growth estimate significantly. However, there is a considerable difference in volume growth percentages obtained by the two methods, i.e., PVOLC1 = 1.73% vs PVOLC2 = 1.19%. That is, the standard volume equation may underestimate the change in rate of growth by about one third; this change might occur in the upper part of the stem as a result of treatment effects.

Table 3 summarizes the stepwise linear regression analysis expressing sectional diameter growth and tree volume growth as functions of tree, stand, site and fertilization treatment factors⁴. The first equation indicates that average annual diameter growth was positively correlated with tree height, crown condition, crown diameter and double bark thickness, and was negatively correlated with DBH, sectional height and tree age. That is, average annual diameter growth was greater for taller trees in good condition, with wider crowns and thicker bark, and less for older trees with larger DBH and shorter crowns. This equation had a very good fit and accounted for 81% of the variability in average annual diameter growth.

The second equation of Table 3 indicates that post-fertilization average annual diameter growth was a function of fertilization treatment (TC) and distance to the nearest tree (DN) in addition to the above-mentioned variables. It indicates that post-fertilization diameter growth rate was positively correlated

³Categorical variables represented by dummy variables may be used along with continuous variable(s) in regression models (linear or nonlinear) and with stepwise or other procedures (see Draper and Smith 1966, Cuna 1973, Challengee and Price 1977, Sokal and Rohlf 1981 and Monsenud 1984, for examples). Stepwise procedures may also be used to determine the significance of individual classes within a categorical variable or their effect on the response variable (see Payandeh 1986, and Payandeh and Wood 1988).

⁴It should be noted that variables selected in stepwise regression analysis, because of high partial correlation with the response variable, do not necessarily represent a cause-and-effect relationship. More important, curvilinear relationships often exist between a response variable and two or more predictor variables. In such cases one or more of the predictor variables take the opposite sign to compensate for the curvilinear relationship. This may appear to be a contradictory biological relationship, but usually it is not.

Table 3. Summary of stepwise linear regression analyses expressing peatland black spruce sectional tree growth^a and individual tree growth as functions of tree^b, stand, site and fertilization treatment variables.

Response variable	Regression equation	R ²	SEE	F
AADG ^a	$Y = 0.127 - 0.008 \text{ DBH} + 0.022 \text{ H} + 0.040 [\text{CN1}] + 0.020 [\text{CN2}] - 0.010 \text{ HC} + 0.041 \text{ CD} + 0.049 \text{ DBT} - 0.002 \text{ A}$	0.812	0.041	152.4
PAADG ^a	$Y = 0.109 + 0.015 \text{ TC} - 0.197 \text{ DN} + 0.088 [\text{CN1}] + 0.044 [\text{CN2}] - 0.026 \text{ HC} + 0.073 \text{ CD} + 0.011 \text{ H} + 0.089 \text{ DBT} - 0.001 \text{ A}$	0.601	0.066	47.9
PADGP1 ^a	$Y = 80.60 + 8.0 \text{ TC} + 57.55 [\text{CN1}] + 28.78 [\text{CN2}] - 5.71 \text{ HC} + 3.69 \text{ H} + 7.11 \text{ A}$	0.365	27.56	29.7
PADGP2 ^a	$Y = 136.58 - 5.72 \text{ DBH} + 3.94 \text{ H} + 25.46 [\text{CN1}] + 12.23 [\text{CN2}] + 1.50 \text{ HC} + 0.112 \text{ A}$	0.178	34.79	11.0
VOLC1 ^b	$Y = 0.0018 + 0.00032 \text{ H} + 0.0002 \text{ HC} + 0.0014 \text{ CD}$	0.867	0.0004	63.7
VOLC2 ^b	$Y = -0.0015 + 0.00027 \text{ H} - 0.0002 [\text{CN1}] - 0.001 [\text{CN2}] + 0.0013 \text{ CD}$	0.870	0.004	95.4
VOLC3 ^b	$Y = -0.013 + 0.00028 \text{ HT} + 0.0003 \text{ HC} + 0.0011 \text{ CD}$	0.834	0.0003	49.6

^aBased on 587 sectional data.^bBased on 87 trees.

with fertilization treatment (TC), tree height (H), crown condition (CN), crown diameter (CD) and double bark thickness (DBT). It was negatively correlated with distance from the nearest tree (DN), height to live crown (HC) and tree age (A). The eight predictor variables of this equation accounted for 60% of the variability in the post-fertilization average annual diameter growth, an indication that fertilization increased the variability of diameter growth, i.e., some trees grew faster than others, etc.

The third equation of Table 3 expresses post-fertilization average annual diameter growth as a percentage of the average annual growth prior to fertilization (PDGP1). It indicates that PDGP1 is positively correlated with fertilization treatment (TC), crown condition (CN), total height (H) and age (A), and negatively correlated with height to live crown (HC). That is, the rate of growth is higher for fertilized trees with good crown condition and for taller and older trees with greater crown length (or shorter distance to live crown). This equation with five predictor variables accounted for 36.5% of the variability in PADGP1⁵.

The fourth equation of Table 3 indicates that post-fertilization diameter growth as a percentage of the average diameter growth for 5 years immediately prior to fertilization, PADGP2, is positively correlated with tree height (H), age (A), crown condition (CN) and height to live crown (HC), but it is negatively correlated with tree DBH. The five predictor variables in this equation accounted for only 18% of the variability⁵.

The next equation of Table 3 indicates that outside-bark tree volume growth after fertilization (VOLC1) was positively correlated with tree height (H), height to live crown (HC) and crown diameter (CD). This equation had an $R^2 = 0.867$, which is considered to be a very good fit for this type of data.

The equation expressing inside-bark tree volume growth (VOLC2, Table 3) indicates that it was positively correlated with

tree height (H) and crown diameter (CD), but negatively correlated with crown condition (CN). This equation also resulted in a very good fit, i.e., the three predictor variables accounted for 87% of the variability in VOLC2.

Finally, the last equation of Table 3 indicates that tree volume growth calculated on the basis of the standard volume equation VOLC3, was positively correlated with tree height (H), height to live crown (HC) and crown diameter (CD). It had an $R = 0.834$, somewhat lower than the previous two equations, but still a very good fit. The last three equations of Table 3 indicate that, as expected, percentage tree volume (or the sum of volume increments over time) may be predicted with fewer predictor variables.

In brief, the results of this study indicate that a) growth rate of trees prior to the application of fertilizer had been declining for some time, perhaps because of stand age and site conditions deteriorating as a result of the decreased effectiveness of drainage ditches; b) post-fertilization average annual diameter growth increased by about 4%; and c) percentage of volume growth calculation based on standard volume equations may underestimate the change in growth rate by about one third; this change might occur in the upper part of the stem as a result of treatment effects.

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⁵It should be noted that expressing growth rate as a response variable in relative terms, i.e., in percent, usually results in poor fit because of high variability and lack of normality and additivity.

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