9575

Silvicultural Treatments for Black Spruce Establishment in Boreal Ontario: Effects of Weed Control, Stock Type, and Planting Season

J.E. Wood[1] and E.G. Mitchell

Natural Resources Canada
Canadian Forest Service–Sault Ste. Marie
Sault Ste. Marie, Ontario

Telephone (705) 949-9461
FAX (705) 759-5700
E-mail JWOOD@FCOR.GLFC.FORESTRY.CA

1995

[1] Author to whom correspondence should be addressed.

NODA • EDNO
CANADA
ONTARIO
Northern Ontario Development Agreement
Entente de développement du nord de l'Ontario
Forestry • Foresterie

Funding for this report has been provided through the Northern Ontario Development Agreement's Northern Forestry Program.

Canadian Cataloguing in Publication Data

The National Library of Canada has catalogued this publication as follows:

Wood, J.E.

Silvicultural treatments for black spruce
establishment in boreal Ontario : Effects of
weed control, stock type, and planting season

(NODA/NFP Technical report ; TR-10)
"Funding for this report has been provided through
the Northern Ontario Development Northern Forestry Program."
Includes an abstract in French.
Includes bibliographical references.
ISBN 0-662-23575-4
Cat. no. Fo29-42/10-1995E

1. Black spruce—Ontario—Growth.
2. Trees—Ontario—Growth.
3. Forest management—Ontario.
I. Mitchell, E.G.
II. Great Lakes Forestry Centre.
III. Title.
IV. Series: NODA/NFP technical report ; TR-10
SD397.B53W66 1995 634.9'75256'0971312 C95-98021419

Catalogue No. Fo29-42/10-1995
ISBN 0-662-23575-4
ISSN 1195-2334

Copies of this publication are available at no charge from:
Publications Services
Natural Resources Canada
Canadian Forest Service–Sault Ste. Marie
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Microfiche copies of this publication may be purchased from:
Micro Media Inc.
Place du Portage
165, Hotel-de-Ville
Hull, Quebec J8X 3X2

Wood, J.E.; Mitchell, E.G. 1995. Silvicultural treatments for black spruce establishment in boreal Ontario: Effects of weed control, stock type, and planting season. Nat. Resour. Can., Canadian Forest Service–Sault Ste. Marie, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. TR-10. 19 p. + appendices

ABSTRACT

Four field experiments were carried out to assess the performance of black spruce (*Picea mariana* [Mill.] B. S. P.) outplants in relation to: weed control (i.e., with vs. without), stock type (i.e., bareroot vs. paperpot), and planting season (i.e., spring vs. summer). In one experiment, planting position (i.e., centre vs. side) within the mechanically site-prepared corridors was evaluated. In total, 1 800 seedlings were planted in each of the four experiments. These were then assessed after five and 11 growing seasons in the field. All experiments are located in northeastern Ontario in the Boreal Forest Region. Three of the four experiments are on upland, mixedwood, herb-rich sites; the fourth experiment is on a feathermoss–*Sphagnum* site type. Total height of black spruce outplants was not significantly improved by weed control 2 to 4 years after treatment. However, 8 to 10 years after release, weed control significantly improved black spruce height growth. Stem diameter was also greatly improved by weed control 2 to 4 and 8 to 10 years after treatment. The benefits of weed control increased over the experimental period and its effects on controlling deciduous trees and brushy plant species was still evident 8 to 10 years after treatment. The application of herbicides in narrow bands over the top of crop trees was shown to be a silviculturally effective alternative to conventional broadcast herbicide applications. Eleven growing seasons after outplanting, on three of the four experimental sites, bareroot stock remained significantly taller and exhibited larger stem diameters than did paperpot stock. However, the relative differences in size between the two stock types tended to decrease over the experimental period. In two of the four experimental plantings, current annual height increment of the bareroot stock was significantly greater than paperpot stock 11 growing seasons after outplanting. In general, the initial size advantage of the spring-planted compared to the summer-planted seedlings was maintained. Planting position within the site-prepared corridors was found to have a significant effect upon crop tree performance. Trees planted in the center of the 5- to 6-m-wide east–west oriented corridors were superior to those planted on either the north side or south side of the corridor. In addition, trees planted along the more exposed north side of the corridor were significantly larger than those planted along the more heavily shaded south side.

RÉSUMÉ

Les auteurs ont mené 4 essais sur le terrain afin d'évaluer la performance des plants d'épinette noire (*Picea mariana* [Mill.] B.S.P.) au regard du désherbage (avec ou sans désherbage), du type de semis (à racines nues ou en paperpot) et de la saison de plantation (printemps ou été). Dans le cadre d'une de leurs expériences, ils ont évalué la position de plantation (centrale ou latérale) dans les couloirs où le terrain avait été préparé mécaniquement. Au total, 1 800 semis ont été plantés dans chaque parcelle. Ils ont ensuite été évalués après 5 et 11 saisons de végétation. Les parcelles sont toutes situées dans le nord-est de l'Ontario, dans la région forestière boréale. 3 d'entre elles occupent des stations sèches dans un secteur de forêt mixte où poussent de nombreuses plantes herbacées et la quatrième, une station à hypnacées et à *Sphagnum*. 2 à 4 ans après le désherbage, celui-ci n'avait pas fait augmenté beaucoup la hauteur des plants d'épinette noire. Cependant, 8 à 10 ans après ce traitement, les résultats étaient très supérieurs. Ce dégagement avait également beaucoup amélioré le diamètre des tiges 2 à 4 ans et 8 à 10 ans plus tard. Les avantages procurés par le désherbage ont augmenté pendant la période des essais, et les effets de la suppression de feuillus et d'espèces végétales broussailleuses étaient encore visibles 8 à 10 ans après. Le traitement en bandes latérales étroites des arbres d'avenir s'est révélé une méthode sylvicole efficace de rechange à l'application en plein d'herbicide. 11 saisons de végétation après leur transplantation, les plants à racines nues de 3 des 4 parcelles expérimentales étaient encore beaucoup plus grands et d'un plus fort diamètre que les plants en paperpot. Toutefois, la différence relative de dimensions entre les 2 types de matériel avait tendance à s'amenuiser avec les années. 11 saisons de végétation après la transplantation, l'accroissement moyen annuel en hauteur des plants à racines nues était très supérieur à celui de plants en paperpot dans 2 des 4 parcelles expérimentales. En règle générale, les semis mis en terre au printemps, en raison de leur taille, jouissaient d'un avantage par rapport à ceux plantés en été, avantage qu'ils ont conservé. La position de plantation dans les couloirs où le terrain avait été préparé avait un effet significatif sur la performance des arbres d'avenir. Les arbres plantés au centre des couloirs de 5 à 6 m de largeur orientés dans l'axe est-ouest se sont mieux développés que ceux mis en terre du côté nord ou sud. De plus, les arbres plantés le long de l'extrémité nord, plus exposée, du couloir étaient beaucoup plus gros que ceux poussant à l'extrémité sud, dans un milieu plus ombragé.

TABLE OF CONTENTS

(cont'd)

TABLE OF CONTENTS (concl.)

SILVICULTURAL TREATMENTS FOR BLACK SPRUCE ESTABLISHMENT IN BOREAL ONTARIO: EFFECTS OF WEED CONTROL, STOCK TYPE, AND PLANTING SEASON

INTRODUCTION

On most cutover sites in boreal Ontario, vegetation management is necessary for the successful regeneration of spruce (*Picea* spp.) and jack pine (*Pinus banksiana* Lamb.) stands (Hearnden et al. 1992). One of the more difficult site types to regenerate in the boreal forest is that of upland black spruce (Weetman 1989). This type, together with white spruce (*Picea glauca* [Moench] Voss) mixedwoods and the pure white spruce types in western Canada, comprises a very large portion of Canada's failed cutovers, or of cutovers converted from conifers to hardwoods and even to grass. Honer et al. (1991) estimated that nationally about 474 000 ha of forest land go out of production annually because of inadequate restocking to commercial tree species.

The interest in vegetation management in the province of Ontario has increased dramatically since the mid-1980s. In part, this heightened interest is the result of a rapid and steady expansion of the provincial planting program from about 50 million trees in the mid-1970s to 171 million trees in 1988. The forestry community has also recognized that competition for site resources is a constraint to conifer establishment (Burton 1993) and, as a result, there has been a rapid increase in the number of hectares treated in the province. For example, the area chemically tended has increased from 30 100 to 93 800 ha in the 9-year period from 1980/81 to 1989/90 (Deloitte and Touche 1992).

McDonald and Fiddler (1993) reported that in most instances forests cannot be managed economically without the use of herbicides if the goal is to grow trees at the potential of the site, and if the plant community includes sprouting hardwoods, shrubs, and other rhizomatous plants. However, throughout North America public and political pressure is increasing to reduce the amount of herbicide being used in the forest. This pressure has also served to focus a great deal of attention, and consequently research activities, on forest vegetation management practices.

Numerous authors (e.g., Scarratt 1982, Ball and Kolabinski 1986, Nelson 1990, Newton et al. 1993, South and Mason 1993) have reported upon the benefits of planting large seedlings, which are capable of rapid early growth after outplanting on fertile competition-prone sites. Increasing restrictions on the use of herbicides for forestry and the limited number of economically viable alternatives has provided an incentive to develop more competitive seedlings as a possible means of reducing long-term tending requirements (Newton et al. 1993, South and Mason 1993). It is, however, unlikely that the planting of larger, rapidly growing seedlings will alone eliminate the need for follow-up weed control on all boreal sites.

Hearnden et al. (1992) stated a need for effective, economic, and environmentally and socially tolerable tending methods to ensure that commercially important conifers are maintained as dominant ecosystems in the boreal forest region. In addition, these authors stressed the importance of examining the effectiveness and impact of silvicultural treatments to establish future research directions and silvicultural practice. To assess the silvicultural impact of treatments used in the establishment of black spruce plantations, the Canadian Forest Service in 1982 initiated a series of comparative planting trials located in the townships of Kenogaming, Lamplugh, Bragg, and Kenning (Fig. 1). The silvicultural treatments included: postplanting weed control, stock type (container stock and bareroot stock), and planting season (spring and summer). This report summarizes the 5th- and 11th-year assessment data.

METHODS AND MATERIALS

Site and Site Preparation

All four experiments are located in northeastern Ontario in the Northern Clay or Missinaibi-Cabonga Forest Sections of the Boreal Forest Region (Rowe 1972). Table 1

Figure 1. Location of the four townships used for competition control experiments.

Table 1. Location and description of experimental sites.

Experiment	Lat. N	Long. W	Forest stand characteristics	Primary Operating Group[1]	Harvesting date (yr)	Site preparation	Weed control	
							Rate (kg/ha)	Date (d/mo/yr)
Kenogaming	48°10'	82°00'	Black spruce, cedar, balsam fir, white spruce, trembling aspen, and white birch	-	1979/80	Bulldozer and straight blade summer 1981	2.14	30/08/84
Lamplugh	48°35'	79°52'	Balsam fir, black spruce, white birch, and white spruce	OG7	1979/80	Winter shearblade 1982	2.14	28/08/84
Bragg	49°30'	80°20'	White spruce, black spruce, trembling aspen, and balsam fir	OG7	1981	Winter shearblade 1982	2.5	24/08/82[2] and 26/08/83
Kenning	49°15'	80°00'	Black spruce and trembling aspen	OG8	1981/82	Winter shearblade 1982	-	-[3]

[1] Operating groups after Jones et al. 1983. OG7 = mixedwood–herb rich; OG8 = feathermoss–*Sphagnum*

[2] Herbicide applied in August in the year of planting and the year after planting.

[3] Entire experiment was treated with the herbicide glyphosate in August 1988 at a rate of 1.8 kg ha^{-1} as part of an operational tending program.

contains background information (position, forest stand characteristics, harvesting date, site preparation method, and weed control) on each of the four experimental sites.

In Kenogaming Township, the site was prepared in summer with a straight blade mounted on a bulldozer. Bladed strips were 5 to 6 m in width with 3 to 8 m of logging debris and standing deciduous and cedar trees (*Thuja* spp.) left between the site-prepared strips. The intervening standing trees and tall woody shrubs shaded the southern side of the cleared strip. The mechanically site-prepared corridors ran in an east–west direction, and trees were planted in rows along the northern and southern edges of the corridors, as well as down the middle of the corridor. The summer site preparation was quite severe and this resulted in considerably more mineral soil exposure than in the strips shearbladed in winter. In an attempt to reduce frost heaving of planted seedlings, planters were instructed to avoid planting into patches of exposed mineral soil.

In Lamplugh, Bragg, and Kenning townships, trees were planted in rows along the outside edges of the winter shearbladed strips. The sharpened blade of the plow removed the duff and living moss layers without exposing the mineral soil. As well, it sheared off smaller residual trees, stumps, and other vegetation at ground level in strips 4 m wide. The debris was aligned in windrows from 3 to 8 m in width.

All planting sites in Bragg, Kenning, and Lamplugh townships had fine-textured soils (Appendix 1). In comparison, the textural class of soils in Kenogaming Township was coarser than in the other locations and ranged from silty sand to loamy sand.

Planting Stock

The spring-planted, 3-year-old transplant stock (1.5 + 1.5) and paperpot stock were planted from 14–28 May 1982. After being lifted from the transplant bed (14 May 1982) the trees were held in cool storage (2°C) until they were transported to the planting site. The spring-planted paperpots were started indoors at the Great Lakes Forestry Centre (47°N, 84°W) and then transferred outdoors for further growth and overwintering. Two sizes of paperpot stock were grown for both the spring and summer plantings. The "large" spring-planted paperpots were sown in mid-February 1981 and the "small" spring-planted paperpots were sown in late May 1981. The "large" summer-planted paperpots were sown in late January 1982 and the "small" summer-planted paperpots were sown in mid-February 1982. Because the large and small summer-planted paperpots were seeded only three weeks apart, size differences were minimal.

The summer-planted transplant and paperpot stock was planted 7–15 July 1982. The transplant stock was fresh-lifted prior to completing its third growing season in the nursery. All summer-planted transplants were planted within 2 days of being lifted. Paperpot stock planted during July were current-year stock, having been seeded indoors from late January to mid-February. The seedlings were moved outdoors under shade about mid-May. A 50-tree subsample was chosen from each stock type for morphological characterization (Table 2) at the time of planting .

Both stock types were grown from seed collected in Site Region 3200 (Skeates 1979). The transplant stock was

Table 2. Morphological characterization of planting stock used in all experiments.

Stock type	Seeding date (d/mo/yr)	Planting season	Shoot length (cm)	Root collar diameter (mm)	Height/ diameter ratio	Total dry weight (mg)	Root area index (cm^2)
"Large" FH408 paperpots	16/02/81	Spring	27.4	2.2	124.1	1 392	37.4
"Small" FH408 paperpots	30/05/81	Spring	12.2	1.6	76.0	597	12.7
1.5 + 1.5 transplants	n/a	Spring	24.7	5.4	46.7	8 596	78.7
"Large" FH408 paperpots	25/01/82	Summer	21.3	1.8	123.9	749	8.8
"Small" FH408 paperpots	15/02/82	Summer	18.0	1.6	113.9	578	8.2
1.5 + 1.5 transplants	n/a	Summer	36.1	5.1	72.0	8 758	46.8

grown by the Ontario Ministry of Natural Resources (OMNR) at its Swastika Tree Nursery (48°N, 80°W). Transplants were planted with a spade by means of the L-slit method (Fig. 2), and paperpot seedlings were planted using a Pottiputki® planting tube (Smith 1979).

Figure 2. Spring planting bareroot transplant stock in the Bragg Township experiment.

Experimental Design and Assessment of Crop Trees

All experiments were established using a randomized block design with the intention of examining the effect of stock type and planting season. Within months of establishing the experiment, however, a decision was made to include weed control as an experimental factor in Kenogaming, Lamplugh, and Bragg townships. Blocks were randomly selected for weed control. Then, depending upon the experiment, each factor was replicated from two to six times. Table 3 contains the experimental treatments. In all four experiments, comparisons between grades of container stock (i.e., large vs. small) were tested separately and the data from these two stock grades were pooled for the main analysis.

Although not part of the original experimental design, planting location in the Kenogaming experiment appeared to be having an effect on black spruce growth. As a result, the effect of planting location on tree survival and growth within the cleared strips (i.e., south side, center, north side) was also tested.

An experimental unit consisted of plots containing 50 planted trees. A total of 1 800 trees was planted in each experiment. Analysis of variance according to Snedecor and Cochran (1989) was done after checking that the data satisfied the necessary assumptions. When treatments had more than 2 factors (i.e., df >1), differences were tested by user defined orthogonal contrasts.

Survival and seedling condition were assessed, and then total height and basal diameter (measured 5 cm above ground level) were measured on all living, planted trees five and 11 growing seasons after planting. Numerous competition indices have been developed to measure competition around individual crop trees and these have been used to assess the need for vegetation control during the early years of forest plantation establishment (Brand 1986, Burton 1993). Various parameters, as described by Brand (1986), were measured or visually estimated at the time of the 11th-year assessment in an attempt to quantify

Table 3. Treatment applied in all experiments.

Experimental treatments	Experimental locations			
	Kenogaming Township	Lamplugh Township	Bragg Township	Kenning Township
Planting stock	Bareroot/paperpot	Bareroot/paperpot	Bareroot/paperpot	Bareroot/paperpot
Planting dates	May/July	May/July	May/July	May/July
Herbicide treatment	None/ 3 years after planting	None/ 3 years after planting	None/ Year of planting/ Year after planting	7 years after planting[1]

[1] Entire experiment was treated with the herbicide glyphosate in August 1988 at a rate of 1.8 kg ha^{-1} as part of an operational tending program.

the brush and/or deciduous tree competition within a 1.41-m radius cylinder around each living, planted tree. Brand's (1986) competition index incorporates brush height, crop tree height, average distance to the brush foliage from the crop tree stem, crown width of the planted tree, and proportion of the plot occupied by continuous foliage (estimated to the nearest 5 percent) of the competitors. From Brand's (1986) assessment procedure a single individual-based competition index (C.I.) was calculated for each living tree seedling.

Weed Control

In Kenogaming and Lamplugh townships, glyphosate (N-[phosphonomethyl]glycine), formulated as Round-up® (356 g a.e. L^{-1}) at 2.14 kg a.e. ha^{-1}, was applied three growing seasons after planting, on 28 August 1984 and 30 August 1984, respectively. Glyphosate was applied with the Micron Herbi 77[1] sprayer designed for low-volume herbicide applications. The sprayer was calibrated to deliver 70 L ha^{-1}, with a swath width of 1.75 m. In both the Kenogaming and Lamplugh plantations the herbicide was applied in a band over the top of the crop trees. The areas between the planted strips that were not mechanically site prepared were not treated.

In Bragg Township, glyphosate was applied at 2.5 kg a.e. ha^{-1} on 24 August 1982 and 26 August 1983. In 1982 the herbicide was applied with a piston pump and OC20 Tee-jet[2] cluster nozzle mounted on a Nodwell Flextrac carrier, calibrated to deliver 591 L spray mix ha^{-1} at 159 kPa. In 1983 the herbicide was applied with a backpack sprayer, calibrated to deliver 300 L ha^{-1} at 207 kPa. In both applications the herbicide was broadcast applied over the entire plot area.

In the Kenning Township planting glyphosate, formulated as Vision™ (356 g a.e. L^{-1}), was applied at 1.8 kg a.e. ha^{-1}. The herbicide was applied to the entire plantation in August 1988. As a result, weed control was not an experimental factor in this study.

Competing Vegetation

The main plant species present on each of the four experimental sites are listed in Appendix 2. At the time of planting in Kenning Township the abundance of noncrop plant species was much lower than in the other three plantings. However, the number of species on this site at time of weed control was greater than on any of the others.

RESULTS

Weed Control

Total Height

In Kenogaming, Lamplugh, and Bragg townships, the overall effect of weed control (stock types and planting dates combined) on total height was nonsignificant 2 to 4 years after release (i.e., 5 years after planting); however, 8 to 10 years after release (i.e., 11 years after planting) weed control had significantly improved total height growth in all three townships (Fig. 3, Appendix 3). In the Bragg Township planting, weed control was applied in August of the year of planting as well as in August of the year after planting. However, the effect of year of application was determined to be nonsignificant by a user-defined orthogonal contrast.

[1] Micron Sprayers Ltd., Three Mills, Bromyard, Herefordshire, England.
[2] Spraying Systems Co., Wheaton, IL.

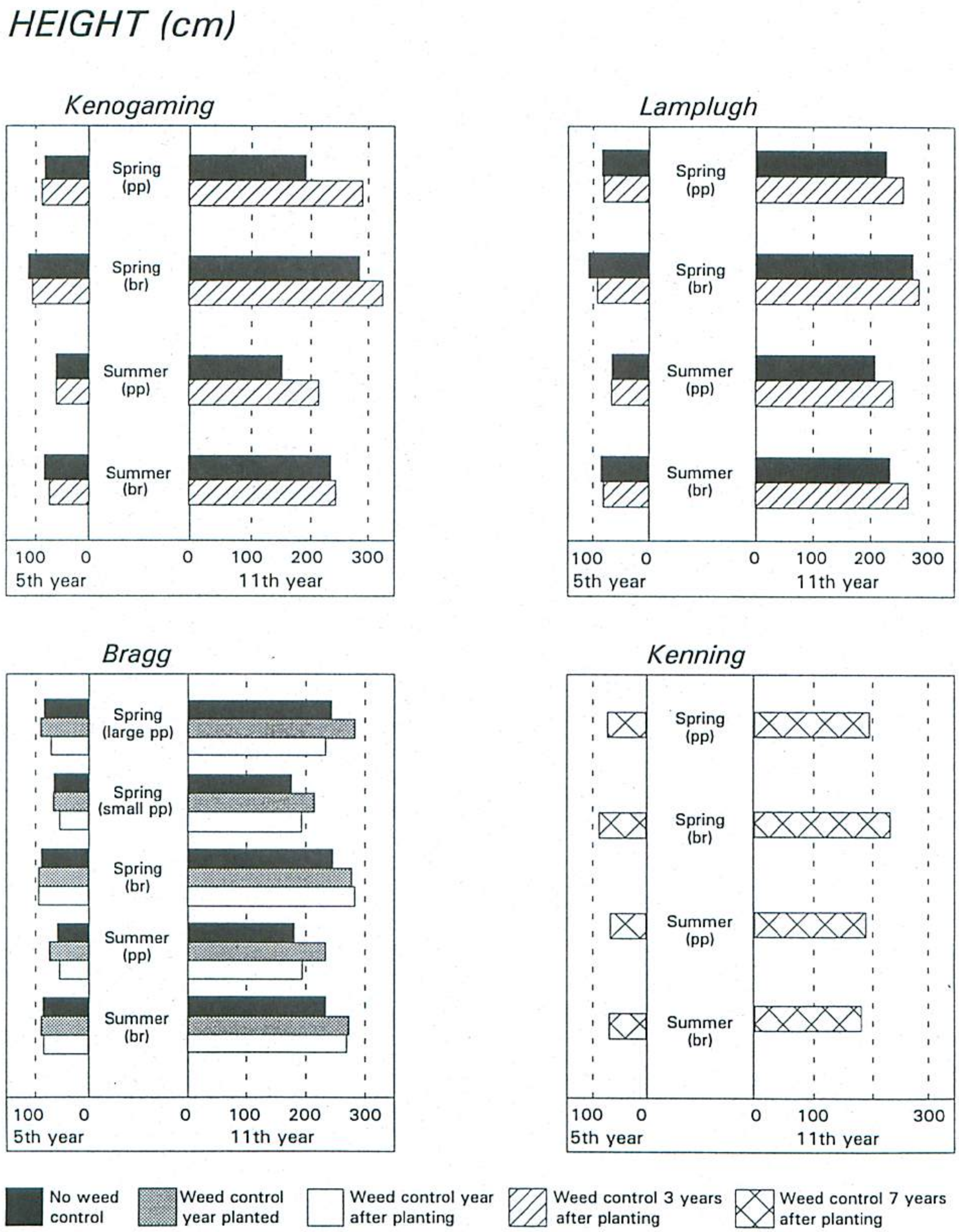

Figure 3. Five- and 11-year total height of black spruce by: stock type, bareroot (br) transplants and paperpots (pp); planting season, spring and summer; and weed control treatment.

Current Annual Height Increment

Differences in current annual height increment between treatments with and without weed control were non-significant at the time of the first assessment (i.e., 2 to 4 years after release) (Fig. 4, Appendix 3). However, these differences increased and by the time of the second assessment the 11th-year current annual height increment (i.e., to 10 years after release) was significantly improved by weed control in all three experiments.

Basal Diameter

Basal diameter was significantly improved by weed control in all three plantings after both the first (i.e., 2 to 4 years after weed control) and second assessments (i.e., 8 to 10 years after weed control) (Fig. 5, Appendix 3). At all three experimental locations (i.e., Kenogaming, Lamplugh, and Bragg) the benefits of weed control increased from the first to the second assessment.

Mortality

The effect of weed control on seedling mortality was highly variable (Fig. 6, Appendix 3). Eleven growing seasons after planting, mortality was not significantly affected by weed control in Kenogaming or Bragg townships. However, in Lamplugh Township mortality was significantly higher with weed control than without weed control. Mortality was particularly high for the summer-planted stock types with weed control. In Bragg Township, mortality was also significantly higher with weed control than without, 3 and 4 years after release, but these differences were nonsignificant 9 and 10 years after release.

Competition Index

In all three plantings where weed control was applied as an experimental treatment, the individual-based C.I. was significantly lower with than without weed control 8 to 10 years after release (11 years after planting) (Fig. 7, Appendix 3). In Bragg Township, weed control timing did not significantly effect C.I.

Nine and ten growing seasons after weed control in Bragg Township, the competing vegetation was comprised of low herbaceous plants, and graminoides in the wetter areas. The predominate competing species on the plots without weed control were trembling aspen (*Populus tremuloides* Michx.) (3 to 6 m tall) and woody shrubs. The broadcast weed control treatment essentially eliminated all of the woody competitors for at least ten growing seasons.

Eight years after the weed control treatment in Kenogaming Township, the major competitors in plots with and without weed control were beaked hazel (*Corylus cornuta* Marsh.); mountain maple (*Acer spicatum* Lam); birch (*Betula* sp.); pin cherry (*Prunus pensylvanica* L. fil); red raspberry (*Rubus idaeus* L. var. *strigosus* [Michx.] Maxim); trembling aspen; and graminoides. Although the above-mentioned competitors were present in plots with and without weed control, the effects of weed control were still evident within the treated bands eight growing seasons after treatment. Similar to Kenogaming Township, weed control in Lamplugh Township reduced the amount of nonconifer vegetation surrounding the crop trees for at least eight growing seasons after treatment (Fig. 8).

Stock Type (bareroot vs. paperpot)

Total Height

The overall effect of stock type (chemical treatments and planting dates combined) on total height at all experimental sites except Kenning Township was significant. The bareroot stock was significantly taller than the paperpot stock five and 11 growing seasons after planting (Fig. 3, Appendix 3). In Kenning Township, the bareroot stock was significantly taller than the paperpot stock after the 5th year but not after the 11th year.

Current Annual Height Increment

Bareroot stock had significantly higher current annual height increment, compared to the paperpot stock, in the 5th and 11th growing seasons after planting in the Kenogaming Township and Bragg Township locations (Fig. 4, Appendix 3). Current annual height increment in Lamplugh and Kenning townships was significantly higher for bareroot stock compared to paperpot stock in the 5th growing season, but not in the 11th growing season. On average, relative differences in height growth related to stock type declined from the 5th to the 11th year.

Basal Diameter

The basal diameter of bareroot stock was significantly larger than paperpot stock after the 5th and 11th growing seasons in Kenogaming, Lamplugh, and Bragg townships (Fig. 5, Appendix 3). Stem diameter was significantly greater for bareroot stock in Kenning after the 5th year but not after the 11th year.

Mortality

Stock type did not differ significantly in mortality after 11 growing seasons in Kenogaming, Lamplugh, or Bragg townships (Fig. 6, Appendix 3). Paperpots had significantly lower mortality than did bareroot stock in Kenning Township.

Interaction Between Weed Control and Stock Type

Only in the Kenogaming Township planting was there a significant interaction between stock type and weed control.

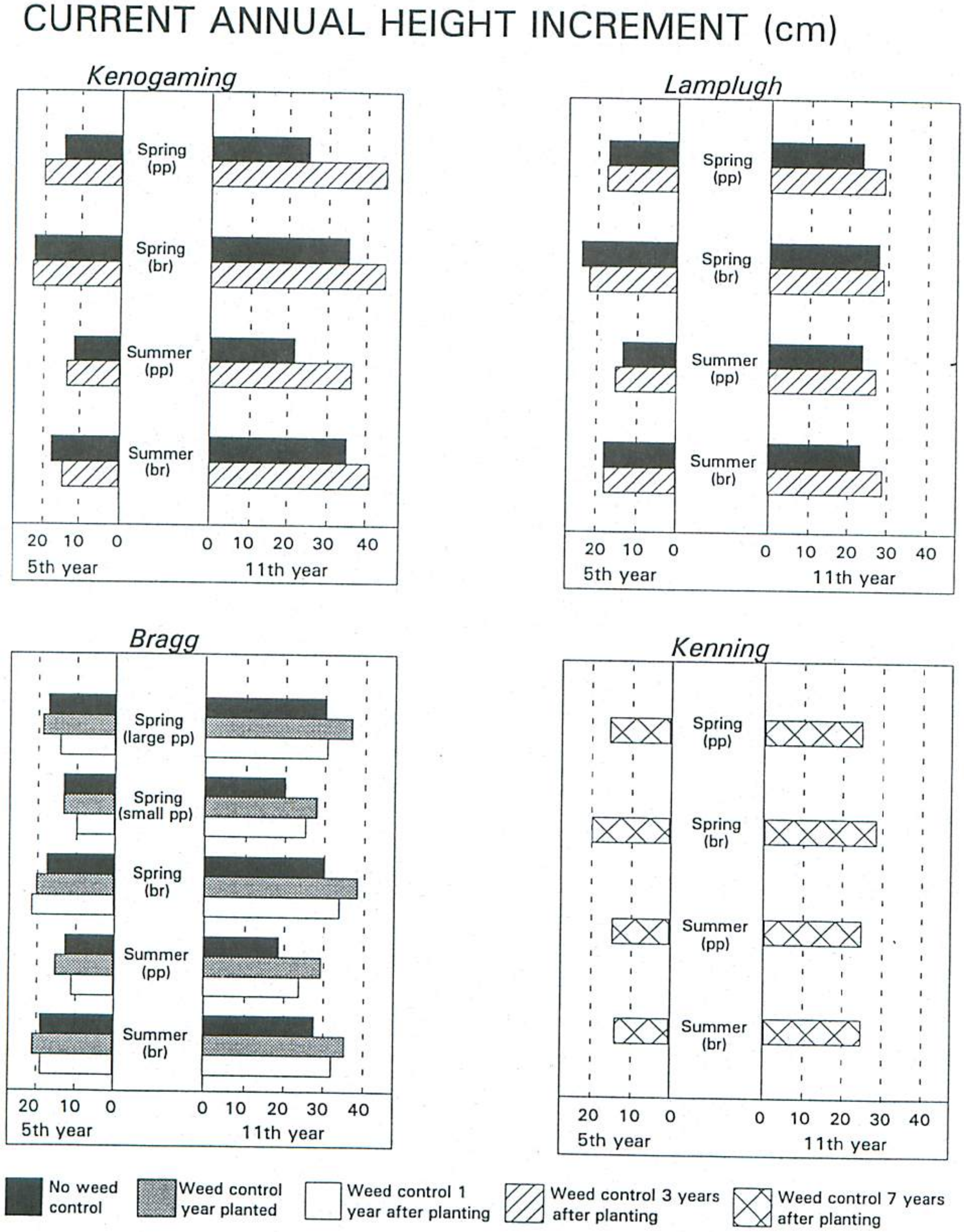

Figure 4. Five- and 11-year current annual height increment of black spruce by: stock type, bareroot (br) transplants and paperpots (pp); planting season, spring and summer; and weed control treatment.

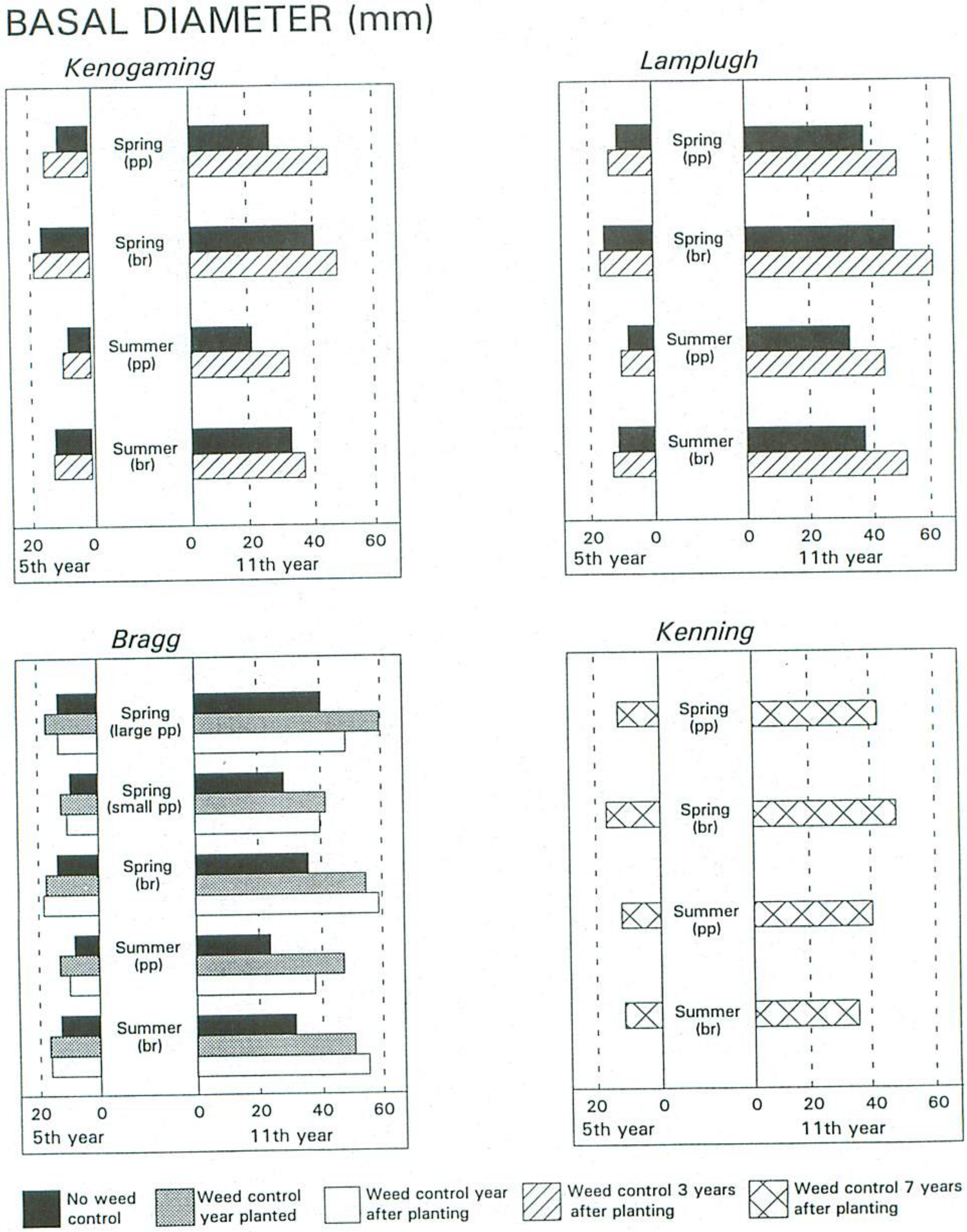

Figure 5. Five- and 11-year basal diameter of black spruce (measured 5 cm above ground level) by: stock type, bareroot (br) transplants and paperpots (pp); planting season, spring and summer; and weed control treatment.

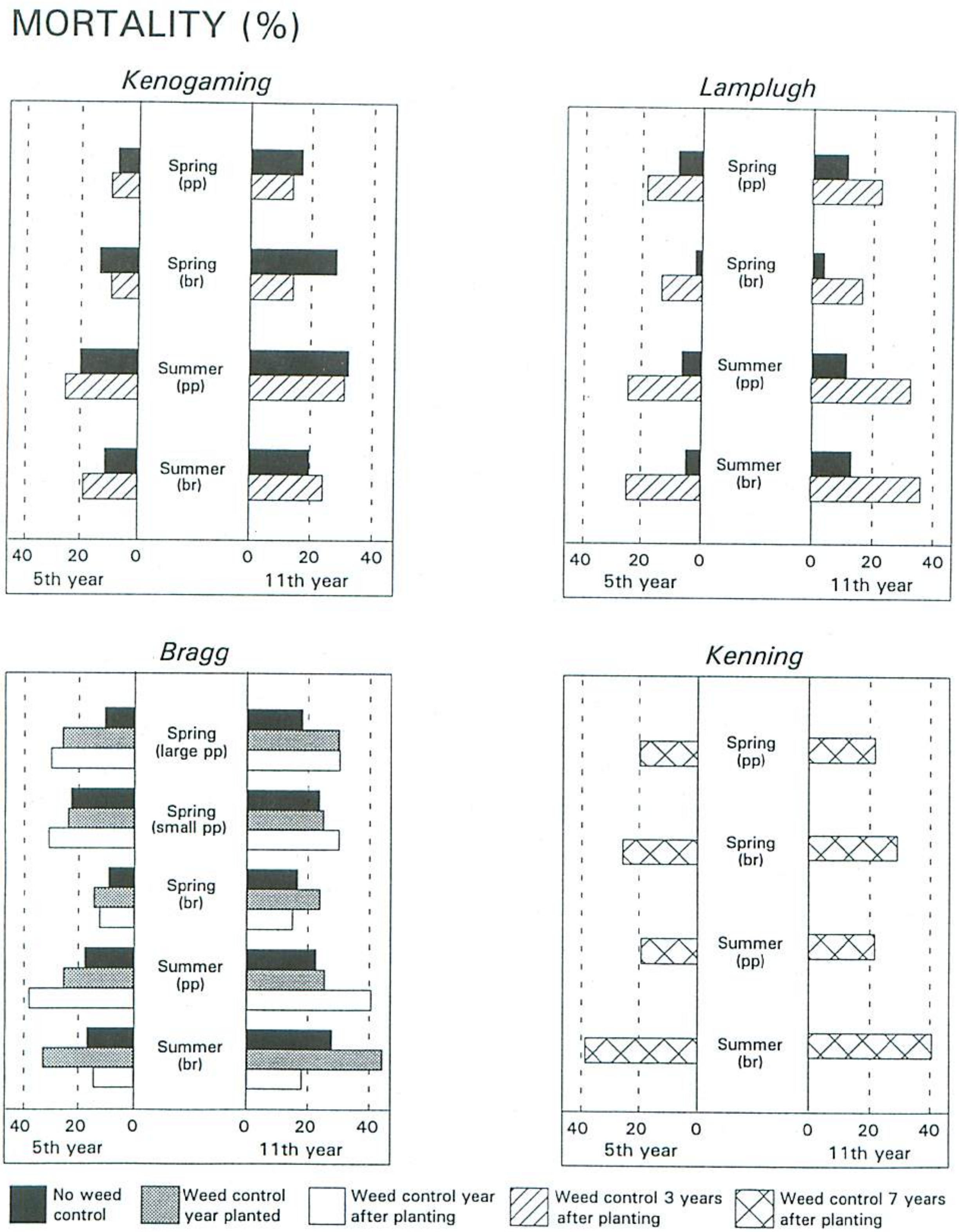

Figure 6. Five- and 11-year mortality of black spruce by: stock type, bareroot (br) transplants and paperpots (pp); planting season, spring and summer; and weed control treatment.

COMPETITION INDEX

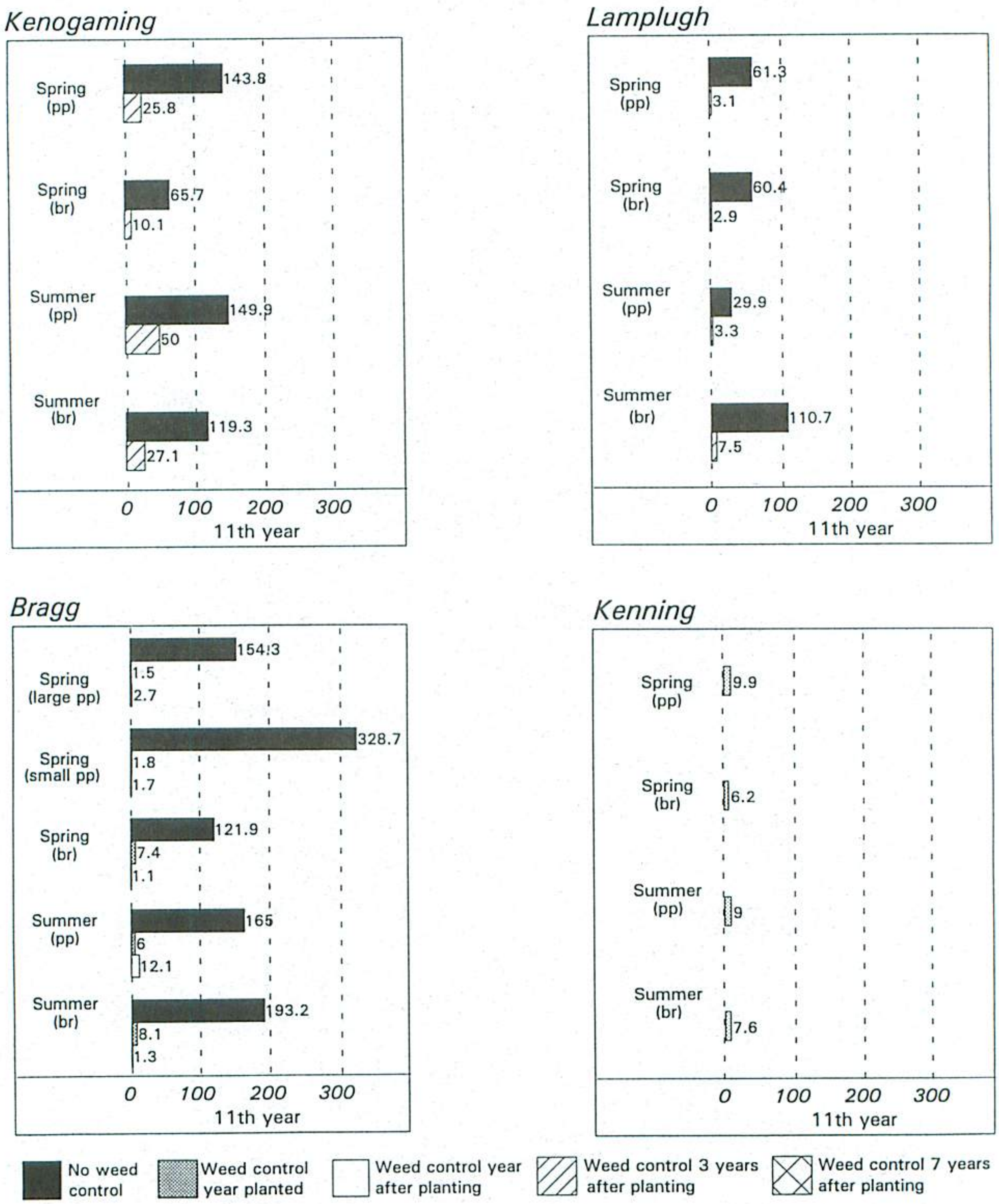

Figure 7. Individual-based competition index (Brand 1986) after eleven growing seasons by black spruce: stock type, bareroot (br) transplants and paperpots (pp); planting season, spring and summer; and weed control treatment.

Figure 8. Row of eleven-year-old spring-planted black spruce transplants with weed control in Lamplugh Township.

In this particular planting, the benefits of weed control were found to be significantly greater for the paperpot stock than for the bareroot stock (Appendix 3).

Planting Season

Total Height

Season of planting had a variable effect on total height that depended upon both stock type and location (Fig. 3, Appendix 3). Planting season had a significant effect upon total height at the Kenogaming, Lamplugh, and Kenning sites five and 11 growing seasons after planting. On average, the bareroot stock was taller when spring-planted than when summer-planted, but the difference was not as large between spring- and summer-planted paperpots.

Current Annual Height Increment

Differences in current annual height growth attributable to planting season declined from the 5th to the 11th year after planting (Fig. 4, Appendix 3). After 11 years, differences in height growth were largely nonsignificant, with the exception of Kenogaming, where the spring-planted seedlings were still growing significantly faster than the summer-planted seedlings.

Basal Diameter

In all plantings, planting season had a significant effect on basal diameter (Fig. 5, Appendix 3). The spring-planted stock had a significantly larger basal diameter than the summer-planted stock.

Mortality

Mortality was significantly higher for summer planting than for spring planting in Kenogaming, Lamplugh, and Bragg townships (Fig. 6, Appendix 3). There were no significant differences in mortality attributable to season of planting in Kenning Township.

Competition Index

In the Kenogaming planting, C.I. was significantly higher for paperpot stock than for bareroot stock. In the Lamplugh, Bragg, and Kenning plantings, C.I. did not differ significantly between stock type and planting dates (Fig. 7, Appendix 3).

Interaction Between Stock Type and Planting Season

Only in the Kenning planting were there significant interactions between stock type and planting season (Appendix 3).

Paperpot Seedling Size

Total Height, Current Annual Height Increment, and Root Collar Diameter

The initial size of paperpot seedlings used in this study had neither a significant effect upon 11th-year total height nor on current annual height increment in the spring or summer plantings. Only in the Bragg plantation were the spring-planted "large" paperpots still significantly larger and growing faster 11 growing seasons after planting (Figs. 3–5) than were the "small" spring-planted paperpots.

Mortality

The effect of initial size of paperpot seedlings was nonsignificant in all plantings after both five and 11 growing seasons (Fig. 6).

Planting Position (Kenogaming Township)

Total Height

Differences in total height related to planting position were nonsignificant five growing seasons after planting, however these differences became significant by the 11th growing season (Fig. 9, Appendix 4). Trees planted on the north side of the corridor were significantly taller than trees planted on the more heavily shaded south side of the corridor. The differences in total height between the center and side planting positions were nonsignificant.

Current Annual Height Increment

Planting position had a significant effect upon current annual height increment five and 11 years after planting (Fig. 9, Appendix 4). Trees planted in the center planting position were growing significantly faster than those planted on either side of the corridor after 11 growing seasons. In addition, trees planted on the more exposed north side of the corridor were growing significantly faster than those growing on the south side.

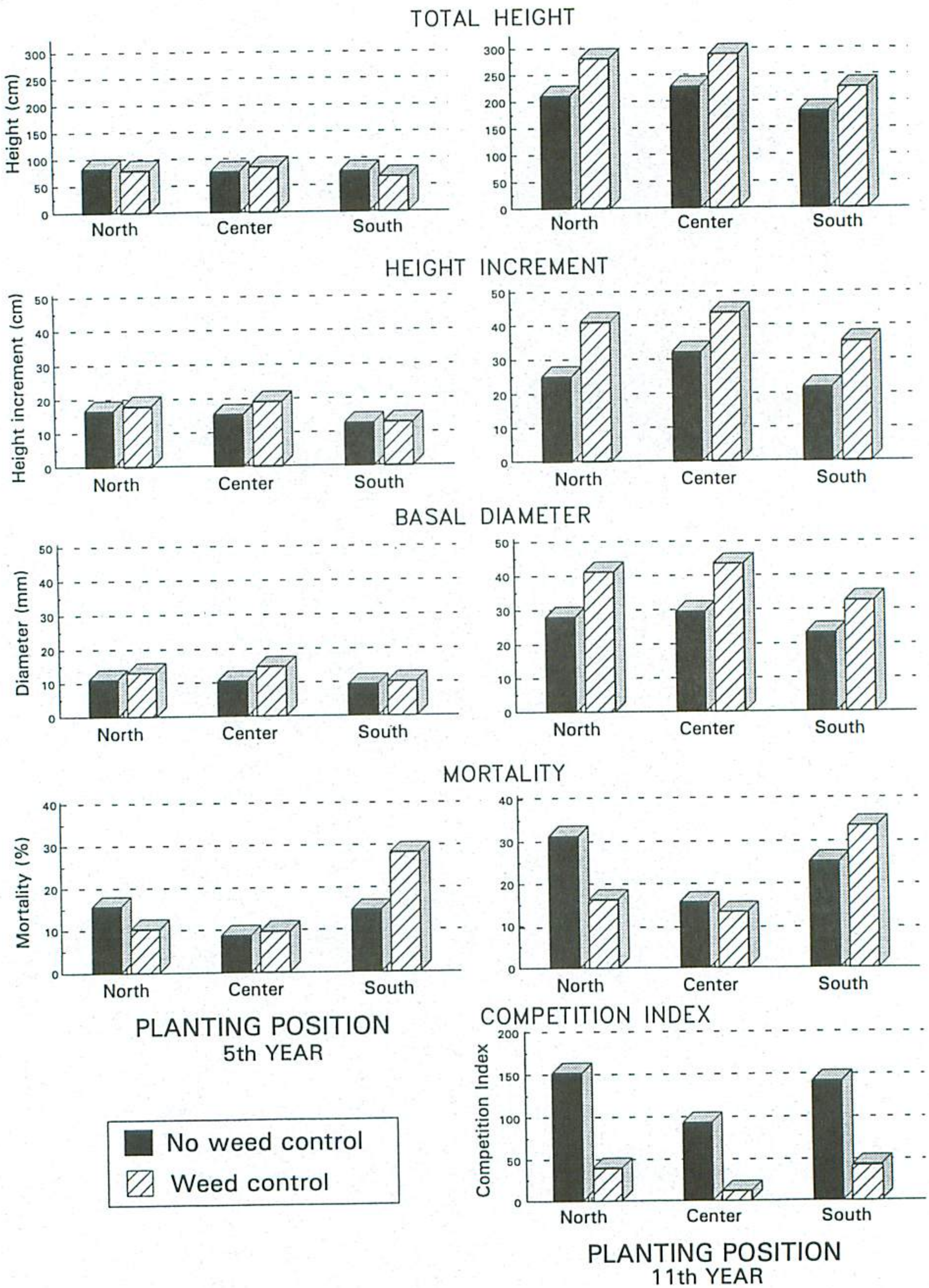

Figure 9. Five- and 11-year total height, height increment, basal diameter, mortality, and 11-year competition index (Brand 1986) of black spruce: bareroot (br) transplants and paperpots (pp) and spring planted and summer planted by weed control treatment and planting position in Kenogaming Township.

Basal Diameter

After five growing seasons, planting position did not significantly affect basal diameter (Fig. 9, Appendix 4). However, after 11 growing seasons planting position had a significant effect upon basal diameter. Similar to total height and current annual height increment, trees planted in the center of the corridor had a significantly larger basal diameter than did those planted on the sides of the corridor. In addition, trees planted on the north side of the corridor had significantly larger diameters than did those planted on the south side.

There were no significant interactions between weed control and planting position, thereby indicating that the effect of planting position was similar with or without weed control.

Mortality

Five and 11 years after planting, the trees in the center of the corridor had significantly lower mortality than did those planted on either side (Fig. 9, Appendix 4). The interaction between planting position and weed control was significant. Mortality was higher with weed control on the south side of the corridor, but it was also higher with no weed control on the north side. This suggests that the primary cause of mortality was not competition for site resources.

Competition Index

The C.I. after 11 growing seasons was significantly higher for the trees planted on either side of the corridor than for those planted in the center, in treatments both with and without weed control (Fig. 9). The better growth of center-planted trees appeared to correspond to a reduction in noncrop vegetation in the center of the corridor, brought about by mechanical site preparation. The differences in C.I. between the north side and south side of the corridor were nonsignificant.

DISCUSSION

Weed Control

Weed control improved the field performance of the black spruce outplants in all three plantings in which it was included as an experimental factor, and the benefits of weed control increased over the experimental period (Fig. 8). In addition, basal diameter growth was more responsive to reductions in competing vegetation than was total height. The results from this study support the findings of Zutter et al. (1986), Frivold and Mielikäinen (1990), Brand (1991), Lautenschlager (1991), and Richardson (1991), who also found that for black spruce and other conifers, basal diameter was more responsive to reductions in competing vegetation than was total height.

Morris (1988) and MacDonald and Weetman (1993) reported that black spruce height growth was neither a sensitive indicator of competition for site resources nor for seedling vigor. Logan (1969) observed that black spruce shoot dry weight, needle number, root collar diameter, and root dry weight decreased as light intensity was reduced. Although height growth also decreased, it was not as sensitive a measure of light intensity as was total shoot weight (i.e., foliage, branch, and stem weights). Johnson (1973) found shoot mass to be a sensitive measure of competition stress; however, he identified root development as a more sensitive indicator.

In the current study, although seedling total height was not significantly improved by weed control 2 to 4 years after treatment, 8 to 10 years after weed control the situation had changed and the released seedlings were significantly taller. Newton et al. (1992a) found white spruce and balsam fir (*Abies balsamea* [L.] Mill.) had increased in height as well as in diameter in response to reduced competition 16 years after clear-cutting and 9 years after release. These results seem to suggest that while height growth is not a good early indicator of competitive pressure, its value may improve as the length of time from release increases. Morris (1988) recommends that black spruce height growth measurements not be used as indicators of treatment response in plantations less than 5 years old.

The results from this study also seem to show that black spruce growth is a much more sensitive indicator of competition for environmental resources (e.g., light, moisture, nutrients) than is survival. Moreover, it appears that growth is affected at lower levels of competition stress than is survival. For example, the presence or absence of noncrop vegetation did not significantly affect seedling mortality in this experiment; however, the same levels of noncrop vegetation significantly reduced seedling growth. McDonald and Helgerson (1990) found in California and Oregon that conifer survival was a less sensitive indicator of competition for site resources than was conifer growth. LeBarron (1948) observed that black spruce could survive in the understorey or on poor sites at minimal growth rates, and he reported finding 15-year-old black spruce seedlings that were 15–30 cm tall.

Wood and von Althen (1993), working in boreal Ontario, found that controlling the competing vegetation in the year of planting was more effective for black spruce and white spruce than waiting until the year after planting. Newton and Preest (1988) reported that the greatest gains in Douglas fir (*Pseudostuga menziesii* [Mirb.] Franco) stem volume growth occurred if weed control was conducted the year of planting; smaller increments came from additional weed control in the second and third years after planting. In the Bragg Township planting reported upon here, weed control in the year of planting was compared to weed control carried out the year after planting. None of the variables measured were significantly improved by weed control in the year of planting versus the year after planting, although the trees in the plots treated the year of planting were often larger than those treated the year after planting. Lund-Høie (1984) found that Norway spruce (*Picea abies* L.) had a greater growth response to chemical site preparation than to chemical release treatments, and that the growth response fell off rapidly as the time interval between planting and chemical release with glyphosate increased. Working with black spruce, Wood and von Althen (1993) also found chemical site preparation with a mist blower to be more effective than chemical release with a standard backpack sprayer.

In the Lamplugh Township plantation mortality was significantly higher with weed control than without five and 11 years after planting. In addition, at the Bragg Township location mortality was significantly higher with weed control than without 5 years after planting (3 and 4 years after weed control). However, 11 years after planting (i.e., 9 and 10 years after weed control) these differences were no longer significant. Lund-Høie (1984) found that the rate of mortality of Norway spruce was higher when glyphosate was applied in the year of planting, compared with application in the year after planting. Tolerance to glyphosate has been reported to vary widely among species, with the physiological state of target plants (King and Radosevich 1985) and the rate and time of application (Radosevich et al. 1980). In this study, glyphosate was applied at 2.14 and 2.5 kg a.e. ha^{-1} rates in 1984 in Kenogaming and Bragg townships, respectively. The current maximum label rate is 2.14 kg a.e. ha^{-1}; however, most forestry herbicide applicators use less than this to release conifers from competing vegetation. Possible explanations for increased crop tree mortality include: herbicide injury, increased frost damage as a result of the removal of the protective vegetative canopy (Krishka and Towill 1989, Frivold and Mielikäinen 1990), and solarization of shade-adapted needles (Salisbury and Ross 1985). However, Haavisto[3] has noted that black spruce does not usually succumb to frost.

Wagner (1992) reported that if the aerial application of herbicides was eliminated in Ontario, all regions of the province would shift their herbicide treatment programs from aerial to ground applications. The results reported upon in this study show that the ground application of herbicides can be a silviculturally effective treatment. Interestingly, the weed control treatments applied in this study were effective whether or not the herbicide was applied as a broadcast application (applied as a continuous sheet over the entire plantation, i.e., Bragg Township) or band application (applied in a 1.75-m-wide linear strip over the top of the crop tree rows, i.e., Kenogaming and Lamplugh townships). Several advantages of band herbicide applications include: 1) reduction in the total amount of herbicide applied to a given area; 2) preservation of hardwoods (e.g., trembling aspen and white birch [*Betula papyrifera* Marsh.]), brushy species, and a wide range of herbaceous plants on the portions of the plantation not planted; 3) provision of some side shading to planted conifers; and 4) a reduction in the visual impact of the herbicide application. Compared to broadcast herbicide applications (either aerial or ground), manually applied band herbicide applications would likely result in increased application costs, risk of worker exposure to herbicides, and risk of nonherbicide related worker injury. In addition, this technique requires that trees be planted at a regular spacing so that the applicator does not have to search for individual crop trees. Despite these potential drawbacks, the data from this and other studies (Wood et al. 1990) show that band herbicide applications are a silviculturally effective alternative to conventional broadcast applications in the boreal forest. Wagner (1993) reported that ground-spraying systems that emphasize spot or band herbicide applications are likely to be more socially acceptable than are broadcast applications. However, he emphasized that research must continue on techniques that greatly reduce or eliminate worker exposure to herbicides.

The herbicide application method may also have an influence on crop tree morphology. For example, in Bragg Township, trees in the broadcast weed control plots had little or no horizontal competing vegetation surrounding them. These trees had larger stem diameters and less height growth compared to similar trees that received weed control in the Kenogaming plantation. The Kenogaming Township trees, on the other hand, were surrounded by more woody plants because of the band herbicide application and as a result had narrower crowns, smaller stem diameters, greater height growth, and better stem form (i.e., less taper) than did the trees in Bragg Township.

Competition Development

Variables for Brand's (1986) individual-based C.I. were assessed to evaluate the long-term herbicidal efficacy of the weed control treatments. C.I. values were significantly lower with weed control than without 8 to 10 years after the application of herbicides. The areas immediately surrounding the treated seedlings tended to be dominated by low herbaceous plants, whereas the areas surrounding the

[3] Haavisto, V.F. 1994. Nat. Resour. Can., Canadian Forest Service–Sault Ste. Marie, Sault Ste. Marie, ON. (Pers. comm.)

seedlings without weed control were primarily dominated by early successional woody or brushy species such as trembling aspen, beaked hazel, and red raspberry. In the Kenogaming, Lamplugh, and Bragg townships sites it is unlikely that the released black spruce will be overtaken by deciduous trees or woody brush.

Glyphosate is a nonpersistent herbicide that is inactivated in the soil by microbial degradation. It is also strongly adsorbed to the adsorption complex in soils (Weed Science Society of America 1989). As a result, the longer-term effects of glyphosate on plant succession are not the result of its ability to remain active in the environment. Rather, the shift in plant succession brought about by the application of glyphosate on these sites is possibly the result of the chemical's ability to control perennial species and changes in seedbed receptivity following disturbance. Perennial sprouting species may have been controlled for a relatively long period of time in this study because glyphosate is rapidly translocated to underground propagules, where it prevents regrowth from these sites and results in their subsequent destruction (Weed Science Society of America 1989). Newton et al. (1992b) found that all glyphosate treatments sharply reduced dominance of all maple (*Acer* spp.), aspens, and birches 9 years after treatment. The shift in vegetational succession brought about by the herbicide application may also have been the result of a reduction in the amount of receptive seedbed that occurred when the forest floor was physically disturbed (e.g., harvesting and site preparation) until the herbicide was applied. During this period, litter fall or the rapid growth of nonvascular plants may have substantially reduced receptive seedbed (Fleming and Mossa 1995). Because chemical tending does little to create new receptive seedbed, regeneration of seeded species may be limited after a herbicide application.

Competing vegetation that overtops a crop tree was reported by Howard and Newton (1984) and Newton et al. (1992a) to be more detrimental than vegetation that was shorter than the crop tree. Newton et al. (1992a) claimed that the benefits of release from woody competition were submarginal if shrubs were less than two-thirds of the height of conifer crop trees. However, Richardson (1991) stated that the growth of an apparently dominant conifer stand can be limited by the presence of understorey vegetation. Although it appears that inadequate light is the most common factor that limits conifer growth, other factors such as soil moisture, temperature, etc. may also play a role. Under these situations, even low levels of competing vegetation may significantly reduce seedling growth (*viz*. MacDonald and Weetman 1993). Under natural forest canopies, where upland conifers are exposed to less than favorable environmental conditions, light intensities from 5 to 15 percent of full sunlight are necessary for survival (Shirley 1943). Under canopies that transmit 20–30 percent full sunlight, light intensity is usually adequate for survival provided that other environmental factors are not limiting. At light intensities of 35–50 percent of full sunlight, survival is usually near its maximum and growth is 30 to 70 percent of maximum. At light levels higher than 30 percent of full sunlight other factors, such as soil moisture and fertility, may become the principal limiting factors to growth (Gast 1937, Shirley 1943). When other environmental factors are not limiting, black spruce makes its best growth under full sunlight (Logan 1969).

Planting Stock

In all plantings except Kenning Township, there were no significant differences between stock type in terms of 11th-year mortality. However, in the same plantings the bareroot stock was still significantly larger than the paperpot stock, and height growth of bareroot stock remained significantly greater than paperpot stock in Kenogaming and Bragg townships 11 years after outplanting. MacDonald and Weetman (1993) reported that in 4-year-old black spruce plantations in northern Ontario, bareroot stock maintained greater height and diameter incremental growth than did paperpot stock across a range of sites with varying levels of competition. In Virginia, Dierauf et al. (1993) observed that the initial stem diameter of loblolly pine seedlings had an effect on pulpwood yields after 20 years. The small seedlings (i.e., 1.6- to 2.4-mm root collar diameter) produced significantly less volume than the average (i.e., 3.2-mm root collar diameter) and large seedlings (i.e., 4.0- to 4.8-mm root collar diameter). Interestingly, in the current study the only site on which the paperpots performed as well as the bareroot stock was the Kenning site, which was imperfectly drained with 15–22 cm of organic matter overlying clay. Numerous reports have referred to the benefits of planting larger stock on sites where the potential for vegetative competition may be high (Scarratt 1982, Howard and Newton 1984, Ball and Kolabinski 1986, Lautenschlager 1991, Long and Carrier 1993, MacDonald and Weetman 1993, Newton et al. 1993). However, in this study, the only site in which there were significant interactions between stock type and weed control was the Kenogaming planting. On this particular site weed control benefited the initially smaller paperpot stock proportionately more than it did the bareroot stock. In a study in Oregon, which examined the effects of competing vegetation, stock type, and site upon Douglas fir outplant performance, Newton et al. (1993) found a positive relationship between initial seedling height and long-term (i.e., 10–14 years) growth on a number of brushy sites. In their study, competition was shown to effect shorter trees more than taller trees and the effect of competition on growth was inversely related to the initial height of planting stock. The fact that all stock types (transplants as well as container stock) reported upon in this study responded positively to weed control, and that on only one site was there a strong interaction term, suggests that weed control benefited the smaller containerized seedlings and the larger bareroot seedlings more or less equally.

Since the current field trials were initiated in the early 1980's, provincial standards for planting stock have continued to evolve in Ontario. For example, the total height of black spruce container stock produced in northeastern Ontario today is 10 to 25 cm and the maximum height:diameter ratio is between 100 and 110 (Morrison).[4] The move toward more well balanced nursery stock for reforestation is supported by Long and Carrier (1993), who found substantial gains in Douglas fir outplant performance following nursery cultural techniques that produced seedlings with large diameters and fibrous root systems. However, Paterson (1991) cautioned that the initial morphological characteristics of planting stock do not always reflect field growth potential. In his field trial with black spruce in boreal Ontario, he found that the smaller outdoor-grown stock actually performed better than the larger greenhouse-grown seedlings in terms of first- and second-year height growth. Perhaps Long and Carrier (1993) most aptly summed up the question of using morphological characteristics to grade nursery stock when they stated that, in general, root collar diameter and root mass are the best predictors of subsequent performance in many species, as long as physiological conditions are not limiting.

In this and other studies (e.g., Wood and Dominy 1985, Scarratt and Wood 1988) it was found that black spruce paperpot stock could be planted successfully until the end of July in northeastern Ontario. In general, however, the initial size advantage of the spring-planted stock was maintained over the experimental period.

Planting Position

In the Kenogaming plantation, position of planting within the 5- to 6-m-wide east–west oriented bladed strips had a significant overall affect upon field performance. The effect was more pronounced after 11 than after five growing seasons. The trees planted in the center of the corridors were growing faster in height than those planted along the sides of the shearbladed swath. Both with and without weed control there was a significant difference in C.I. between the center versus side planting positions. The higher competition values for trees planted at the sides of the corridors were largely the result of woody competitors encroaching from the intervening areas that had not been mechanically site prepared. The crop trees planted along the north side of the site-prepared corridor were taller, had better height growth, and had larger basal stem diameters than did those planted along the south side of the corridor. From visual observations, it appeared that the trees planted along the south side of the bladed strips were more heavily shaded from standing trees in the leave strips than were those planted along the north side. Competition index values did not reflect the heavier shading on the south side of the strip than on the north side because the trees in the leave strip were outside of the 1.41-m radius, crop-tree centered C.I. plots.

CONCLUSIONS

In this study weed control improved the growth of black spruce outplants and the benefits of such control increased over the experimental period. Basal diameter growth was found to be more sensitive to competition for site resources than was total height. However, the results from this study suggest that while height growth is not a good early indicator of competitive pressure, its value improves as the length of time from release increases. In general, mortality was the least sensitive measure of competition for site resources assessed. It was either not significantly affected by weed control or was significantly higher with weed control than without.

Both the manual broadcast and band application of herbicides were effective silvicultural release treatments on the sites studied. C.I. values, reflecting differences in the amount of nonconifer vegetation surrounding the planted trees, were significantly lower with weed control than without. These differences were maintained for at least 8 to 10 years after release.

In three of the four plantings, total height and stem diameter of bareroot stock was significantly greater than that of the paperpot stock. In two of the four sites (i.e., Kenogaming and Bragg) height growth remained significantly greater 11 years after outplanting. In general, the grades of container stock used in this study had little or no effect on mortality or growth rate. Only in the Bragg spring planting were there significant differences in growth performance related to container stock grade.

The lack of a strong interaction term between stock type and weed control indicates that weed control benefited both the smaller containerized and the larger bareroot seedlings more or less equally. Based upon limited findings, the present authors recommend that bareroot transplant stock not be used as a substitute for vegetation

[4] Morrison, R. 1993. Ontario Ministry of Natural Resources, Swastika Tree Nursery, Swastika, ON. (Pers. comm.)

control. On productive, competition-prone sites, it appears that substantial gains in seedling growth can be made both by planting large, healthy stock (either bareroot or container) and carrying out effective weed control.

The grades of container stock used in this experiment could be planted successfully until the end of July in northeastern Ontario.

ACKNOWLEDGMENTS

The authors wish to acknowledge: Fred Curtis (retired from the Canadian Forest Service–Sault Ste. Marie) for providing technical assistance; and Fred Haavisto (Canadian Forest Service–Sault Ste. Marie) and Wayne Bell (Ontario Ministry of Natural Resources) for their helpful reviews of the draft report. The following companies made a substantial contribution to the project by assisting with plot layout in the field, and with the planting and assessment of crop trees: Arbex Forest Development Company Ltd., Ecological Services for Planning Ltd., and Matcam Forestry Consultants Inc. Thanks are also extended to the staff of the Swastika Forest Tree Nursery for providing the bareroot planting stock and to the staff of the Ontario Ministry of Natural Resources Cochrane, Kirkland Lake, and Timmins district offices for their cooperation. In addition, we wish to thank the woodlands staff of the Abitibi-Price Company in Iroquois Falls for their assistance. Funding for this project was provided in part through the Northern Ontario Development Agreement, Northern Forestry Program and the former Department of Regional Economic Expansion, Forest Management Subsidiary Agreement.

LITERATURE CITED

Ball, W.J.; Kolabinski, V.S. 1986. Performance of container and bare-root stock on prescribed burns in Saskatchewan. Can. For. Serv., North. For. Cent., Edmonton, AB. Inf. Rep. NOR-X-283. 16 p.

Brand, D.G. 1986. A competition index for predicting the vigour of planted Douglas-fir in southwestern British Columbia. Can. J. For. Res. 16:23–29.

Brand, D.G. 1991. The establishment of boreal and sub-boreal conifer plantations: An integrated analysis of environmental conditions and seedling growth. For. Sci. 37:68–100.

Burton, P.J. 1993. Some limitations inherent to static indices of plant competition. Can. J. For. Res. 23:2141–2152.

Deloitte and Touche. 1992. An assessment of the economic benefits of pest control in forestry. Deloitte and Touche Management Consultants, Guelph, ON. 156 p. + appendices.

Dierauf, T.A.; Scrivani, J.A.; Chandler, L.A. 1993. Loblolly pine seedling grade-effect on survival and growth through 20 years. Virginia Dep. For. Occasional Report 107. 30 p. + appendix.

Fleming, R.L.; Mossa, D.S. 1995. Direct seeding of black spruce in northwestern Ontario: Temporal changes in seed-bed coverage and receptivity. For. Chron. 71:219–227.

Frivold, L.H.; Mielikäinen K. 1990. The effects of hardwoods on softwood growth in mixed stands in Fennoscandia. p. 75–82 *in* B.D. Titus, M.B. Lavigne, P.F. Newton and W.J. Meades, eds. The Silvics and Ecology of Boreal Spruces. For. Can., St. John's, NF. Inf. Rep. N-X-271. 197 p.

Gast, P.R. 1937. Studies on the development of conifers in raw humus. III. The growth of scots pine (*Pinus silvestris* L.) seedlings in pot cultures of different soils under varied radiation intensities. Meddel. fr. Statens. Skogsfor-sökanstalt 29:587–82.

Hearnden, K.W.; Millson, S.V.; Wilson, W.C. 1992. A report on the status of forest regeneration. Ont. Min. Nat. Resour., Sault Ste. Marie, ON. 31 p. + appendices.

Honer, T.G.; Clark, W.R.; Gray, S.L. 1991. Determining Canada's forest area and wood volume balance, 1977–1986. p. 17–25 *in* D.G. Brand, ed. Canada's Timber Resources. For. Can., Chalk River, ON. Inf. Rep. PI-X-101. 174 p.

Howard, K.M.; Newton M. 1984. Overtopping by successional coast-range vegetation slows Douglas-fir seedlings. J. For. 82:178–180.

Johnson, W.F. 1973. Seeding black spruce on brushy lowland successful if vegetation density kept low. USDA For. Serv., St. Paul, MN. Res. Note NC-139. 4 p.

Jones, R.K.; Pierpoint, G.; Wickware, G.M.; Jeglum, J.K.; Arnup, R.W.; Bowles, J.M. 1983. Field guide to forest ecosystem classification for the Clay Belt, Site Region 3e. Ont. Min. Nat. Resour., Toronto, ON. 122 p.

King, S.P.; Radosevich, S.R. 1985. Herbicide tolerance in relation to growth and stress in conifers. Weed Sci. 33:472–478.

Krishka, C.S.; Towill, W.D. 1989. Spruce height and volume growth response to an aerial release treatment using 2,4-D on three plantations near Manitouwadge, Ontario. Ont. Min. Nat. Resour., Northwestern Ont. For. Tech. Develop. Unit., Thunder Bay, ON. Tech. Rep. 8. 22 p.

Lautenschlager, R.A. 1991. Red raspberry ecology and the effect of raspberry and other forest brush on white spruce growth. Univ. Maine, Coll. For. Resour., Orono, MA. Misc. Rep. 360. 7 p.

LeBarron, R.K. 1948. Silvicultural management of black spruce in Minnesota. USDA, Washington, DC. Circ. No. 791. 60 p.

Logan, K.T. 1969. Growth of tree seedlings as affected by light intensity IV. Black spruce, white spruce, balsam fir, and eastern white cedar. Dep. Fish. For., Can. For. Serv., Ottawa, ON. Publ. 1256. 12 p.

Long, A.J.; Carrier B.D. 1993. Effects of Douglas-fir 2+0 seedling morphology on field performance. New Forests 7:19–32.

Lund-Høie, K. 1984. Growth responses of Norway spruce (*Picea abies* L.) to different vegetation management programmes-preliminary results. Aspects of Applied Biology 5:127–133.

MacDonald, G.B.; Weetman, G.F. 1993. Functional growth analysis of conifer seedling responses to competing vegetation. For. Chron. 69:64–68.

McDonald, P.M.; Fiddler, G.O. 1993. Feasibility of alternatives to herbicides in young conifer plantations in California. Can. J. For. Res. 23:2015–2022.

McDonald, P.M.; Helgerson, O.T. 1990. Mulches aid in regenerating California and Oregon forests past, present, and future. USDA For. Serv., Berkeley, CA. Gen. Tech. Rep. PSW-123. 19 p.

Morris, D.M. 1988. Evaluation of morphological and physiological response variables of four-year old black spruce seedlings to perennial competition. Ont. Min. Nat. Resour., Northwestern Ont. For. Tech. Develop. Unit., Thunder Bay, ON. Tech. Rep. 23. 16 p.

Nelson, D.G. 1990. Restocking with sitka spruce on uncultivated gley soils–the effects of fencing, weeding and initial plant size on survival and growth. Scottish For. 44:266–272.

Newton, M.; Preest, D.S. 1988. Growth and water relations of Douglas Fir (*Pseudotsuga menziesii*) seedlings under different weed control regimes. Weed Sci. 36:653–662.

Newton, M.; Cole, E.C.; McCormack, M.L.; White, D.E. 1992a. Young spruce–fir forests released by herbicides. II. Conifer response to residual hardwoods and overstocking. North. J. Appl. For. 9:130–135.

Newton, M.; Cole, E.C.; White D.E.; McCormack, M.L. 1992b. Young spruce–fir forests released by herbicides I. Response of hardwoods and shrubs. North. J. Appl. For. 9:126–130.

Newton, M.; Cole, E.C.; White, D.E. 1993. Tall planting stock for enhanced growth and domination of brush in the Douglas-fir region. New For. 7:107–121.

Paterson, J. 1991. Field performance of black spruce container stock. Number 1. Comparison of two growing environments and four container types–second-year field results from 1989 outplanting. Ont. Min. Nat. Resour., Sault Ste. Marie, ON. For. Res. Rep. 127. 9 p. + appendix.

Radosevich, S.R.; Roncoroni, E.J.; Conard, S.G.; McHenry, W.B. 1980. Seasonal tolerance of six coniferous species to eight foliage-active herbicides. For. Sci. 26:3–9.

Richardson, B. 1991. The effects of plant competition on growth of radiata pine. p. 242–249 *in* M.I. Menzies, G.E. Parrott and L.J. Whitehouse, eds. Efficiency of Stand Establishment Operations. New Zealand Min. For., For. Res. Inst., Rotorua, New Zealand. Bulletin 156. 391 p.

Rowe, J.S. 1972. Forest Regions of Canada. Dept. Environ., Can. For. Serv., Ottawa, ON. Publ. 1300. 130 p. + appendices.

Salisbury, F.B.; Ross, C.W. 1985. Plant Physiology. Third Edition. Wadsworth, Belmont, CA. 540 p.

Scarratt, J.B. 1982. Container stock specifications for northern Ontario. p. 343–354 *in* J.B. Scarratt, C. Glerum and C.A. Plexman, eds. Proc. Canadian Containerized Tree Seedling Symposium. 14–16 Sept. 1981, Toronto, Ontario. Dep. Environ., Can. For. Serv., Sault Ste. Marie, ON. COJFRC Symp. Proc. O-P-10. 460 p.

Scarratt, J.B.; Wood, J.E. 1988. Nine-year results of a black spruce and white spruce paperpot planting trial in boreal Ontario. Gov't Can., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O-X-391. 24 p.

Shirley, H.L. 1943. Is tolerance the capacity to endure shade? J. For. 41:339–345.

Skeates, D.A. 1979. Seed registration in Ontario: A historical review and a look toward the future. p. 168–180 *in* Proceedings of the Tree Improvement Symposium. 19–21 Sept. 1978, Toronto, Ontario. Can. For. Serv., Sault Ste. Marie, ON. Symp. Proc. O-P-7. 233 p. + appendix.

Smith, C.R. 1979. Pottiputki planting tube. Silvicultural equipment reference catalogue for northern Ontario. Ont. Min. Nat. Resour., For. Resour. Br., Toronto, ON. Leaflet H1.

Snedecor, G.W.; Cochran, W.G. 1989. Statistical Methods. Eighth Edition. Iowa State University Press, Ames, IA. 503 p.

South, D.B.; Mason, W.L. 1993. Influence of differences in planting stock size on early height growth of sitka spruce. For. 66:83–96.

Wagner, R.G. 1992. Survey of impacts resulting from herbicide restrictions. Ont. For. Res. Inst., Sault Ste. Marie, ON. VAMP Rep. 1(2):6–7.

Wagner, R.G. 1993. Research directions to advance forest vegetation management in North America. Can. J. For. Res. 23:2317–2327.

Weed Science Society of America. 1989. Herbicide Handbook. Sixth Edition. Weed Science Society of America. Champaign, IL. 301 p.

Weetman, G.F. 1989. Boreal forest pre-harvest silviculture prescriptions: Problems, issues and solutions. For. Chron. 65:85–88.

Wood, J.E.; Dominy, S.W.J. 1985. Black spruce, white spruce, and jack pine outplantings in boreal Ontario: Bareroot vs. paperpot stock and spring vs. summer planting. Gov't of Can., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O-X-368. 67 p. + appendices.

Wood, J.E.; von Althen, F.W.; Campbell, R.A. 1990. Black spruce outplant performance: Effect of winter application of hexazinone on shear-bladed sites in boreal Ontario. Can. J. For. Res. 20:1541–1548.

Wood, J.E.; von Althen, F.W. 1993. Establishment of white spruce and black spruce in boreal Ontario: Effects of chemical site preparation and post-planting weed control. For. Chron. 69:554–560.

Zutter, B.R.; Gjerstad, D.H.; Glover, G.R. 1986. Effects of interfering vegetation on biomass, fascicle morphology and leaf area of loblolly pine seedlings. For. Sci. 32:1016–1031.

Appendix 1. Analyses of soils sampled in 1982 by experiment.

Pit	Depth) (cm)	N (%)	P (ppm)	K (ppm)	pH	Organic matter (%)	Sand (%)	Silt (%)	Clay (%)	Texture class
					Bragg					
1	14	0.066	3.967	0.0122	5.11	1.775	25.1	54.8	20.1	Silt loam
1	62	0.043	4.481	0.0134	6.59	0.707	20.1	41.6	38.3	Clay loam
2	18	0.059	0.59	0.0068	5.58	1.598	27.4	40.2	32.4	Clay loam
2	49	0.016	0.89	0.0054	8.18	0.307	38.0	45.0	17.0	Loam
					Kenning					
1	3	0.044	0.279	0.0067	7.69	1.371	11.2	68.8	20.0	Silt loam
1	20	0.036	2.874	0.0094	7.32	0.904	10.8	58.7	30.5	Silty clay loam
1	82	0.010	1.753	0.0058	8.45	0.134	0.0	80.4	19.6	Silt loam
2	12	0.044	6.171	0.0095	7.76	1.514	11.9	59.9	28.2	Silty clay loam
2	85	0.010	0.035	0.0081	8.37	0.195	1.1	76.6	22.3	Silt loam
					Kenogaming					
1	22	0.132	2.39	0.0036	4.90	4.377	68.5	31.5	0.0	Silty sand
1	42	0.046	4.80	0.0032	5.03	1.358	68.2	31.2	0.6	Silty sand
1	74	0.005	7.18	0.0029	5.60	0.131	72.0	25.6	2.4	Loamy sand
					Lamplugh					
1	15	0.081	2.47	0.0216	5.73	1.280	9.5	30.7	59.8	Clay
1	25	0.058	2.86	0.0201	6.37	0.721	18.1	25.5	56.4	Clay
1	50	0.033	0.84	0.0142	7.87	0.422	16.1	25.8	58.1	Clay
1	56	0.036	0.73	0.0150	7.95	0.370	19.0	27.0	54.0	Clay
2	11	0.402	7.34	0.0204	4.92	9.94	26.6	35.4	38.0	Clay loam
2	32	0.069	3.46	0.0186	5.50	1.00	12.2	31.2	56.5	Clay
2	61	0.048	1.68	0.0160	6.83	0.52	35.45	25.3	39.2	Clay loam
2	81	0.036	0.825	0.0138	7.88	0.41	21.25	26.5	52.25	Clay

Appendix 2. Main plant species present at time of weed control at the four experimental locations.

Common name	Botanical name	Experimental locations: Kenogaming Township	Lamplugh Township	Bragg Township	Kenning Township
alder, speckled	*Alnus rugosa*				✓
aspen, trembling	*Populus tremuloides*	✓ [1]	✓	✓	
aster, big leaf	*Aster macrophyllus*	✓	✓	✓	
bed straw	*Galium* spp.		✓	✓	✓
birch, white	*Betula papyrifera*	✓	✓		
bunchberry	*Cornus canadensis*				✓
cherry, pin	*Prunus pensylvanica*	✓			
fern		✓			
fireweed	*Epilobium angustifolium*		✓		
goldthread	*Coptis trifolia*				✓
grass, brome	*Bromus* L	✓		✓	
grass, Canada blue joint	*Calamagrostis canadensis*	✓	✓	✓	✓
hazel, beaked	*Corylus cornuta*	✓			
honeysuckle, bush	*Diervilla lonicera*	✓			
honeysuckle spp.	*Lonicera* spp.	✓			
horsetail	*Equisetum* spp.				✓
Labrador tea	*Ledum groenlandicum*				✓
laurel, sheep	*Kalmia angustifolia*				✓
maple, mountain	*Acer spicatum*	✓		✓	
mayflower, Canada	*Maianthemum canadense*				✓
moss, haircap	*Polytrichum* spp.				✓
moss, schreber's	*Pleurozium schreberi*				✓
raspberry, red	*Rubus idaeus*	✓	✓	✓	✓
raspberry, dwarf	*Rubus pubescens*		✓	✓	
rose, prickly wild	*Rosa acicularis*		✓		✓
sedge	*Carex*	✓	✓		✓
Sphagnum girgensohnii	*Sphagnum girgensohnii*				✓
Sphagnum nemoreum	*Sphagnum nemoreum*				✓
willow	*Salix* spp.				✓

[1] Indicates species presence.

Appendix 3. Probability of significant effect (P) from analysis of variance of 5th-year and 11th-year black spruce total height, height increment, stem diameter, mortality, and competition index by weed control, stock type, and planting season.[1]

Source	Total height		Height increment		Basal diameter		Mortality		C.I.
	5th year	11th year	5th year	11th year	5th year	11th year	5th year	11th year	11th year
				Kenogaming					
Weed control	0.1048	**0.0001**	0.2286	**0.0001**	**0.0001**	**0.0001**	0.3927	0.3734	**0.0001**
Stock type	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.4818	0.6325	**0.0087**
Planting season	**0.0001**	**0.0001**	**0.0001**	**0.0088**	**0.0001**	**0.0001**	**0.0101**	**0.0354**	0.0642
Weed control x stock type	**0.0134**	**0.0065**	**0.0087**	**0.0028**	0.1541	**0.0018**	0.7902	0.7361	0.1924
Stock type x planting season	0.0860	0.7799	0.3311	0.1456	0.2881	0.9106	0.1008	0.0546	0.4483
				Lamplugh					
Weed control	0.1926	**0.0269**	0.9205	**0.0173**	**0.0216**	**0.0002**	**0.0001**	**0.0001**	**0.0035**
Stock type	**0.0002**	**0.0044**	**0.0012**	0.3211	**0.0001**	**0.0042**	0.3734	0.5569	0.2877
Planting season	**0.0005**	**0.0247**	**0.0038**	0.2333	**0.0001**	**0.0160**	0.1893	**0.0127**	0.7618
Weed control x stock type	0.3456	0.7186	0.5109	0.7864	0.6290	0.6960	0.8275	0.8208	0.3334
Stock type x planting season	0.9587	0.6848	0.5187	0.7738	0.7631	0.4143	0.4843	0.2105	0.2746
				Bragg					
Weed control	0.0696	**0.0376**	0.1314	**0.0208**	**0.0003**	**0.0001**	**0.0436**	0.1586	**0.0001**
weed control vs. none	0.6789	**0.0242**	0.4770	**0.0210**	**0.0001**	**0.0001**	**0.0132**	0.1034	**0.0001**
year of planting vs. year after planting	0.0240	0.2006	0.0598	0.0977	0.1116	0.4254	0.9025	0.3030	0.8626
Stock type	**0.0001**	**0.0002**	**0.0001**	**0.0052**	**0.0001**	**0.0049**	**0.0111**	0.2938	0.3434
Planting season	**0.0303**	0.1719	0.4068	0.1444	**0.0174**	**0.0304**	0.0634	**0.0362**	0.9941
Weed control x stock type	0.2190	0.3907	0.1430	0.9566	0.1171	0.0541	**0.0413**	**0.0105**	0.5456
Stock type x planting season	0.5815	0.6457	0.4199	0.7269	0.4328	0.5570	0.3369	0.2448	0.1965
				Kenning					
Stock type	**0.0080**	0.1724	**0.0383**	0.1523	**0.0451**	0.7139	**0.0227**	**0.0122**	**0.4523**
Planting season	**0.0007**	**0.0043**	**0.0003**	0.1333	**0.0005**	**0.0009**	0.2495	0.2652	0.9378
Stock type x planting season	0.0537	**0.0311**	**0.0077**	0.1495	**0.0054**	**0.0146**	0.2135	0.2515	0.7344

[1] Bolded values are significant at the $P < 0.05$ level.

Appendix 4. Probability of significant effect (P) from analysis of variance of 5th-year and 11th-year black spruce total height, height increment, stem diameter, mortality and competition index, by planting position and weed control.[1]

	df	Total height		Height increment		Basal diameter		Mortality		C.I.
		5th year	11th year	5th year	11th year	5th year	11th year	5th year	11th year	11th year
Position	2	0.2755	**0.0184**	**0.0109**	**0.0003**	0.0760	**0.0176**	**0.0054**	**0.0032**	**0.0167**
center vs. north & south	1	0.4284	0.0510	0.1127	**0.0004**	0.1235	**0.0497**	**0.0137**	**0.0016**	**0.0046**
north vs. south	1	0.1628	**0.0325**	**0.0087**	**0.0297**	0.0879	**0.0316**	**0.0244**	0.1765	0.8406
Weed control	1	0.7763	**0.0007**	0.1704	**0.0001**	**0.0333**	**0.0001**	0.2981	0.3657	**0.0001**
Position x weed control	2	0.4215	0.7894	0.5346	0.6455	0.4344	0.7160	**0.0370**	**0.0247**	0.6268

[1] Bolded values are significant at P < 0.05.