

ESTABLISHMENT AND GROWTH OF SEEDED UPLAND BLACK SPRUCE: 7-12 YEAR RESPONSE

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ABSTRACT

Direct seeding has considerable potential as a cost-effective reforestation technique for black spruce. Seed spots were used to investigate black spruce site, seedbed, and sowing requirements on coarse-textured upland sites near Thunder Bay, Ontario. Seedling establishment was better on Moderately Moist to Moist than on Moderately Fresh to Fresh Soil Moisture Regimes, and on seedbeds near the mineral soil–humus interface than on thick surface organic horizons. Seedling establishment and growth were both better following seeding the first spring, in comparison with seeding the second or third spring, after summer scarification. Seedling establishment was often better on mineral soil, but seedling growth was often better on thin organic horizons. Microsite position across scarified furrows had no consistent effect on seedling establishment or growth. Mean black spruce heights 12 years after seeding with no competition control ranged from 90 to 110 cm, while those of dominant competing jack pine and trembling aspen ranged from 250 to 400 cm. Suppression of black spruce height increment was evident 7–9 years after seeding.

RÉSUMÉ

L'ensemencement direct est une technique de reboisement efficace et économique qui présente un potentiel considérable pour l'épinette noire. Une étude a été effectuée sur des placeaux établis sur des sols à texture grossière de hautes terres près de Thunder Bay, en Ontario, afin de déterminer les exigences de l'épinette noire concernant le site, le lit de germination et l'ensemencement. On a constaté que l'établissement des semis était meilleur sur les sols modérément humides à humides que sur les sols modérément frais à frais et qu'il était préférable que les lits de germination soient situés à proximité de l'interface sol minéral-humus que sur des horizons organiques superficiels épais. Par ailleurs, on a observé un meilleur établissement et une meilleure croissance des semis lorsque l'ensemencement avait eu lieu le premier printemps suivant le scarifiage (réalisée en été) plutôt que le deuxième ou le troisième. L'établissement des semis s'est également révélé souvent meilleur sur le sol minéral; par contre, la croissance des semis était souvent supérieure sur les horizons organiques minces. Quant à la position du microsite sur les sillons de scarifiage, aucun effet constant de celle-ci sur l'établissement ou la croissance des semis n'a été

constaté. Et 12 ans après l'ensemencement, la hauteur moyenne des épinettes noires, en l'absence de mesure de lutte contre la végétation concurrente, variait de 90 à 110cm, tandis que celle des pins gris et des peupliers faux-trembles dominants qui leur faisaient concurrence variait de 250 à 400cm. De 7 à 9 ans après l'ensemencement, l'oppression exercée par les arbres dominants est perceptible dans les chiffres de l'accroissement en hauteur des épinettes noires.

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ESTABLISHMENT AND GROWTH OF SEEDED UPLAND BLACK SPRUCE: 7–12 YEAR RESPONSE

INTRODUCTION

Black spruce (*Picea mariana* [Mill.] B.S.P.) is one of Canada's most important commercial tree species. In Ontario, it accounts for approximately 40% of the province's gross total wood volume and annual wood harvest (Campbell 1990). Harvesting and regeneration practices over the past 20 years, however, have resulted in substantial decreases in the black spruce component of many second growth forests in northern Ontario (Hearnden et al. 1992).

With the present constraints on silviculture budgets and increased emphasis on cost-effective reforestation alternatives, there is now renewed interest in direct seeding (Jeglum 1990). Direct seeding would be particularly useful for regenerating the numerous black spruce dominated stands in northern Ontario that are characterized by poor access, long distances from mills, or limited site productivity. Currently, such sites cannot be treated cost-effectively by planting (Benson 1988), and may receive no silvicultural treatment following harvesting.

Most previous attempts at direct seeding black spruce on upland sites in northern Ontario have failed (Scott 1968, Fraser 1981a). To improve success rates, Fraser (1981b) identified three ecological requirements that must be addressed: (1) the selection of suitable sites, (2) the creation of sufficient quantities and an adequate distribution of receptive seedbeds and microsites, and (3) the development of appropriate seeding regimes for these conditions. The experiments reported here formed part of a larger study of black spruce direct seeding, and were designed to identify site-specific seedbed, microsite, and seeding requirements for black spruce on upland, coarse-textured soils (Fleming and Mossa 1994, 1995).

The objectives of this report are: (1) to describe trends in black spruce establishment and growth on coarse-textured upland sites in northwestern Ontario for the first 7–12 years following sowing; (2) to relate these trends to differences in seedbed, microsite, time of seeding, and Soil Moisture Regime (Ontario Institute of Pedology 1985); and (3) to compare black spruce growth over this period with that of commonly occurring woody competitors.

METHODS AND MATERIALS

Experimental Procedures

The three experimental areas were located 120–140 km north of Thunder Bay, Ontario (48°25'N, 89°15'W), at an elevation of 450–500 m, within the current Abitibi-Price

Spruce River Forest Management Agreement area. In this region, mean growing season (May 1–August 31) precipitation ranges from 300 to 375 mm, with an average of 11 to 13 days of rain per month. There are 1,300–1,400 mean annual growing degree days (daily mean temperature >5°C) (Atmospheric Environment Service 1982). The soils are predominantly Brunisols (Canada Soil Survey Committee 1978) with mean coarse fragment contents ranging from 0.20 to 0.30 m³m⁻³. They were derived from sandy till ground moraines and glaciofluvial deposits of low relief and varying thickness over bedrock (Mollard and Mollard 1980, 1983). The lithology of the till and topography of the landscape primarily reflects the local bedrock, which is composed of Archean volcanic and gneissic rocks (migmatite, biotite, and hornblende–quartz–feldspar gneiss) with broad rolling surfaces (Milne 1964, Zoltai 1965).

Site and soil conditions for the experimental areas are given in Table 1. Soil and site information were collected for each plot of each year's experiment, and plots were then grouped into broad Soil Moisture Regime categories (A = Moderately Fresh to Fresh, B = Moderately Moist to Moist) (Ontario Institute of Pedology 1985).

The Goodlad Lake and Grew River sites were clear-cut in April 1980 and scarified in August 1980 with a modified Cazes and Heppner (C&H) scarification plow (Fleming et al. 1987), thereby creating furrows about 250 cm wide, with spoil banks about 75 cm high and 75 cm wide on either side. The Kearns Lake site was clear-cut in the winter of 1982 and scarified in October 1983 with a TTS Model 35 Disc Trencher (Fleming et al. 1987). This scarifier created continuous furrows 15–30 cm deep and 40–60 cm wide, with low berms of organic debris and soil on either side.

Each experiment was laid out using a randomized complete block design with five 60-m x 20-m blocks. Within each block, separate 20-m x 20-m plots were randomly assigned to each of 3 consecutive years of May seeding, commencing the first spring following scarification. At the Goodlad Lake and Grew River sites, 45 rows of five, equally spaced seed spots, representing five microsite positions, were set out across the scarified furrows in each of the seeded plots each year (1981, 1982, and 1983) (Fig. 1). Wherever possible, these seed spots were placed on thin-F or shallow-mineral seedbeds (Appendix 1). At the Kearns Lake site, 30 seed spots were set out in each plot on each of six preselected seedbed types each year (1984, 1985, and 1986).

Table 1. Site and soil conditions for the experimental sites.

Site and symbol	Seeding years	Soil depth (cm)	B, C horizon soil texture	B, C horizon Moisture Regime ¹	NWO FEC ² soil type	NWO FEC vegetation type
Goodlad Lake A (GL-A)	1981–83	100+	B: SiL C: LfS	B: 2 C: 1,2	S2	V19
Goodlad Lake B (GL-B)	1981–83	100+	B: SiL C: SivfS	B: 4,5 C: 4,5	S8	V19
Grew River A (GR-A)	1981–83	100+	B: SivfS C: SivfS	B: 2 C: 2,3	S3	V33
Grew River B (GR-B)	1981–83	100+	B: SivfS C: SivfS	B: 4,5 C: 4,5	S8	V34
Kearns Lake A (KL-A)	1984–86	100+	B: SivfS C: SifS	B: 2 C: 1	S3	V32
Kearns Lake B (KL-B)	1984–86	100+	B: SivfS C: SiL	B: 4,5 C: 4,5	S8	V33

¹Ontario Institute of Pedology (1985).

²Northwestern Ontario Forest Ecosystem Classification (Sims et al. 1989).

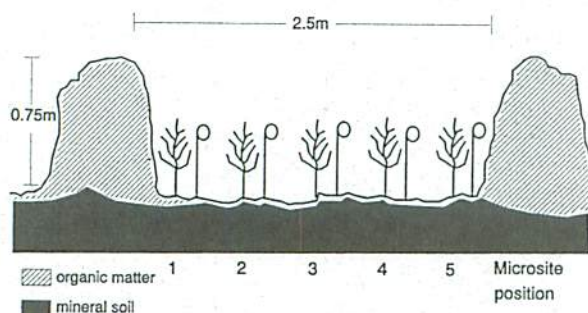


Figure 1. Layout of seed spots, across the scarified furrow within a seeding plot at Goodlad Lake, showing the five microsite positions.

At all sites, each seed spot consisted of five surface-sown, dewinged black spruce seeds from local seed sources. All seed spots were marked with flagged, numbered steel pins. Germination percentages at the time of sowing, determined at a constant temperature of 21°C (±0.5°C) on four 100-seed replicates (Fleming and Lister 1984), ranged from 89 to 98% for the different seedlot–sowing date combinations. None of the plots has ever been weeded or tended.

Assessments carried out in July and August 1992 included measurements of black spruce survival, total height, ground level stem diameter (GLSD), and current annual height increment (CAHI) from the age of four to the time of assessment. The species, height, and GLSD of the largest woody competitor were also recorded for each quadrant of a 2-m radius circular plot centred at the largest seedling per seed spot (MacDonald 1991).

A competition index developed by MacDonald (1991) and seedling height measurements of photosynthetically active photon flux density (PPFD) were used to investigate effects of interspecific competition on black spruce seedling growth. For the competition index, the sum of the calculated stem volumes of the largest woody competitor in each quadrant within a 2-m radius of the seedling was used as a measure of competing stem volume (CSB):

$$CSB = (\sum(B_i \cdot H_i))$$

where B_i is root collar basal area of the largest competitor in the i^{th} quadrant and H_i is the height of the largest competitor in the i^{th} quadrant. The competition index (CI) was then calculated as:

$$CI = CSB / (B_s \cdot H_s)$$

where B_s is the seedling ground level basal area and H_s is the seedling height (MacDonald 1991).

On a smaller subsample, seedling leader illumination was determined between 9:00 and 15:00 h EST on clear days. Readings of PPFD were taken with a Sunfleck Ceptometer (Decagon Devices Inc., Pullman, WA) at the base of the current year's terminal shoot of the largest black spruce seedling per seed spot while simultaneous unobstructed readings of PPFD were made in an adjacent clearing (LICOR Inc., Lincoln, NB, Model LI190SB Quantum Sensor attached to a Campbell Scientific Inc., Logan, UT, Model CR21X data logger). Leader illumination was calculated as leader PPFD/unobstructed PPFD.

Relationships between CSB, CI, and leader illumination and black spruce seedling growth were investigated using height increment, relative height growth rate, and relative height production rate. Two year (1991+1992) height increment was used as an integrated measure of current growth performance. Relative height growth rate (G_h) for 1991+1992 was calculated as (Hunt 1982):

$$G_h = \ln(H_2 / H_1) / (t_2 - t_1)$$

where H_2 and H_1 are the total seedling heights in year t_2 (1992) and t_1 (1990), respectively. Relative height production rate (P_h) for 1991+1992 was calculated as (Brand et al. 1987):

$$P_h = \ln(I_2 / I_1) / (t_2 - t_1)$$

where I_2 and I_1 are the height increments for times t_2 (1991+1992) and t_1 (1989+1990), respectively.

Data Analysis

Seedling establishment ratios (surviving seedlings/seed sown) were calculated for the different seeding years, seedbeds, and microsites for each block, and arcsine transformed (Zar 1984) before parametric analyses (analysis of variance [ANOVA]). Differences among individual treatments were identified using linear contrasts and Newman-Keuls multiple comparison test. The contribution of different factors to the variation in seedling establishment was determined by dividing the respective factor sum of squares by the total sum of squares, as determined by ANOVA.

Total heights, root collar diameters, and height increments of the largest seedling per seed spot were compared in each experiment using unbalanced two- and three-way ANOVA with seedbed, seeding year, Soil Moisture Regime, and microsite position as fixed-effect variables. In most cases, seedling height distributions were positively skewed and were first log-transformed to improve normality and homoscedasticity. Levene's test for equality of variances indicated very few significant departures ($p \leq 0.10$) from equality following data transformation. Significant differences among treatments were identified using linear contrasts and Newman-Keuls multiple comparison test.

Comparisons of seedling establishment and growth on different seedbed types were not planned at Goodlad Lake or Grew River, and sample sizes were often not large enough to permit such comparisons of seedbed over the full variable space (i.e., with seeding year, Soil Moisture Regime, and microsite position as covariates).

RESULTS

Seedling Establishment

Seedling establishment ratios at all locations were much higher on seedbeds near the mineral soil-humus interface,

such as thin-F and shallow-mineral, than on thick surface organic horizons such as thick-F and litter (Fig. 2). There was little seedling establishment on thick organic horizons at any of the sites, regardless of seeding year or Soil Moisture Regime. As a result, this report concentrates on results obtained on thin-F and shallow-mineral seedbeds. These are the two most commonly occurring receptive seedbed types on upland sites following scarification (Fleming et al. 1987).

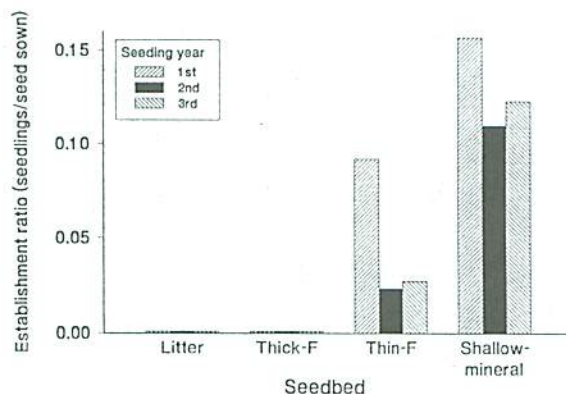


Figure 2. Mean black spruce seedling establishment ratios, by seedbed type, at Kearns Lake. Shown are values for the principal receptive (thin-F and shallow-mineral) and nonreceptive (thick-F and litter) seedbed types. Seeding was carried out in May of 1984, 1985, and 1986. Assessments were conducted in August 1992.

At all three experimental locations there were significant relationships between seedling establishment ratios, and both seeding year and Soil Moisture Regime (Tables 2–5). Better results ($p < 0.01$) at each location were obtained on plots with Moist Soil Moisture Regimes than on plots with Fresh Soil Moisture Regimes. At Goodlad Lake and Kearns Lake, seedling establishment was greater ($p \leq 0.10$) for the first seeding year than for subsequent seeding years. At Grew River, seedling establishment in the second seeding year was poorer ($p \leq 0.10$) than in either the first or third years. On average, Soil Moisture Regime and seeding year accounted for 33 and 17%, respectively, of the total variation in seedling establishment on receptive seedbeds at the three sites (cf. Tables 2 and 4).

At Goodlad Lake, microsite position was also a significant factor (Table 3), with greater ($p = 0.002$) seedling establishment occurring near the middle of the furrow than at the outside edges. When only seed spots on thin-F and shallow-mineral seedbeds were considered, however, neither microsite position nor seedbed type had a significant effect ($p > 0.10$) on seedling establishment. At Grew River, microsite position was not a significant factor ($p > 0.10$) influencing seedling establishment (Table 3).

Table 2. Analysis of variance of black spruce seedling establishment ratios at Goodlad Lake and Grew River, by seeding year, Soil Moisture Regime, and microsite position. Seeding was carried out in May of 1981, 1982, and 1983. Assessments were conducted in July 1992.

Source	df*	Sum of squares	F-ratio	p ⁺
Goodlad Lake				
Seeding year (SY)	2	1,190.2	31.30	0.000
Soil Moisture Regime (SMR)	1	1,094.0	57.54	0.000
SY x SMR	2	75.5	1.99	0.149
Microsite (MS)	4	213.6	2.81	0.037
SY x MS	4	82.3	0.54	0.819
SMR x MS	4	50.9	0.67	0.617
SY x SMR x MS	8	71.9	0.47	0.869
Error	45	855.6		
Grew River				
Seeding year (SY)	2	673.8	4.42	0.018
Soil Moisture Regime (SMR)	1	1,205.0	15.81	0.000
SY x SMR	2	80.3	1.05	0.357
Microsite (MS)	4	186.0	0.61	0.657
SY x MS	4	52.0	0.09	0.999
SMR x MS	4	5.5	0.02	0.999
SY x SMR x MS	8	79.7	0.13	0.998
Error	45	3,428.8		

*df = degrees of freedom.

⁺p = probability.

Table 3. Mean seedling establishment ratios at Goodlad Lake and Grew River, by seeding year, Soil Moisture Regime, and microsite position. Seeding was carried out in May of 1981, 1982, and 1983. Assessments were conducted in July 1992. There is no significant difference ($p > 0.10$) between values with the same lower case letter in any given row.

	Seedling establishment (surviving seedlings/viable seed sown)				
	Seeding year				
	1	2	3		
Goodlad Lake	0.067 ^a	0.025 ^b	0.010 ^c		
Grew River	0.134 ^a	0.073 ^b	0.117 ^a		
	Soil Moisture Regime				
	Fresh	Moist			
Goodlad Lake	0.011 ^b	0.057 ^a			
Grew River	0.074 ^b	0.142 ^a			
	Microsite position				
	1	2	3	4	5
Goodlad Lake	0.022 ^b	0.038 ^a	0.041 ^a	0.045 ^a	0.022 ^b
Grew River	0.105 ^a	0.097 ^a	0.125 ^a	0.129 ^a	0.084 ^a

At Kearns Lake, seedling establishment was better in all 3 years on shallow-mineral seedbeds than on thin-F seedbeds ($p < 0.001$). Seedling establishment was also consistently better on Moist plots than on Fresh plots (Table 5).

There were no significant interactions ($p > 0.10$) between seeding year, Soil Moisture Regime, microsite position (Goodlad Lake and Grew River), or receptive seedbed type (Kearns Lake) at any site.

Table 4. Analysis of variance of black spruce seedling establishment ratios at Kearns Lake, by seeding year, Soil Moisture Regime, and seedbed. Only data for the two principal receptive seedbed types, thin-F and shallow-mineral, are included. Seeding was carried out in May of 1984, 1985, and 1986. Assessments were conducted in August 1992.

Source	df*	Sum of squares	F-ratio	p ⁺
Seeding year (SY)	2	185.2	5.47	0.014
Soil Moisture Regime (SMR)	1	1,253.1	74.02	0.000
SY x SMR	2	64.0	1.89	0.180
Seedbed (SB)	1	621.8	36.73	0.000
SY x SB	2	38.7	1.14	0.341
SMR x SB	1	3.1	0.18	0.673
SY x SMR x SB	2	4.6	0.14	0.874
Error	18	304.7		

*df = degrees of freedom.

⁺p = probability.

Table 5. Mean seedling establishment ratios at Kearns Lake, by Soil Moisture Regime and receptive seedbed type. Seeding was carried out in May of 1984, 1985, and 1986. Assessments were conducted in August 1992. There is no significant difference ($p > 0.10$) between values with the same lower case letter in any given row.

Seeding year	Seedbed	
	Thin-F	Shallow-mineral
1984	0.073 ^b	0.137 ^a
1985	0.018 ^b	0.099 ^a
1986	0.020 ^b	0.110 ^a
Seeding year	Soil Moisture Regime	
	Fresh	Moist
1984	0.030 ^b	0.212 ^a
1985	0.018 ^b	0.099 ^a
1986	0.020 ^b	0.112 ^a

Seedling Growth

Total Height

Height distributions for most seedlings were positively skewed and showed substantial size inequality among individual seedlings. For instance, the median height values for the 1981 Grew River seedlings were 67 and 73 cm on the Fresh and Moist Soil Moisture Regimes, respectively; the 10th percentile values were 22 and 25 cm, respectively; and the 90th percentile values were 165 and 138 cm, respectively (Fig. 3).

At each study location, seedlings from the first seeding year were substantially taller ($p \leq 0.10$) at an equivalent age (10 years at Goodlad Lake and Grew River, and 7 years at Kearns Lake) than those from the second or third seeding year (Fig. 4). At Goodlad Lake and Grew River, seedling heights for the second seeding year were also larger ($p \leq 0.10$) than those for the third seeding year at the age of 10.

At Grew River, seedlings were significantly taller ($p = 0.001$) at the age of 10 on thin-F than on shallow-mineral seedbeds, but were of similar height on Fresh and Moist Soil Moisture Regimes. At Goodlad Lake, sample sizes (i.e., number of surviving seedlings) were too small to permit full comparisons of seedling height as a function of seedbed, seeding year, and Soil Moisture Regime. On Moist Soil Moisture Regimes, however, receptive seedbed type had no significant effect ($p = 0.783$) on seedling height after 10 years. At Kearns Lake, neither Soil Moisture Regime nor receptive seedbed type (thin-F versus shallow-mineral) had a significant effect ($p > 0.10$) on total seedling height after 7 years.

Height comparisons among 9-year-old seedlings at the three locations and on the two Soil Moisture Regimes for the first seeding year revealed no significant differences between Soil Moisture Regimes ($p = 0.939$), but showed substantial differences ($p = 0.003$) among locations (Fig. 5). The best growth was obtained at Kearns Lake, while the poorest growth was at Grew River. There was also a significant interaction between location and Soil Moisture Regime. At Kearns Lake, height growth was greater on Fresh than on Moist Soil Moisture Regimes; the opposite situation occurred at Goodlad Lake. When all 3 seeding years were compared for Moist Soil Moisture

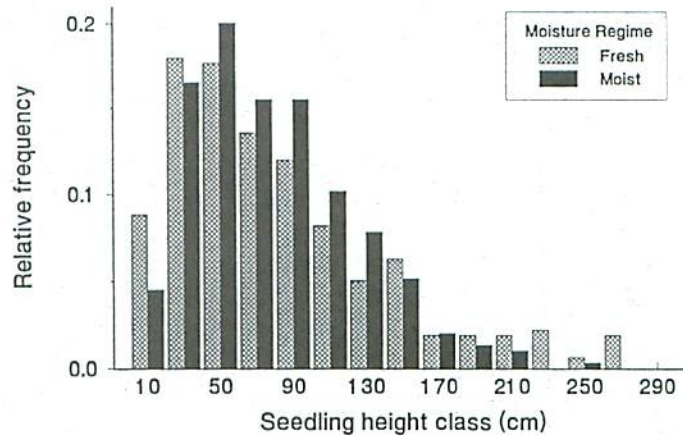


Figure 3. Relative frequency distribution of black spruce seedling heights at Grew River, by Soil Moisture Regime, 12 growing seasons after seeding.

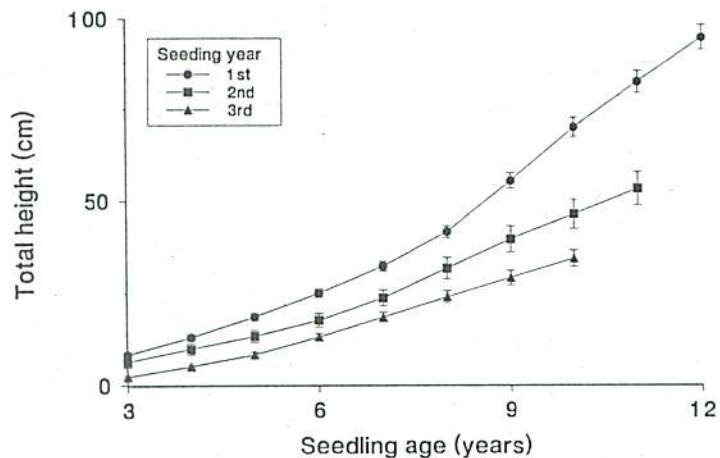


Figure 4. Mean black spruce seedling height as a function of seedling age, for seedlings originating from the first, second, and third year of seeding at Grew River B. Also shown are \pm one standard error about the mean.

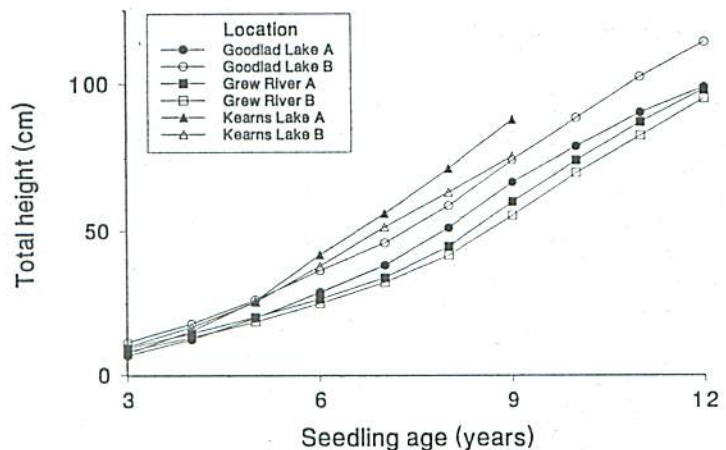


Figure 5. Mean black spruce seedling height as a function of seedling age and Soil Moisture Regime, for seedlings originating from the first seeding at Goodlad Lake, Grew River, and Kearns Lake.

Regimes, seedlings were tallest after 7 years ($p \leq 0.10$) at Kearns Lake and shortest at Grew River (Table 6). They were also taller for the first seeding than for subsequent seedings.

Microsite position had no significant effect ($p = 0.788$) on total seedling height on Moist Soil Moisture Regimes at Grew River and Goodlad Lake 12 years after seeding (Table 7). Seedlings were taller, however, on thin-F seedbeds than on shallow-mineral seedbeds and there was a significant interaction ($p = 0.045$) between location and microsite position. At Goodlad Lake, but not Grew River, seedlings near the middle of the furrows (microsite positions 2, 3, and 4 [Fig. 1]) were taller ($p = 0.086$) than those near the edges of the furrows (microsite positions 1 and 5). Separate analysis of the 1981 Grew River data set for both Fresh and Moist Soil Moisture Regimes revealed no significant effect of Soil Moisture Regime on seedling height ($p = 0.33$), or interaction ($p = 0.53$) between Soil Moisture Regime and seedbed or microsite position.

Current Annual Height Increment

Mean CAHI at Goodlad Lake and Grew River peaked between the ages of 7 and 9 on both Fresh and Moist Soil Moisture Regimes in all 3 seeding years (Fig. 6–7). Soil Moisture Regime had no consistent effect on CAHI, but

Table 6. Analysis of variance of black spruce seedling height 7 years after seeding, by seeding year and location. Data pertain only to Moist Soil Moisture Regimes. Seeding was carried out in May of 1981, 1982, and 1983 (Goodlad Lake and Grew River) or May of 1984, 1985, and 1986 (Kearns Lake). Assessments were conducted in the summer of 1992. There is no significant difference ($p > 0.10$) between values with the same lower case letter in any given row.

Source	df*	Sum of squares	F-ratio	p ⁺
Location	2	1237.3	23.42	0.000
Seeding year (SY)	2	1337.5	25.34	0.000
Location x SY	4	213.6	2.02	0.143
Error	15	396.3		

Total height (cm) after 7 years			
Location			
Goodlad Lake	Grew River	Kearns Lake	
28.9 ^b	21.9 ^c	39.8 ^a	

Seeding year			
One	Two	Three	
40.8 ^a	26.6 ^b	23.2 ^b	

*df = degrees of freedom.

⁺p = probability.

Table 7. Mean black spruce seedling height and root collar cross-sectional area 12 years after seeding at Goodlad Lake and Grew River, by microsite position, receptive seedbed type, and location. Data pertain only to Moist Soil Moisture Regimes. Assessments were conducted in August 1992. There is no significant difference ($p > 0.10$) between values with the same lower case letter in any given row.

	Microsite position		
	Furrow edge	Mid-furrow	Centre furrow
Total height (cm)	98.1 ^a	102.2 ^a	102.0 ^a
Root collar basal area (cm ²)	1.67 ^a	1.88 ^a	2.00 ^a

	Seedbed	
	Thin-F	Shallow-mineral
Total height (cm)	109.0 ^a	92.6 ^b
Root collar basal area (cm ²)	2.00 ^a	1.71 ^b

	Location	
	Goodlad Lake	Grew River
Total height (cm)	107.1 ^a	94.5 ^b
Root collar cross-sectional area (cm ²)	1.76 ^a	1.95 ^a

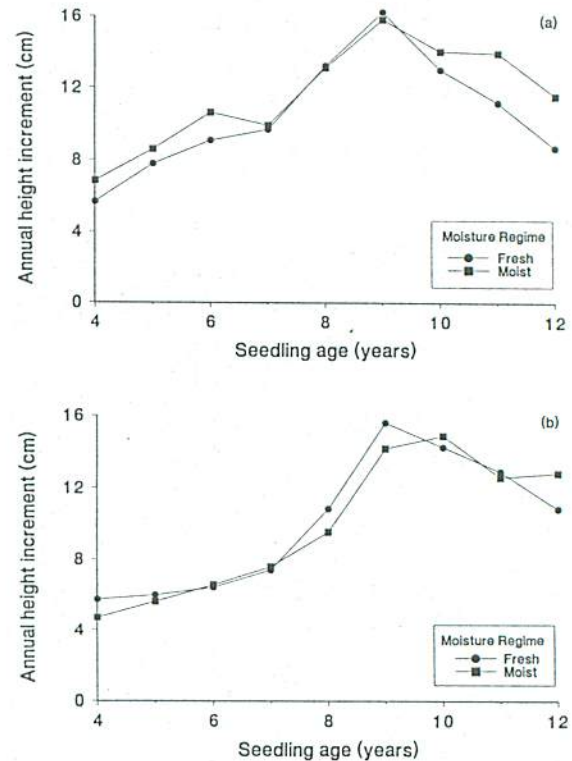


Figure 6. Mean black spruce annual height increment, by Soil Moisture Regime, for seedlings originating from the first seeding at: (a) Goodlad Lake and (b) Grew River.

CAHI was larger, usually peaked later, and showed greater subsequent declines for earlier seeding years than for later seeding years at a given location (Fig. 7).

Trends in CAHI at Kearns Lake were similar to those at Goodlad Lake and Grew River. However, there was slightly greater CAHI in later years on the Fresh than on the Moist Soil Moisture Regimes for each seeding year (Fig. 8).

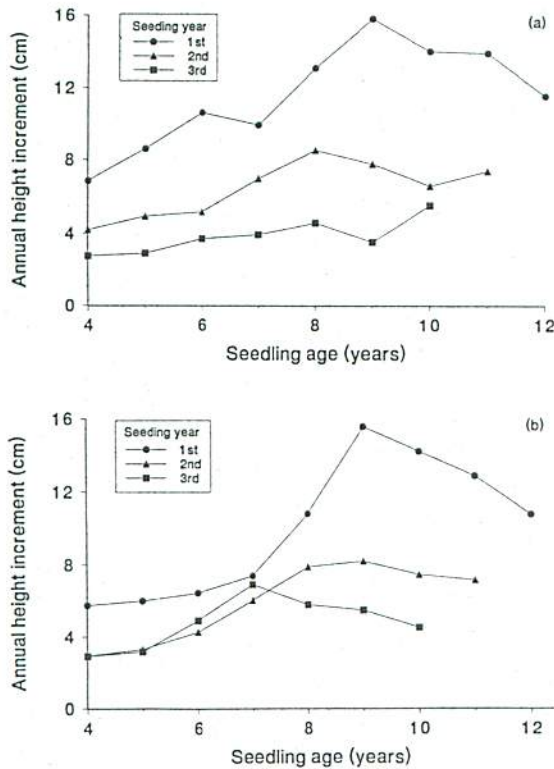


Figure 7. Mean black spruce annual height increment for 3 consecutive seeding years at (a) Goodlad Lake B and (b) Grew River A.

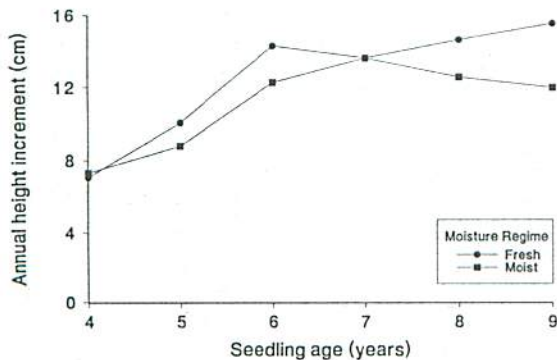


Figure 8. Mean black spruce annual height increment, by Soil Moisture Regime, for seedlings originating from the first seeding at Kearns Lake.

Ground Level Cross-sectional Area

Ground level cross-sectional area (GLCSA = $GLSD \pi/4$) was more variable and showed fewer significant treatment effects than seedling height. There were no significant effects ($p > 0.10$) of Soil Moisture Regime, location, or microsite position on GLCSA at the age of 12 at Grew River and Goodlad Lake. However, GLCSA was greater ($p = 0.083$) on thin-F than shallow-mineral seedbeds at these sites (Table 7). There was little difference ($p > 0.10$) in GLCSA on thin-F versus shallow-mineral seedbeds or on Fresh versus Moist Soil Moisture Regimes at Kearns Lake after 9 years.

Growth of Competitors

Many woody competitors, including jack pine (*Pinus banksiana* Lamb.), trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), pin cherry (*Prunus pensylvanica* L.f.), alder (*Alnus* spp.), and willow (*Salix* spp.), invaded the experimental areas shortly after scarification. Most jack pine originated from seed-bearing cones in logging slash. The aspen and birch primarily seeded in from residual trees.

By 1992, dominant individuals of these species were substantially taller ($p < 0.01$) at each location than were the tallest black spruce per seed spot. At Goodlad Lake and Grew River, mean heights of dominant jack pine and trembling aspen were 1.5 to 3.0 m taller than the black spruce 12 years after seeding (Fig. 9–10). At Kearns Lake, mean heights of dominant white birch, willow, and pin cherry exceeded that of the black spruce by > 0.7 m 9 years after seeding (Fig. 11).

At Grew River, dominant jack pine and trembling aspen were substantially taller ($p = 0.002$) on Fresh than on Moist Soil Moisture Regimes in 1992 (Fig. 10). In contrast, Soil

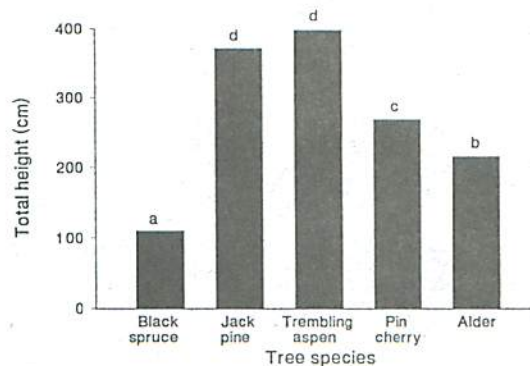


Figure 9. Mean heights of dominant competitors and 1981 seeded black spruce at Goodlad Lake in 1992, 13 growing seasons after harvesting and site preparation. There is no significant difference ($p > 0.10$) between bars with the same lower case letter above them.

Moisture Regime had no significant effect ($p>0.10$) on the mean height of dominant competitors at either Goodlad Lake or Kearns Lake at this time.

Competition Indices

Although inverse curvilinear relationships between seedling height increment and CI were obtained (Fig. 12), there was little relationship between G_h or P_h and CI (Fig. 13); or between height increment, G_h or P_h and CSB. There was also little relationship between seedling size (total height, diameter, and stem volume) and CSV (Fig. 14). There was a direct curvilinear relationship between seedling height increment and seedling stem volume (Fig. 15), but no apparent relationship between G_h or P_h and seedling stem volume.

Although there were no consistent relationships between black spruce seedling size (total height, diameter, or stem

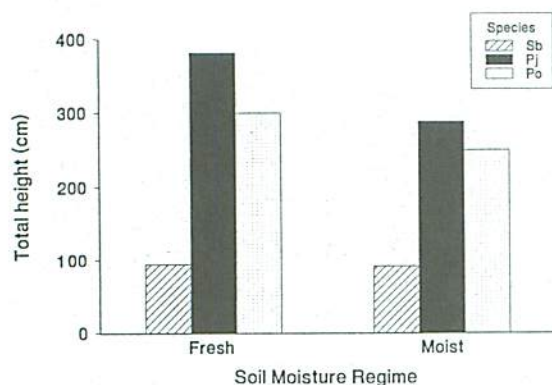


Figure 10. Mean heights of dominant jack pine (Pj), trembling aspen (Po), and 1981 seeded black spruce (Sb) at Grew River in 1992, 13 growing seasons after harvesting and site preparation. Values are shown separately for Fresh and Moist Soil Moisture Regimes.

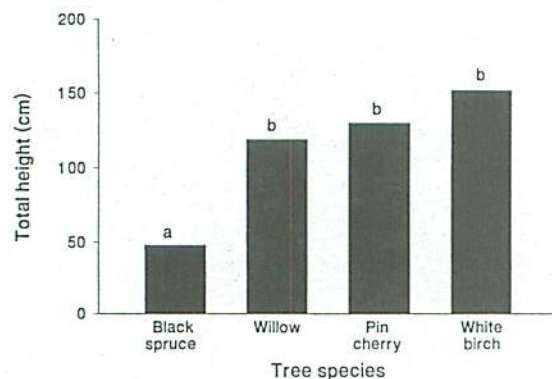


Figure 11. Mean heights of dominant competitors and 1984 seeded black spruce at Kearns Lake in 1992, 10 growing seasons after harvesting and site preparation. There is no significant difference ($p>0.10$) between bars with the same letter above them.

volume) and leader illumination (incident PPFD/above canopy PPFD), the taller trees usually had leader illumination levels exceeding 0.7 (Fig. 16a). Likewise, larger 1991+1992 height increments were usually associated with leader illuminations levels > 0.7 (Fig. 16b). However, there were no strong relationships between leader illumination and either 1991+1992 G_h ($r^2 = 0.204$) or P_h ($r^2 = 0.019$) (Fig. 16c).

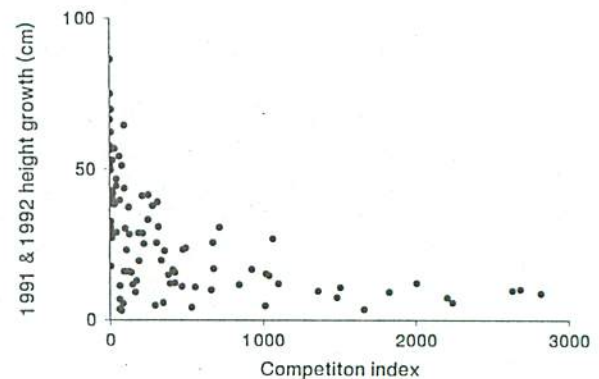


Figure 12. Relationship between competition index and black spruce 1991+1992 height increment, for the 1981 seeding at Grew River.

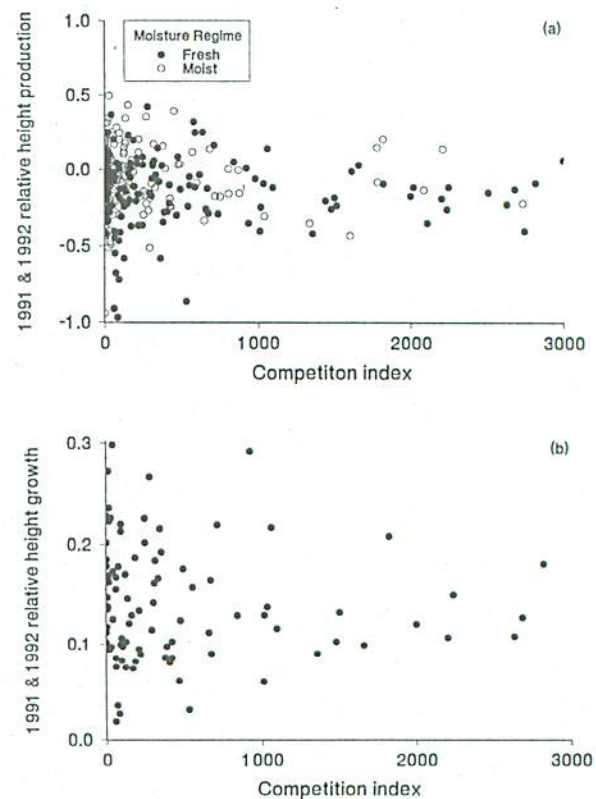


Figure 13. Relationship between competition index and black spruce height growth for the 1981 seeding at Grew River, using: (a) 1991+1992 relative height growth rate, and (b) 1991+1992 relative height production rate.

DISCUSSION

Both these experiments and complimentary research on a broader range of site types in this area (Fleming and Mossa 1994) highlight the importance of Soil Moisture Regime, as well as seedbed, to black spruce seedling success. Given appropriate site preparation (i.e., adequate exposure of thin-F, thin-H, or shallow-mineral seedbeds), better black spruce seedling establishment on coarse-textured soils can be expected on Moderately Moist to Moist than on Moderately Fresh to Fresh Soil Moisture Regimes. Successful seeding of Fresh Soil Moisture Regimes will require higher seeding rates and/or exposure of greater quantities of receptive seedbed. On Dry to Moderately Fresh Soil Moisture Regimes on deep soils in this region, direct seeding black spruce is unlikely to result in adequately stocked stands, regardless of site preparation or commonly used seeding regimes (Fleming and Mossa 1994). These results and observations are consistent with those of Chrosiewicz (1990) for jack pine, although the latter species is less demanding in terms of seedbed moisture availability (LeBarron 1944, Thomas and Wein 1985).

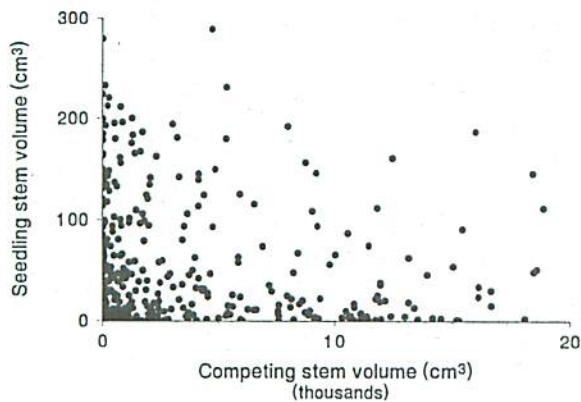


Figure 14. Relationship between competing stem volume and black spruce seedling stem volume, for the 1981 seeding at Grew River.

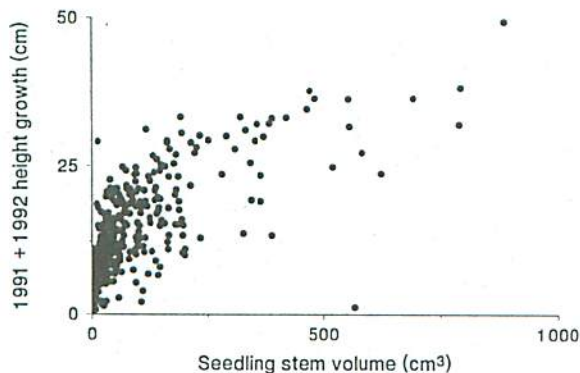


Figure 15. Relationship between black spruce stem volume and 1991+1992 black spruce height increment, for the 1981 seeding at Grew River.

Receptive seedbed type (thin-F versus shallow-mineral) and microsite position had less effect on black spruce seedling establishment and growth than did Soil Moisture Regime and seeding year. As Soil Moisture Regime increases (i.e., soil water supply increases), the most receptive black spruce seedbeds are found higher in the soil profile (Fleming and Mossa 1994). In these studies, seedling establishment was often better on shallow-mineral than on thin-F seedbeds, but seedling growth was as good or better on thin-F than on shallow-mineral seedbeds.

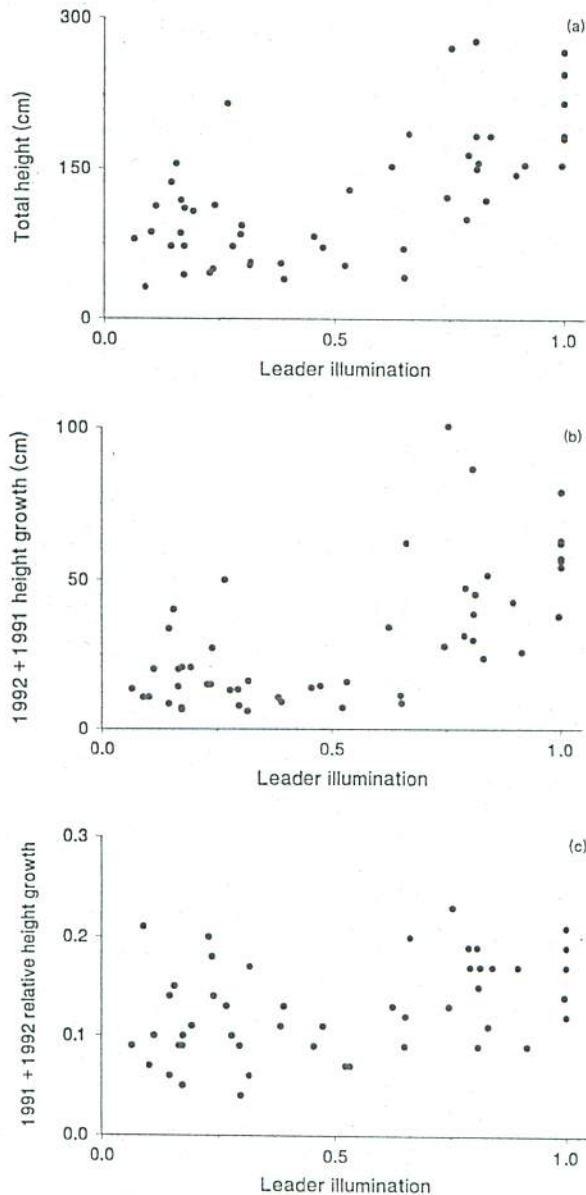


Figure 16. Relationship between leader illumination (incident PPFD at the base of the current year's leader/above canopy PPFD) and (a) black spruce total height, (b) 1991+1992 black spruce height increment, and (c) 1991+1992 black spruce relative height growth rate, for the 1981 seeding at Goodlad Lake.

Seedling establishment, and in most cases seedling growth, was similar among different microsite positions across scarified furrows once seedbed type was accounted for. Instances where seedling growth was greater in the middle than near the edges of the furrows are attributed to reduced competition. While these results suggest that the creation of 2- to 3-m-wide, continuous furrows is an acceptable way of achieving greater receptive seedbed coverage, removal of all surface organic horizons from large, contiguous areas may reduce long-term stand productivity on more nutrient-poor sites (Foster and Morrison 1987). For instance, Nyland et al. (1979) reported greater Norway spruce (*Picea abies* [L.] Karst) growth and foliar N and P 9 years after seeding for seedlings within 2 m of the edge of 10-m-wide scalped strips than for seedlings near the centre of the scalped strips.

In this study, it took seeded stands at least 10–12 years to reach mean heights of 1 m. This is consistent with results from natural regeneration in both fire-origin stands (Morin and Gagnon 1992) and following harvesting (Jarvis and Cayford 1967). In contrast, planted and tended black spruce may attain total heights of 1.3–2.0 m 10 years after planting (Mullin 1978, Scarratt and Wood 1988, Wood 1990).

The early peak and subsequent decline in black spruce CAHI 7–9 years after seeding is atypical for this species. For instance, Lussier et al. (1992) reported that black spruce CAHI in fire-origin stands peaked between the ages of 20 and 25, while Mullin (1978) found the CAHI of bare-root stock often peaked between 10 and 15 years. Undoubtedly, tending of these developing stands 3–5 years after seeding would have improved seedling growth rates and resulted in a longer period of increasing CAHI.

In these and other trials (Fleming and Mossa 1995), seeding within a year of scarification often resulted in the highest rates of seedling establishment and produced the most rapid black spruce seedling growth. Seedling establishment on thin organic and shallow-mineral seedbeds is usually better while these surfaces remain loose and friable than once they develop surface crusts and are colonized by lichens. Comparisons are needed of seeding immediately after scarification with results from seeding the spring following summer scarification, as was done here. Brown (1973) and Rudolph (1973) have suggested that soil settling and slumping would reduce seedling establishment if seeds were sown immediately after scarification. Soil compaction during scarification, however, may circumvent this problem (Van Damme 1988).

The consistently greater total height at an equivalent age and later peak in CAHI for seedlings from the first seeding, compared to seedlings from later seeding, is attributed to competition. Ten years after scarification some competing

species were more than 1 m taller than the spruce, and often completely overtopped them. Seeding within 1 year of site preparation permitted seedlings to compete more effectively than did seeding in later years. To obtain free-to-grow status and permit maximum black spruce growth on these and similar sites, tending is required.

Positively skewed tree height–frequency distributions are commonly observed in developing forests, including naturally regenerated black spruce stands (Newton 1990). In this study, large size inequalities and positively skewed seedling size hierarchies developed among seedlings established at the same time, on the same morphologic seedbed types, and on the same Soil Moisture Regimes.

With both direct seeding and seed-dependent natural regeneration, there is concern that regenerating stands that are adequately stocked may be overly dense, thereby lengthening rotation periods (Fraser 1981a, Jeglum 1987). The results reported here attest to the development of a small but important portion of the seedling population that is of considerably greater size than average. This suggests there is sufficient variation in growth that individual trees will express early dominance and that stagnation through interspecific competition will not occur. Of greater concern is black spruce growth suppression and eventual mortality from competition with other woody species.

In this study there was little relation between cumulative stem volumes of the largest competitors per quadrant within a 2-m radius (MacDonald 1991) and black spruce seedling growth. Attempts to establish such relationships may be confounded by several factors: competition for resources such as soil nutrients and moisture, or effects of soil temperature (Brand and Janas 1988) not related to competitor size; positive relationships between both seedling and competitor growth and microsite suitability; the relative insensitivity of total height or current height increment to competition for light (Morris et al. 1990, MacDonald and Weetman 1993); and difficulty in deriving an appropriate measure of competition by surrounding vegetation.

The inverse curvilinear relationship between height increment and CI (Fig. 12) may be largely an artifact of the positive curvilinear relationship between height increment and seedling stem volume (Fig. 15). As noted by Brand (1986), a dependent variable of absolute growth will necessarily be reflected in (i.e., not independent of) an independent variable based on relative measures of crop-tree/competitor size.

CONCLUSIONS

The following conclusions pertain to direct seeding black spruce on upland, coarse-textured soils in northwestern Ontario.

- 1) Successful direct seeding of black spruce requires adequate quantities of receptive seedbed, which is primarily located just above and below the mineral soil-humus interface. Little establishment can be expected on thick surface organic horizons. In these trials, seedling establishment was often better on shallow-mineral than on thin-F seedbeds, but seedling growth was as good or better on thin-F than on shallow-mineral seedbeds.
- 2) Better seedling establishment can usually be expected on sites with Moderately Moist to Moist Soil Moisture Regimes than on sites with Moderately Fresh to Fresh Soil Moisture Regimes.
- 3) Seeding within a year of scarification resulted in greater seedling establishment and growth than did seeding 2 or 3 years after scarification.
- 4) Microsite position across 2.5-m-wide scarified furrows had no consistent effect, independent of receptive seedbed type, on seedling establishment or growth.
- 5) Black spruce seedling growth is slow and common woody competitors will grow much more rapidly. Twelve years after seeding, mean black spruce seedling heights ranged from 90 to 110 cm. In comparison, mean heights of dominant competing jack pine and trembling aspen of similar age ranged from 250 to 400 cm.
- 6) Tending of seeded stands is recommended within 3 to 5 years of establishment to prevent growth reductions from competition with faster growing, woody species.
- 7) There appears to be sufficient variation in growth rates among individual black spruce that dense, regenerating stands will not stagnate from interspecific competition.

The results of these and similar trials support Fraser's (1981b) conjecture that the poor record of success with direct seeding black spruce can largely be attributed to: (a) poor site selection, (b) inadequate seedbed preparation, and (c) inappropriate seeding regimes. In many instances, direct seeding was employed as a last resort on sites which, for operational or biological reasons, could not be regenerated by more conventional means. Such attempts were often doomed to failure because of the constraints mentioned above. Seeding is biologically a more difficult and demanding method of regeneration than is planting, and requires strict attention to site selection and careful site preparation. When such conditions are met, however, direct seeding affords a reasonably reliable, low cost method of successfully establishing black spruce (Fleming and Mossa 1989). Black spruce direct seeding on upland sites in this region should be concentrated on Very Fresh to Moist, fine sandy and coarse loamy sites that have been specifically site prepared to provide adequate quantities of receptive seedbed for this species.

Growth of seeded black spruce is slow, and seedlings are quickly overtopped by other species such as jack pine, trembling aspen, and white birch. On most upland sites, tending will be necessary if seeded black spruce are to attain free-to-grow status within 10 to 15 years.

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APPENDIX I: Commonly Occurring Upland Black Spruce Seedbed Types

Commonly occurring upland black spruce seedbed types, defined in terms of morphology, thickness, and location (Ontario Institute of Pedology 1985, Sims et al. 1989).

Seedbed type	Definition	Vertical distance from mineral soil/humus interface
Litter	under composed organic matter (L-horizon)	≥5 cm above interface
Thick-F	partially decomposed organic matter (F-horizon)	≥5 cm above interface
Thin-F	partially decomposed organic matter (F-horizon)	<5 cm above interface
Thin-H	well-decomposed organic matter (H, H _i horizons)	<5 cm above interface
Shallow-mineral	B mineral soil horizons	<10 cm below interface
Deep-mineral	B, C mineral soil horizons	≥10 cm below interface