BLACK SPRUCE OUTPLANTINGS IN BOREAL ONTARIO: CHEMICAL SITE PREPARATION WITH HEXAZINONE

J.E. Wood, R.A. Campbell[1], and F.W. Curtis

FORESTRY CANADA

ONTARIO REGION

GREAT LAKES FORESTRY CENTRE

1989

INFORMATION REPORT O-X-398

1 Ontario Ministry of Natural Resources, Pest Management Section, P.O. Box 1000, Sault Ste. Marie, Ontario, Canada P6A 5N5

Catalogue No. Fo46-14/398E
ISBN 0-662-16810-0
ISSN 0832-7122

Additional copies of this publication
are available at no charge from:

Communications Services
Great Lakes Forestry Centre
Ontario Region
Forestry Canada
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Microfiches of this publication may be purchased from:

Micromedia Inc.
Place du Portage
165, Hôtel-de-Ville
Hull, Quebec
J8X 3X2

Wood, J.E., Campbell, R.A. and Curtis, F.W. 1989. Black spruce outplantings in boreal Ontario: chemical site preparation with hexazinone. For. Can., Ontario Region, Sault Ste. Marie, Ont. Inf. Rep. O-X-398. 22 p. + appendices.

ABSTRACT

Fifth-year field performance results are reported from five chemical site preparation experiments with black spruce (**Picea mariana** [Mill.] B.S.P.) in boreal Ontario. Productive upland sites with silty clay to silt loam soils were selected for experimentation. Chemical site preparation with hexazinone applied at several dosages was investigated. Hexazinone, as Velpar® L spray, was applied in the spring after snowmelt. Two stock types, 1½ + 1½ transplants and FH408 Japanese paperpots, were planted up to four weeks after chemical site preparation and also about one year after chemical site preparation. In all, about 9,000 seedlings were studied. Average fifth-year total height and stem diameter of transplants and paperpots were significantly improved by the application of hexazinone at about 2 and 4 kg active ingredient (a.i.) per ha. Both stock types were safely planted up to four weeks after chemical site preparation at maximum dosages of about 2 kg a.i. per ha. At higher dosages, damage was greater among containerized than among transplant stock. When planting was delayed by about one year, both stock types were safely planted at all dosages studied. On clay loam or finer textured soils, chemical site preparation with hexazinone at 2 kg a.i. per ha should be followed as soon as practicable by planting of either bare-root or paperpot stock.

RÉSUMÉ

Dans le cadre d'une étude du rendement en conditions réelles qui se poursuit depuis cinq ans, on rend compte des résultats de cinq expériences de préparation chimique du terrain qui s'effectuent avec de l'épinette noire dans la zone boréale ontarienne. On a choisi des terrains élevés fertiles à sol d'argile silteuse ou de loam sablo-silteux. On a étudié la préparation du terrain avec l'hexazinone à diverses doses. On a appliqué ce produit, en pulvérisation Velpar® L, au printemps après la fonte des neiges, après quoi on a planté deux types de plants, en contenants de carton 1½ + 1½ et FH408 japonais, jusqu'à quatre semaines après le traitement, ainsi qu'au bout d'un an environ. En tout, on a suivi 9 000 plants. On a constaté que la moyenne de la longueur totale et du diamètre de la tige à la cinquième année des plants repiqués et des plants en contenants de carton s'amélioraient dans une mesure significative aven un traitement à l'hexazinone appliquée à raison de 2 et de 4 kg d'ingrédient actif par ha. Les deux types de plants sont restés bien plantés jusqu'à quatre semaines après l'application de doses allant seulement jusqu'à 2 kg d'ingrédient actif par hectare. À plus forte dose, on a constaté que les plants en contenants étaient plus endommagés que les plants repiqués. Les plants dont la plantation a été retardée d'environ un an sont restés bien plantés à toutes les doses étudiées. Dans les sols de loam argileux ou de texture plus fine traités à l'hexazinone à raison de 2 kg d'ingrédient actif par hectare, il est conseillé de procéder dès que possible à la plantation des plants, qu'il s'agisse de plants à racine nues ou en contenants de carton.

ACKNOWLEDGMENTS

The authors wish to acknowledge J.B. Scarratt of the Great Lakes Forestry Centre for providing the paperpot stock and the late L.J. Forcier, of the Swastika Tree Nursery, for providing bare-root stock. In addition, we are indebted to Ontario Ministry of Natural Resources timber management staff in the Kirkland Lake and Hearst districts for assisting with site selection, plot layout, and herbicide application. In particular, R. Dennis made a substantial contribution to the study. Funding by the Canada-Ontario Forest Management Subsidiary Agreement is also gratefully acknowledged.

TABLE OF CONTENTS

INTRODUCTION

Some form of site preparation is virtually always needed to achieve success with forest outplants (e.g., Bärring 1967, Martinsson 1985, Stafford et al. 1985, Ross et al. 1986, Wood et al. 1988). On fertile sites, one of the principal objectives of site preparation is to reduce vegetative competition. Herbicides, used either alone or in combination with other site preparation tools, have the potential to reduce weed competition effectively and efficiently (Sajdak 1982, Preest 1985, Ross et al. 1986).

Herbicides used for site preparation do not need to demonstrate the same degree of safety to the crop as those used for conifer release (Cantrell et al. 1985); residual weed control and the ability to plant crop trees safely at a later date are of greater importance (Cantrell et al. 1985). Velpar® L, a liquid herbicide containing the active ingredient hexazinone, is currently being studied for its site preparation potential in northern Ontario. Hexazinone is a triazine herbicide that can control a broad spectrum of annual and perennial weeds effectively (Neary et al. 1983); it is absorbed primarily through the roots, with some foliar absorption. Although its mode of action has not been clearly established it appears to be an inhibitor of photosynthesis (Beste 1983, Sung et al. 1985). Because of the herbicide's adsorptive properties, higher dosages are required on sites whose soils are rich in organic matter content or clay than on other sites (Cantrell et al. 1985). Minogue et al. (1988) found that when hexazinone was applied as a broadcast foliar spray, hardwood control was positively correlated with increased hexazinone rates of application and negatively correlated with increased soil pH. The liquid formulation of hexazinone has been used to a limited extent by forest managers for conifer site preparation in both the Lake States (Sajdak 1982) and northern Ontario.

To evaluate hexazinone's potential as a site preparation tool for establishing black spruce (**Picea mariana** [Mill.] B.S.P.) on productive upland boreal sites in northern Ontario, a cooperative study was initiated in 1979 by the Ontario Ministry of Natural Resources (OMNR) and the Canadian Forestry Service (now Forestry Canada) (FORCAN). Over a four-year period, five experiments were begun. The study also sought to determine the delay required between chemical site preparation and planting.

This report contains five-year results from the crop-tree response portion of the above study. An in-depth discussion of the herbicide's efficacy will be published in a subsequent report to be prepared by OMNR.

MATERIALS AND METHODS

Experimental Sites

Details are provided in Table 1.

Table 1. Description of the study areas.

Exp.	Twp	Lat. (N)	Long. (W)	Boreal forest region (Section)[a]	Soil texture class	Soil moisture regime[b]	Climatic region[c]	Mean length of growing season (days)[cd]	Mean date of last spring frost[c]	Mean date of first fall frost[c]	Mean annual precip.[c] (cm)
1	Davidson	47°53′	80°16′	Missinaibi-Cabonga (B.7)	deep silt loam	fresh to very fresh	Height of Land	162	15 June	2 Sept.	76.2
2	Davidson	47°53′	80°16′	Missinaibi-Cabonga (B.7)	deep silt loam	very moist	Height of Land	162	15 June	2 Sept.	76.2
3	Lamplugh	48°35′	79°52′	Northern Clay (B.4)	deep silty clay	moderately to very moist	Northern Clay Belt	160	8 June	7 Sept.	78.7
4	Shannon	49°49′	83°28′	Northern Clay (B.4)	shallow sandy clay loam to deep clay loam	very fresh to very moist	Northern Clay Belt	160	8 June	7 Sept.	78.7
5	Lamplugh	48°35′	79°52′	Northern Clay (B.4)	deep silty clay	moderately to very moist	Northern Clay Belt	160	8 June	7 Sept.	78.7

[a] after Rowe 1972
[b] after Anon. 1985
[c] after Chapman and Thomas 1968
[d] No. of days with mean daily temperatures above 5.6°C

Site Histories

Experimental sites 1 and 2 were clear cut between 1959 and 1962. Several years later 2,4-D was applied aerially at 3.4 kg acid per ha. Because the treatment was ineffective the site was prepared in 1970 with shark-fin drums (cf. Smith 1979a). A further application of 2,4-D at 3.4 kg acid per ha followed in 1971. The site was burned by a wildfire in May of 1977 and was unsuccessfully seeded to jack pine (**Pinus banksiana** Lamb.) in the fall of 1977. The site was selected for experimentation because of the dense cover of Canada blue joint grass (**Calamagrostis canadensis** [Michaux] Nutt.), red raspberry (**Rubus idaeus** L. var. **strigosus** [Michx.] Maxim.), and goldenrod (**Solidago** L. spp.).

Prior to harvesting, experimental site 3 supported a mixedwood stand of balsam fir (**Abies balsamea** [L.] Mill.), trembling aspen (**Populus tremuloides** Michx.), black spruce, white birch (**Betula papyrifera** Marsh.), and white spruce (**Picea glauca** [Moench] Voss). The site was cut in 1980 and 1981 and mechanically site prepared with a shearing type blade (cf. Smith 1979b) mounted on a crawler tractor while the ground was covered with snow in March of 1981. Residual white birch and trembling aspen in the experimental area were felled prior to chemical site preparation. Canada blue joint grass, nodding wood grass (**Cinnia latifolia** [Trev.] Griseb.), red raspberry, mountain maple (**Acer spicatum** Lam.), trembling aspen, and speckled alder (**Alnus incana** [L.] Moench spp. **rugosa** [DuRoi] Clausen) were the main plant species competing with the black spruce outplants during the first five growing seasons.

Prior to harvesting, experimental site 4 supported a mixedwood stand of white and black spruces, trembling aspen and white birch. The spruce component was greatest on the lower slopes, and eastern white cedar (**Thuja occidentalis** L.) was also present in the moist depressions. The experimental site was harvested in the fall of 1975 and was site prepared mechanically with a shearing blade (cf. Smith 1979b) mounted on a crawler tractor while the ground was covered with snow, in March of 1981. Residual trembling aspen and white birch in the experimental area were felled prior to chemical site preparation. The main plant species competing with the black spruce outplants during the first five growing seasons were Canada blue joint grass, red raspberry, fireweed (**Epilobium** L. spp.), goldenrod, mountain maple, willow (**Salix** L. spp.), and trembling aspen.

White and black spruces, trembling aspen, white birch and balsam fir were the major tree species in the original stand on experimental site 5. This site was cut in 1980 and 1981. Residual trees, mainly trembling aspen and white birch, were felled in May of 1982 prior to chemical site preparation. The experimental site was not site prepared mechanically because good utilization during harvesting resulted in little slash and there was adequate access for planters to the site. Planters in this experiment were instructed to clear the dry litter layer away from potential planting spots by scuffing with their boots. The main competing plant species during the first five growing seasons were nodding wood grass, red raspberry, spotted touch-me-not (**Impatiens capensis** Meerb.), mountain maple, speckled alder, beaked hazel (**Corylus cornuta** Marsh.), and trembling aspen.

Chemical Site Preparation

Hexazinone was applied before vegetation had flushed in all experiments except experiment 5, in which it was applied in late May (Table 2). Rotary- wing aircraft (Fig. 1) were used to apply herbicide in all experiments except experiment 1, in which a skidder equipped with a ground sprayer was used. With the aerial applications, the average total volume of spray used (water plus herbicide) was 36 L/ha (Table 2); with ground applications, however, approximately 10 times this volume is required to distribute the herbicide evenly. For example, 382 L/ha of water plus chemical were applied by ground sprayer in experiment 1. Vegetation outside of the treatment blocks did not appear to be affected in any of the experiments, and this indicates that there was little off-site deposit or movement of the herbicide with either aerial or ground application.

In general, hexazinone at dosages of 2.0, 4.0 and 9.0 kg a.i. per ha controlled herbaceous vegetation effectively but was relatively ineffective on brush and competing tree species (Fig. 2). In particular, the herbicide provided excellent control of both red raspberry and grasses (Fig. 2). Reynolds et al. (1986) also found that hexazinone provided excellent control of red raspberry. In experiment 2, the application was less uniform than in the other experiments and this resulted in streaky vegetation control.

Table 2. Herbicide treatments applied.

Exp.	Application rates (kg a.i./ha)	Application date	Application equipment	Total spray volume[a] (L/ha)	Spray pressure (KPa)	Travel speed (km/hr)	Swath width (m)
1	0.0, 4.5, and 9.0	19 May 1978	skidder equipped with ground sprayer and Boom Jet 5880-OC20 boomless nozzle cluster	382	275	2.6	15
2	0.0, 1.1, 2.2, and 4.5	15 May 1980	rotary-wing aircraft equipped with 24 D-7 nozzles, on a skid-mounted boom, oriented back 45°C below horizontal	39	210	97	20
3 and 4	0.0, 1.0, 2.0, and 4.0	Exp. 3— 30 April 1981 Exp. 4— 1 May 1981	rotary-wing aircraft equipped with 30 6508 flat fan nozzles, on a skid-mounted boom, oriented back 45° below horizontal	35	240	97	15
5	0.0, 2.0, and 4.0	31 May 1982	rotary-wing aircraft equipped with 29 6508 flat fan nozzles, on a skid-mounted boom, oriented straight back	35	200	89	15

[a] water and chemical combined

Figure 1. Application of hexazinone to experimental block with rotary-wing aircraft.

Figure 2. General view of 2 kg a.i. per ha treatment block in experiment 5. Hexazinone was applied in May of 1982 and the photograph was taken in August of 1983. Herbaceous vegetation and raspberry were well controlled; however, regeneration of competing tree species (viz. pin cherry and birch) and brush (viz. mountain maple and beaked hazel) was not controlled.

Planting Stock

Bare-root transplant stock and Japanese FH408 paperpots were planted on all five experimental sites.

Spring-lifted bare-root transplant (1½ + 1½) stock from Site Region 3200 (Skeates 1979) was used. This stock was supplied by OMNR from the Swastika Tree Nursery. Stock was lifted from the transplant bed, packed in lined kraft bags and placed in cool storage (2°C) at the nursery for as long as two weeks before transport to the planting site. The one-year-old Japanese FH408 paperpots from Site Region 3200 (ibid.) were started indoors, then transferred outdoors for further growth, after which they were over-wintered out of doors at the Great Lakes Forestry Centre. All stock was hand planted. Planting dates and the number of weeks separating chemical site preparation and planting are listed in Table 3. Appendix A contains a description of the characteristics of the planting stock.

Table 3. Planting dates, application dates and number of weeks between chemical site preparation and planting, by experiment.

Experiment	Application date	Planting dates	Approx. no. of weeks between chemical site preparation and planting
1	19 May 1978	29 May to 4 June 1979	53
2	15 May 1980	4-7 June 1980	3
3	30 April 1981	12-25 May 1981 27-28 May 1982	3 52
4	1 May 1981	27 May to 2 June 1981 4-5 June 1982	4 56
5	31 May 1982	31 May to 3 June 1982 16-19 May 1983	0 50

Experimental Design

All five experiments were established according to a completely randomized design. Treatment blocks ranged in size from 0.2 to 2.0 ha and there were from one to two treatment blocks per application rate. Subplots that contained individual stock type and planting date combinations were replicated from two to five times within each treatment block. Specific details are provided in Table 4.

Table 4. Experimental design.

Experiment	Size of main treatment blocks (m)	No. of treatment blocks per application rate	Planting date	No. of seedling subplots per treatment block	No. of seedlings planted per subplot
1	30.5 x 61 (4.5 and 9.0 kg ai/ha rates)	1	1979	4	25
	15.2 x 61 (0.0 kg ai/ha rate)	2	1979	4	13
2	80 x 250	1	1980	5	50
3 and 4	75 x 278	1	1981	5	50
			1982[a]	3	25
5	75 x 267	2	1982	2	25
			1983	2	25

[a] Because insufficient space was left among the 1981 subplots, 1982 subplots contained only 25 seedlings and were replicated three times instead of five times within each treatment block.

Data Analysis

The following crop-tree parameters were examined: survival, total height, and mean relative growth rate (of total height). Stem diameter (outside bark at 1 cm above ground level) was also assessed in experiments 3 to 5. Survival and height data were collected after the first, second, third, and fifth growing seasons. Survival and total height data from the first three assessments are on file but are not described in the present report. Treatment means were compared within each stock type/planting date combination.

Relative growth rate (RGR) can be defined as the change in plant size (in this study, height) per unit of size per unit of time, and is analogous to the rate of return on a financial investment (Hunt 1978, 1982). In the present study, RGR between years one (T_1) and five (T_5) of the study (RGR5) is defined as follows:

$$RGR5 = \frac{\ln\ (\text{height at } T_5) - \ln\ (\text{height at T1})}{T_5 - T_1}$$

Final plant size, therefore, depends upon initial plant size (amount of money invested), period of growth (investment period) and absolute growth rate (interest rate). RGR is a useful measure of a plant's growth efficiency. Scarratt and Wood (1988) concluded that RGR was a useful adjunct to indices of absolute growth for evaluating plantation performance.

In many situations, RGR can provide valuable information on the growth dynamics of a situation and can be useful in the interpretation of biological response.

RGR can be expressed as an instantaneous value or as a mean value (Hunt 1978). The former is the rate of growth at a particular point in time, and is free to change with time, whereas the latter is the average rate of growth over a fixed period, e.g., from year 1 to year 5 (Hunt 1978). Both instantaneous and mean RGR values can be derived from the plot of the natural logarithm of plant size against time (Fig. 3). Instantaneous RGR is the slope of the line that plots the natural logarithm of height versus time, at a particular point in time; mean RGR is the slope of the line that connects two values of height at the beginning and end of the desired time period.

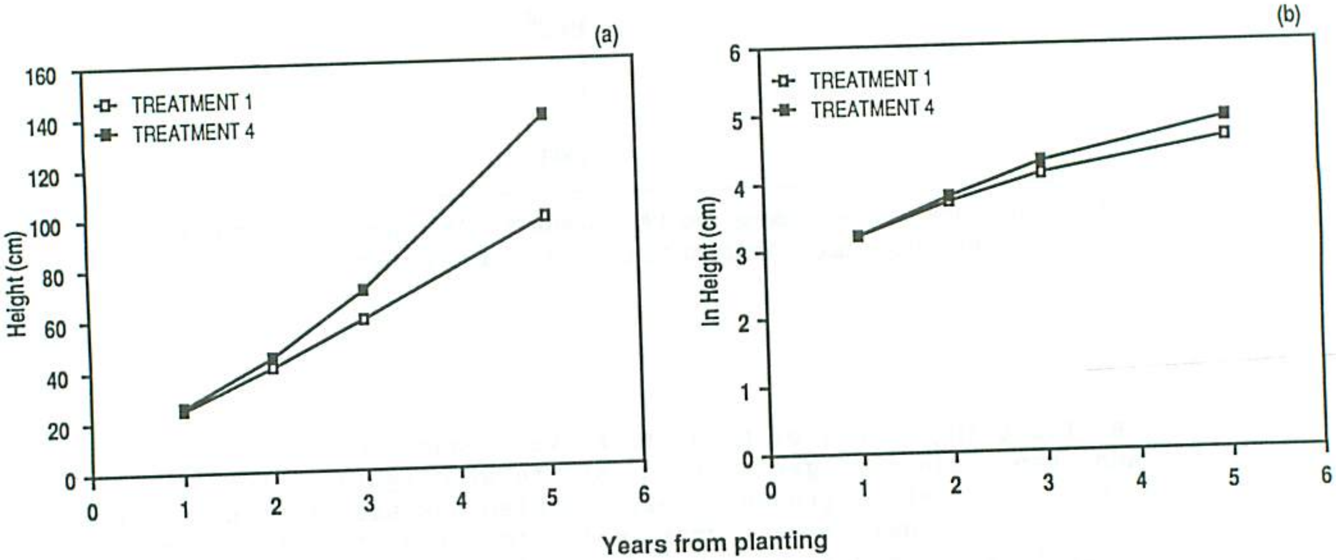

Figure 3. Bare-root height data plotted against the number of years after planting for two treatments in experiment 3, (a) progression of total height against time, (b) progression of the natural logarithm of total height against time.

Mean RGR (total height) was calculated for individual seedlings, by means of the formula provided above, over the period from the end of the first to the end of the fifth growing season.

Plot means were analyzed by means of analysis of variance (Steel and Torrie 1980) and significant differences were identified by means of the Waller-Duncan procedure (Milliken and Johnson 1984). Survival data were transformed (y=arcsine $\sqrt{\text{percent}/100}$) before analysis (Freese 1967).

RESULTS

Experiment 1

Average fifth-year survival of **transplant stock** planted one year after chemical site preparation ranged from 88 to 91%; no difference among treatment means was significant (Table 5 and Appendix B). Average total height and RGR5 (total height) per annum were significantly greater for the 4.5 and 9.0 kg a.i. per ha treatments than for the nonchemical treatment. Since the transplant stock in experiment 1 varied little in size at time of planting and was presumed to vary little in physiological status, higher RGR5 values can be interpreted to mean that the trees in the chemical treatments have been increasing in height at a faster rate than those in the nonchemical treatments. The differences between the two chemically site prepared treatments in average total height and RGR5 were nonsignificant.

Table 5. Experiment 1. Survival and total height five growing seasons after outplanting and mean relative growth rate (total height) per annum from year 1 to year 5 for black spruce bare-root 1½ + 1½ transplant stock and FH408 Japanese paperpots.

Variables	Rates (kg a.i./ha)	Stock type/year planted[a]			
		Bare-root/1979		Paperpot/1979	
		(%)		(%)	
SURV5[b]	0.0	88 a		89 a	
	4.5	88 a		87 a	
	9.0	91 a		83 a	
		(cm)	(%)	(cm)	(%)
THT5[c]	0.0	42 b	100	30 c	100
	4.5	65 a	155	52 b	173
	9.0	68 a	162	59 a	197
		(yr^{-1})	(%)	(yr^{-1})	(%)
RGR5[d]	0.0	.165 b	100	.314 b	100
	4.5	.268 a	162	.432 a	138
	9.0	.296 a	179	.444 a	141

[a] Numbers followed by the same letter, for the same stock type, are not significantly different at the p = 0.05 level.
[b] SURV5 = survival five growing seasons after outplanting
[c] THT5 = total height five growing seasons after outplanting
[d] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

Average fifth-year survival for **paperpots** planted one year after chemical site preparation averaged 86%; no difference between treatment means was significant. Nevertheless, all differences in average total height after five growing seasons were significant. The 9.0 kg a.i. per ha treatment resulted in the tallest trees, followed by the 4.5 kg a.i. per ha treatment. The trees in the nonchemical treatment were shortest. RGR5 was significantly higher with chemical site preparation than without. However, differences between rates were nonsignificant.

Experiment 2

Average fifth-year survival of **transplants** planted three weeks after chemical site preparation ranged from 89 to 97% for all but one treatment (Table 6 and Appendix B). There was some evidence of injury from the 4.5 kg

Table 6. Experiment 2. Survival and total height five growing seasons after outplanting and mean relative growth rate (total height) per annum from year 1 to year 5 for black spruce bare-root 1½ + 1½ transplant stock and FH408 Japanese paperpots.

		Stock type/year planted[a]			
Variables	Rates (kg a.i./ha)	Bare-root/1980		Paperpot/1980	
		(%)		(%)	
SURV5[b]	0.0	92 ab		80 ab	
	1.1	97 a		90 a	
	2.2	89 bc		77 ab	
	4.5	79 c		66 b	
		(cm)	(%)	(cm)	(%)
THT5[c]	0.0	57 b	100	35 d	100
	1.1	66 a,b	116	48 b	137
	2.2	64 a,b	112	43 c	123
	4.5	72 a	126	62 a	177
		(yr^{-1})	(%)	(yr^{-1})	(%)
RGR5[d]	0.0	.263 a	100	.378 b	100
	1.1	.286 a	109	.412 b	109
	2.2	.276 a	105	.395 b	104
	4.5	.309 a	117	.475 a	126

[a] Numbers followed by the same letter, for the same stock type, are not significantly different at the p = 0.05 level.
[b] SURV5 = survival five growing seasons after outplanting
[c] THT5 = total height five growing seasons after outplanting
[d] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

a.i. per ha treatment since survival (79%) was significantly lower than in the nonchemical treatment or in the 1.1 kg a.i. per ha treatment. However, average total height in the 4.5 kg a.i. per ha treatment was significantly greater (126% of the nonchemical treatment) than in the nonchemical treatment; all other differences were nonsignificant. None of the RGR5 treatment means differed significantly.

Average fifth-year survival of **paperpot** stock planted three weeks after chemical site preparation was significantly greater in the 1.1 kg a.i. per ha treatment than in the 4.5 kg a.i. per ha treatment. All differences in average total height among the four treatment means were significant. Average total height was greatest in the 4.5 kg a.i. per ha treatment, followed by the 1.1, 2.2 and 0.0 kg a.i. per ha treatments, respectively. Average RGR5 ranged from 0.378 to 0.412 for all treatments except the 4.5 kg a.i. per ha treatment, in which growth was significantly higher (126% of the value for the nonchemical treatment).

Experiment 3

Differences among average fifth-year survival treatment values for **transplants** planted in 1981, 3 weeks after chemical site preparation, ranged from 83 to 90% (Table 7 and Appendix B). However, all differences among these values were nonsignificant. Average total height and average stem diameter were significantly greater in the 4.0 and 2.0 kg a.i. per ha treatments than in the 1.0 kg a.i. per ha and the nonchemical treatments. Average total height and stem diameter were significantly greater in the 1.0 kg a.i. per ha treatment than in the nonchemical treatment (118% and 124%, respectively, of the value for the nonchemical treatment). All of the comparisons among average RGR5 treatment values were nonsignificant.

Average fifth-year survival of **transplants** planted in 1982 (i.e., those planted one year after chemical site preparation) ranged from 84 to 96%. The average total height of transplants was significantly greater in the 4.0 kg a.i. per ha treatment than in all other treatments. Average total height in the 2.0 kg a.i. per ha treatment was significantly greater (131% of the nonchemical treatment) than that in the nonchemical treatment. Average stem diameter ranged from 13 to 19 mm for all except the 4.0 kg a.i. per ha treatment, in which growth was significantly greater (at 26 mm). Average RGR5 (total height) values in the 4.0 and 2.0 kg a.i. per ha treatments did not differ significantly, but both were significantly higher than that in the nonchemical treatment.

Average fifth-year survival of **paperpots** planted in 1981 (i.e., those planted 3 weeks after chemical site preparation) was significantly higher (at 79%) in the 2.0 kg a.i. per ha treatment than that in the other treatments. Average survival was significantly higher in both the 1.0 and 2.0 kg a.i. per ha treatments than in the 4.0 kg a.i. per ha treatment. Average total height in the 2.0 and 4.0 kg a.i. per ha treatments was 160 and 148% of that in the nonchemical treatment, respectively. However, differences in average total height between the 2.0 and 4.0 kg a.i. per ha treatments were nonsignificant. The average stem diameters in both the 2.0

and 4.0 kg a.i. per ha treatments were significantly greater than those in the 1.0 kg a.i. per ha and the nonchemical treatments. Average RGR5 (total height) in the chemical treatments was significantly higher than that in the nonchemical treatment (117 to 123% of the value for the nonchemical treatment).

Table 7. Experiment 3. Survival, total height, and stem diameter five growing seasons after outplanting and mean relative growth rate (total height) per annum from year 1 to year 5 for black spruce bare-root 1½ + 1½ transplant stock and FH408 Japanese paperpots.

Variables	Rates (kg a.i./ha)	Stock type/year planted[a] Bare-root/1981		Bare-root/1982		Paperpot/1981		Paperpot/1982	
		(%)		(%)		(%)		(%)	
SURV5[b]	0.0	83 a		84 a		48 b,c		71 a	
	1.0	90 a		85 a		63 b		75 a	
	2.0	90 a		84 a		79 a		79 a	
	4.0	87 a		96 a		39 c		91 a	
		(cm)	(%)	(cm)	(%)	(cm)	(%)	(cm)	(%)
THT5[c]	0.0	98 c	100	85 c	100	58 c	100	52 c	100
	1.0	116 b	118	96 bc	113	82 b	141	67 b,c	129
	2.0	131 a	134	111 b	131	93 a	160	80 b	154
	4.0	138 a	141	131 a	154	86 a,b	148	111 a	213
		(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
DIA5[d]	0.0	17 c	100	13 b	100	9 c	100	7 c	100
	1.0	21 b	124	15 b	115	14 b	156	9 c	129
	2.0	28 a	165	19 b	146	18 a	200	12 b	171
	4.0	30 a	176	26 a	200	18 a	200	22 a	314
		(yr^{-1})	(%)	(yr^{-1})	(%)	(yr^{-1})	(%)	(yr^{-1})	(%)
RGR5[e]	0.0	.394 a	100	.282 c	100	.394 b	100	.355 b	100
	1.0	.398 a	101	.325 b,c	115	.486 a	123	.377 b	106
	2.0	.407 a	103	.364 a,b	129	.462 a	117	.439 a	124
	4.0	.424 a	108	.400 a	142	.461 a	117	.484 a	136

[a] Numbers followed by the same letter, for the same stock type, are not significantly different at the p = 0.05 level.
[b] SURV5 = survival five growing seasons after outplanting
[c] THT5 = total height five growing seasons after outplanting
[d] DIA5 = stem diameter 1 cm above ground level five growing seasons after outplanting
[e] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

Average fifth-year survival of **paperpots** planted in 1982 (i.e., those planted one year after chemical site preparation) ranged from 71 to 91%. Average total height was significantly greater in the 4.0 kg a.i. per ha treatment than in all other treatments. There were no significant differences between average total height in the 2.0 and 1.0 kg a.i. per ha treatments, but mean total height in the 2.0 kg a.i. per ha treatment was significantly higher than that in the nonchemical treatment. In terms of average stem diameter and average RGR5 (total height), the 1.0 kg a.i. per ha treatment and the nonchemical treatment were not significantly different. However, the two best treatments (i.e., 2.0 and 4.0 kg a.i. per ha) resulted in significantly larger stem diameters (171 and 314%, respectively, of the nonchemical treatment) and had higher average RGR5 values (124 and 136%, respectively, of the nonchemical treatment) than the two poorest (i.e., the 1.0 kg a.i. per ha and nonchemical treatments).

Experiment 4

Results from experiment 4 (Table 8 and Appendix B) resembled those from experiment 3. The main difference was that the superiority of the heavier herbicide treatment over the lighter was more significant in experiment 4 than in experiment 3.

Experiment 5

Experiment 5 differed from the other four experiments in that it was not mechanically site prepared. Average fifth-year survival of **transplants** planted in 1982 (i.e., those planted immediately after chemical site preparation) ranged from 89 to 96% in all treatments (Table 9 and Appendix B). Average total height and mean ground level stem diameters for the 2.0 and 4.0 kg a.i. per ha treatments did not differ significantly, but were both significantly higher than those in the nonchemical treatment. Average RGR5 (total height) ranged from 0.383 to 0.386 in all treatments except the nonchemical treatment, which was significantly lower at 0.296.

Average fifth-year survival of **transplants** planted in 1983 (i.e., those planted one year after chemical site preparation) did not differ significantly among treatments. Differences among treatment means for average total height, average stem diameter, and RGR5 (total height) were also nonsignificant.

Most of the differences between treatment means (e.g., survival, total height, and stem diameter at ground level) for **paperpots** planted in 1982 (i.e., those planted immediately after chemical site preparation) were nonsignificant. None of the average RGR5 values differed significantly except that for the nonchemical treatment, which was significantly lower.

Average survival of **paperpots** planted in 1983 (i.e., those planted one year after chemical site preparation) was significantly higher in the 2.0 kg a.i. per ha treatment than that in the nonchemical treatment; all other treatment differences were nonsignificant. Mean total height and

Table 8. Experiment 4. Survival, total height, and stem diameter five growing seasons after outplanting and mean relative growth rate (total height) per annum from year 1 to year 5 for black spruce bare-root 1½ + 1½ transplant stock and FH408 Japanese paperpots.

Variables	Rates (kg a.i./ha)	Stock type/year planted[a] Bare-root/1981		Bare-root/1982		Paperpot/1981		Paperpot/1982	
		(%)		(%)		(%)		(%)	
SURV5[b]	0.0	95 a		97 a,b		86 a		97 a	
	1.0	94 a		93 b		87 a		100 a	
	2.0	92 a,b		96 b		80 a		100 a	
	4.0	80 b		100 a		52 b		89 a	
		(cm)	(%)	(cm)	(%)	(cm)	(%)	(cm)	(%)
THT5[c]	0.0	83 c	100	69 b	100	53 b	100	52 b	100
	1.0	91 b	110	66 b	96	64 a,b	121	63 b	121
	2.0	95 b	114	78 b	113	66 a	125	66 b	127
	4.0	110 a	133	101 a	146	76 a	143	87 a	167
		(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
DIA5[d]	0.0	13 c	100	11 b,c	100	7 b	100	8 b	100
	1.0	16 b	123	10 c	91	10 b	143	9 b	118
	2.0	16 b	123	13 b	118	10 b	143	10 b	125
	4.0	23 a	177	18 a	164	13 a	186	17 a	212
		(yr^{-1})	(%)	(yr^{-1})	(%)	(yr^{-1})	(%)	(yr^{-1})	(%)
RGR5[e]	0.0	.329 c	100	.301 b	100	.380 a	100	.316 a	100
	1.0	.346 b,c	105	.269 b	89	.370 a	97	.352 a	111
	2.0	.361 a,b	110	.306 b	102	.445 a	117	.334 a	106
	4.0	.381 a	116	.385 a	128	.439 a	116	.374 a	118

[a] Numbers followed by the same letter, for the same stock type, are not significantly dif-different at the p = 0.05 level.

[b] SURV5 = survival five growing seasons after outplanting

[c] THT5 = total height five growing seasons after outplanting

[d] DIA5 = stem diameter 1 cm above ground level five growing seasons after outplanting

[e] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

Table 9. Experiment 5. Survival, total height, and stem diameter five growing seasons after outplanting and mean relative growth rate (total height) per annum from year 1 to year 5 for black spruce bare-root 1½ + 1½ transplant stock and FH408 Japanese paperpots.

Variables	Rates (kg a.i./ha)	Stock type/year planted[a]							
		Bare-root/1982		Bare-root/1983		Paperpot/1982		Paperpot/1983	
		(%)		(%)		(%)		(%)	
SURV5[b]	0.0	96 a		79 a		70 a		29 b	
	2.0	90 a		94 a		85 a		70 a	
	4.0	89 a		93 a		69 a		51 a,b	
		(cm)	(%)	(cm)	(%)	(cm)	(%)	(cm)	(%)
THT5[c]	0.0	79 b	100	94 a	100	64 a	100	44 b	100
	2.0	118 a	149	111 a	118	83 a	130	79 a	180
	4.0	108 a	137	120 a	128	79 a	123	85 a	193
		(mm)	(%)	(mm)	(%)	(mm)	(%)	(mm)	(%)
DIA5[d]	0.0	12 b	100	14 a	100	9 a	100	6 b	100
	2.0	20 a	167	18 a	129	13 a	144	12 a,b	200
	4.0	21 a	175	23 a	171	17 a	189	17 a	283
		(yr^{-1})	(%)	(yr^{-1})	(%)	(yr^{-1})	(%)	(yr^{-1})	(%)
RGR5[e]	0.0	.296 b	100	.224 a	100	.356 b	100	.249 b	100
	2.0	.383 a	129	.266 a	119	.430 a	121	.364 a	146
	4.0	.386 a	130	.289 a	129	.446 a	125	.417 a	167

[a] Numbers followed by the same letter, for the same stock type, are not significantly different at the p = 0.05 level.
[b] SURV5 = survival five growing seasons after outplanting
[c] THT5 = total height five growing seasons after outplanting
[d] DIA5 = stem diameter 1 cm above ground level five growing seasons after outplanting
[e] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

RGR5 were significantly greater in the 4.0 and 2.0 kg a.i. per ha treatments than in the nonchemical treatment. Average stem diameter was significantly greater in the 4.0 kg a.i. per ha treatment than in the nonchemical treatment (283% of the nonchemical treatment); all other differences among treatments were nonsignificant.

DISCUSSION

Site preparation with hexazinone significantly improved the field performance of both transplant (Fig. 4) and paperpot stock during the first five growing seasons when planting was carried out up to four weeks after chemical site preparation. In experiment 4, the 4 kg a.i. per ha dosage improved the height growth and diameter of the transplant stock significantly more than did the 2 kg a.i. per ha dosage. In experiment 2, paperpots generally benefited from the higher dosage. In Oregon and Washington, Dimock et al. (1983) applied hexazinone at 2.2 kg a.i. per ha two weeks before outplantings of two-year-old, bare-root nursery-grown ponderosa pine (**Pinus ponderosa** Laws.) and Douglas-fir (**Pseudotsuga menziesii** var. **glauca** [Beissn.] Franco) seedlings. Height and stem diameter of Ponderosa pine six growing seasons after outplanting were increased to 142 and 159%, respectively, of those of the untreated controls; the corresponding increases for Douglas-fir were 166 and 169%. In the present study, total height of transplants in treatments with chemical site preparation at the 2 and 4 kg a.i. per ha dosages was an average of 129% and 135%, respectively, of that of the nonchemical treatment after five growing seasons (Table 10) and average stem diameter at ground level was 152 and 179%, respectively, of that of the nonchemical treatment. The corresponding increases for paperpots after five growing seasons averaged 137 and 146%, respectively, in mean total height, and 175 and 200%, respectively, for mean stem diameter.

When planting was carried out one year after chemical site preparation, both the 2.0 and 4.0 kg a.i. per ha treatments improved the field performance of the transplant stock and paperpots. Total height of transplant stock after five growing seasons in treatments with chemical site preparation at the nominal 2.0 and 4.0 kg a.i. per ha dosages was 138 and 143%, respectively, of that in the nonchemical treatment (Table 10). For the same two treatments, mean stem diameter at ground level was 131 and 176%, respectively, of that of the nonchemical treatment. The corresponding 5th-year comparisons for paperpots were 169 and 188%, respectively, for mean total height, and 161 and 267%, respectively, for mean stem diameter at ground level.

Values of RGR5 (total height) were greater in the treatments with chemical site preparation at the 2.0 or 4.0 kg a.i. per ha rates (for both stock types) than in the nonchemical treatments, an indication that the differential in total height between the chemical and nonchemical treatments increased during the first five growing seasons. For each stock type and time of planting, the differential in total height between chemical and nonchemical treatments increased from the third to fifth growing seasons (Table 10). The benefits of weed control that were realized in the first five years of this study seem to be increasing.

Figure 4. Black spruce transplants, five growing seasons after planting, illustrating differences in shoot form between trees grown among raspberry and other competing species (top) and trees grown in the open (bottom).

Table 10. Summary of total height data for experiments 1 to 5, expressed as a percentage of the value for the treatment with no chemical site preparation.

Nominal rate (kg a.i./ha)	3rd-year assessment		5th-year assessment	
	Bare-root	Paperpot	Bare-root	Paperpot
	Planted same year as chemical site preparation (%)			
0	100	100	100	100
2	123	126	129	137
4	125	131	135	146
	Planted one year after chemical site preparation (%)			
0	100	100	100	100
2	110	142	138	169
4	127	155	143	188

When planting was carried out up to four weeks after chemical site preparation, average mortality after five growing seasons was higher in the treatments that received 4 kg a.i. per ha of hexazinone than in the other treatments. For instance, in comparison with the nonchemical treatment, mortality of transplant stock and paperpots averaged 7 and 15% more, respectively, as a result of the 4.0 kg a.i. per ha dosage. These comparisons indicate that, on sites similar to those studied, hexazinone site preparation at rates of 4 kg a.i. per ha or more will increase mortality. These comparisons also indicate that the transplants in our study were more tolerant of the 4 kg a.i. per ha herbicide application than the paperpots were. Bärring (1967), working with Norway spruce (**Picea abies** [L.] Karst.) on damp soils in central Sweden, found that when the soil-active herbicides simazine, atrazine, and diuron were applied around established seedlings mortality was significantly less among outplants whose root systems were inserted vertically into the soil than among those whose root systems were not vertical. He hypothesized that because of the damp soil conditions, the seedlings with shallowly planted root systems absorbed toxic levels of herbicide. The root systems of the paperpot stock that we used in our study were also initially closer to the soil surface than those of the bare-root stock and hence may have absorbed more of the herbicide than the bare-root stock did. Other possible explanations for the differential tolerance of the two stock types to hexazinone might include initial differences between the size of stock and physiological differences (e.g., dormant, cool-stored transplant stock versus flushed, containerized seedlings) at time of planting.

When planted about one year after chemical site preparation, stock of both types was tolerant of hexazinone up to the maximum dosages applied. In several instances, survival was improved by the application of hexazinone.

On productive boreal forest planting sites, weed control is an important aspect of site preparation. Bärring (1967), studying regeneration on abandoned farmland in central Sweden, concluded that screefing, ridge plowing, and herbicide application were all acceptable methods of weed control. However, he found herbicides to be more effective than the other methods on heavy soils. In fact, herbicides offer a number of potential advantages over other site-preparation methods. For example, herbicides are often less expensive than mechanical site preparation or burning; they result in less soil disturbance and smaller increases in soil bulk density; they do not remove or concentrate the site's nutrient capital; and they can be quickly applied over large areas and used in rough terrain (cf. Newton 1975, MacKasey 1983, Corns 1988). In our study, experiment 5 was the only experiment in which comparisons between chemical site preparation and no site preparation were made. Results obtained from the 1982 bare-root and paperpot plantings and the 1983 bare-root planting in experiment 5 were comparable with the results that were obtained in the other four experiments. These data seem to indicate that, for upland boreal sites with fine-textured soils, the option may exist to replace or supplement certain forms of mechanical site preparation with herbicides. However, the forest manager must realize that the amount and type of debris remaining on the site after harvest and the depth of organic layer will influence the practicability of using only chemical site preparation. Before the forest manager adopts hexazinone as an alternative to mechanical site preparation, spatially and temporally replicated experimentation, in which various site preparation and regeneration techniques are compared, needs to be carried out.

Working in southern Ontario on clay soils, von Althen (1970) reported that the survival of white spruce after complete weed control was reduced significantly as a result of severe frost heaving. In areas with below-freezing temperatures, adequate soil water and susceptible soils, frost heaving is a major cause of tree seedling mortality (Heidmann 1976). Heidmann recommended the use of mulches, shade, or soil coatings to reduce heat loss from the soil and thereby to maintain soil water above the freezing point so as to reduce heaving. Furthermore, Graber (1971) recommended that some portion of residual vegetation be maintained on the site to moderate temperature fluctuations at the soil surface. For white spruce at least, Sutton (1984) found that some residual vegetative cover can be beneficial from the point of view of protecting young outplants from late-spring or early-fall frosts. Although frost heaving was not rigorously assessed in our study, we did observe that the incidence of frost heaving on the plots with better weed control was greater than that on the plots with poorer weed control. This observation can be combined with Graber's (1971) recommendation to reinforce our suggestion that 2.0 kg a.i. per ha of hexazinone be used for chemical site preparation on sites similar to those we studied.

Results from our study suggest that, for paperpots at least, treatment with 4.0 kg a.i. per ha is not advisable unless the site is left fallow for one full year after chemical site preparation. With transplants, it is questionable whether or not the increased chemical costs as a result of using the higher (4.0 kg a.i. per ha) dosage can be justified by the better field performance of crop trees at that higher dosage. Over all, the safest chemical site preparation option on clay loam or finer textured soils, for both stock types, is to apply hexazinone at the 2 kg a.i. per ha level and to plant as soon as practicable afterwards so that the crop trees may take maximum advantage of the weed control. However, the forest manager must realize that the initial weed control will not be as complete nor the residual weed control as prolonged with the 2 kg a.i. per ha dosage as with the 4 kg a.i. per ha dosage (cf. Lehela and Campbell 1986).

LITERATURE CITED

Anon. 1985. Field manual for describing soils. 3rd ed. Univ. Guelph, Ont. Inst. Pedol., Publ. No. 85-3. 42 p.

Bärring, U. 1967. Studier av metoder for plantering av gran och tall på åkermark i sodra och mellersta Sverige. Stud. For. Suec. No. 50:1-332.

Beste, C.E. 1983. Herbicide Handbook. 5th ed. Weed Sci. Soc. Am., Champaign, Ill. 515 p.

Cantrell, R.L., Minogue, P.J., Metcalfe, C.S. and Zutter, B.R. 1985. Silvicultural herbicide uses. p. 2-1 to 2-15 **in** R.L. Cantrell, **Ed.** A guide to silvicultural herbicide use in the southern United States. Auburn Univ. Sch. For., Alabama Agric. Exp. Stn.

Chapman, L.J. and Thomas, M.K. 1968. The climate of northern Ontario. Dep. Transp., Meteorol. Br., Climatol. Stud. No. 6. 58 p.

Corns, I.G.W. 1988. Compaction by forestry equipment and effects on coniferous seedling growth on four soils in the Alberta foothills. Can. J. For. Res. 18:75-84.

Dimock, E.J., Beebe, T.F. and Collard, E.B. 1983. Planting-site preparation with herbicides to aid conifer reforestation. Weed Sci. 31:215-221.

Freese, F. 1967. Elementary statistical methods for foresters. USDA For. Serv., Agric. Handb. 317. 75 p. + appendices.

Graber, R.E. 1971. Frost heaving... seedling losses can be reduced. USDA For. Serv., Tree Plant. Notes 22:24-28.

Heidmann, L.J. 1976. Frost heaving of tree seedlings: a literature review of causes and possible control. USDA For. Serv., Gen. Tech. Rep. RM-21. 10 p.

Hunt, R. 1978. Plant growth analysis. Edward Arnold, London. Inst. Biol., Stud. in Biol. No. 96. 67 p.

Hunt, R. 1982. Plant growth curves: the functional approach to plant growth analysis. Edward Arnold, London. 248 p.

Lehela, A. and Campbell, R.A. 1986. Changes in numbers of plant species following hexazinone application to a forest site. p. 217 **in** B.H. Marose, **Ed.** Proc. 40th Annu. Meet. Northeastern Weed Sci. Soc., Vol. 40.

MacKasey, M.M. 1983. Using herbicides now can help to ensure adequate timber supplies in the 21st century. Pulp Pap. Can. 84:21-22.

Martinsson, O. 1985. The influence of site preparation on survival, growth and shoot/root ratio in young stands of Scots pine, Norway spruce and lodgepole pine. Sveriges Lantbr. f. Skogsskötsel, Rapp. No. 15. 29 p.

Morrison, I.K. and Armson, K.A. 1968. The rhizometer--a device for measuring roots of tree seedlings. For. Chron. 44:21-23.

Milliken, G.A. and Johnson, D.E. 1984. Analysis of messy data. Volume 1: designed experiments. Lifetime Learning Publications, London. 473 p.

Minogue, P.J., Zutter, B.R. and Gjerstad, D.H. 1988. Soil factors and efficacy of hexazinone formulations for loblolly pine (**Pinus taeda** L.) release. Weed Sci. 36:399-405.

Neary, D.G., Bush, P.B. and Douglass, J.E. 1983. Off-site movement of hexazinone in stormflow and baseflow from forest watersheds. Weed Sci. 31:543-551.

Newton, M. 1975. Constructive use of herbicides in forest resource management. J. For. 73:329-336.

Preest, D.S. 1985. Chemical aids to planting site preparation. N.Z. For. Serv., Rotorua, N.Z. FRI Bull. No. 100. 10 p. + appendices.

Reynolds, P.E., MacKay, T.S. and McCormack, M.L. 1986. Results of a hexazinone-mechanical site preparation trial. p. 222-229 **in** B.H. Marose, **Ed.** Proc. 40th Annu. Meet. Northeastern Weed Sci. Soc., Vol. 40.

Ross, D.W., Scott, W., Heninger, R.L. and Walstad, J.D. 1986. Effects of site preparation on ponderosa pine (**Pinus ponderosa**), associated vegetation, and soil properties in south central Oregon. Can. J. For. Res. 16:612-618.

Rowe, J. S. 1972. Forest regions of Canada. Dep. Environ., Can. For. Serv., Ottawa, Ont. Publ. No. 1300, 172 p.

Sajdak, R.L. 1982. Site preparation in the Upper Great Lakes Region. p. 209-214 **in** G.D. Mroz and J.F. Berner, **Comp.** Proc. Artific. Regen. Conifers in the Upper Great Lakes Region. Mich. Tech. Univ., Houghton, Mich.

Scarratt, J.B. and Wood, J.E. 1988. Nine-year results of a black spruce and white spruce paperpot trial in boreal Ontario. Gov't of Can., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-393. 24 p.

Skeates, D.A. 1979. Seed registration in Ontario: a historical review and a look toward the future. p. 168-180 **in** Proc. Tree Improvement Symp. Dep. Environ., Can. For. Serv., Sault Ste. Marie, Ont., Symp. Proc. O-P-7.

Smith, C.R. 1979a. Scarification barrels. Silvicultural equipment reference catalogue for northern Ontario. Ont. Min. Nat. Resour., For. Resour. Br., Toronto, Ont. Leaflet E.1.

Smith, C.R. 1979b. Rome K/G clearing blade. Silvicultural equipment reference catalogue for northern Ontario. Ont. Min. Nat. Resour., For. Resour. Br., Toronto, Ont. Leaflet B.2.

Stafford, C.W., Torbert, J.L. and Burger, J.A. 1985. An evaluation of site preparation methods for loblolly pine regeneration on the Piedmont. p. 57-64 **in** E. Shoulders, **Ed.** Proc. Third Biennial South. Silvic. Res. Conf., USDA For. Serv., New Orleans, La. Gen. Tech. Rep. SO-54.

Steel, R.G.D. and Torrie, J.H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York. 633 p.

Sung, S.S., South, D.B. and Gjerstad, D.H. 1985. Bioassay indicates a metabolite of hexazinone affects photosynthesis of loblolly pine (**Pinus taeda**). Weed Sci. 33:440-442.

Sutton, R.F. 1984. Plantation establishment in the boreal forest: glyphosate, hexazinone, and manual weed control. For. Chron. 60:283-287.

von Althen, F.W. 1970. Methods for successful afforestation of a weed infested clay soil. For. Chron. 46:139-143.

Wood, J.E., Sutton, R.F., Weldon, T.P. and Rissanen, H. 1988. Jack pine establishment: effect of stock type, Bräcke scarification, mounding, and chemical site preparation. Three-year results. Gov't of Can., Can. For. Serv., Sault Ste. Marie, Ont. Inf. Rep. O-X-393. 16 p. + appendices.

APPENDICES

Appendix A. Morphological characteristics of black spruce planting stock.

Stock type	Planting date (d/mo/yr)	Total oven-dry mass (g)	Root collar diam (mm)	Root area index (cm)[a]	Shoot: root ratio	Shoot length (cm)
Expt. 1						
Bare-root	29/5/79 to 4/6/79	4.8 (±1.5)[b]	4.6 (±0.9)	31.3 (±16.7)	6.5 (±6.8)	24.1 (±3.3)
Paperpot	29/5/79 to 4/6/79	0.7 (±0.1)	1.5 (±0.3)	10.0 (±8.3)	2.3 (±0.6)	8.8 (±1.8)
Expt. 2						
Bare-root	4-7/6/80	6.0 (±1.4)	4.4 (±0.9)	59.9 (±20.3)	2.1 (±0.6)	21.5 (±2.7)
Paperpot	4-7/6/80	0.4 (±0.1)	1.5 (±0.2)	7.0 (±1.8)	3.4 (±1.8)	9.6 (±1.3)
Expt. 3						
Bare-root	12-25/5/81	7.4 (N/A)	4.9 (±1.2)	53.6 (±19.3)	3.4 (N/A)	25.5 (±5.4)
Paperpot	12-25/5/81	1.1 (±0.3)	1.4 (±0.3)	6.5 (±3.4)	12.1 (±8.7)	14.0 (±2.6)
Bare-root	27-28/5/82	6.7 (N/A)	5.1 (±1.1)	73.0 (±20.7)	2.9 (N/A)	24.3 (±4.1)
Paperpot	27-28/5/82	0.7 (N/A)	1.8 (±0.3)	13.7 (±4.3)	4.2 (N/A)	15.9 (±1.9)
Expt. 4						
Bare-root	27/5/81 to 2/6/81	7.5 (±3.4)	5.4 (±1.2)	54.2 (±22.2)	2.6 (±0.7)	26.7 (±5.1)
Paperpot	27/5/81 to 2/6/81	1.2 (±0.2)	1.5 (±0.2)	8.1 (±2.3)	2.2 (±0.3)	12.4 (±1.4)
Bare-root	4-5/6/82	8.4 (N/A)	4.7 (±0.9)	41.8 (±13.4)	4.1 (N/A)	26.5 (±4.3)
Paperpot	4-5/6/82	0.8 (N/A)	2.0 (±0.3)	15.2 (±5.6)	2.9 (N/A)	14.7 (±2.3)
Expt. 5						
Bare-root	31/5/82 to 3/6/82	6.7 (N/A)	5.1 (±1.1)	73.0 (±20.7)	2.9 (N/A)	24.3 (±4.1)
Paperpot	31/5/82 to 3/6/82	0.7 (N/A)	1.8 (±0.3)	13.7 (±4.3)	4.2 (N/A)	15.9 (±1.9)
Bare-root	16-19/5/83	6.8 (±3.1)	4.8 (±1.1)	69.6 (±22.2)	2.2 (±0.6)	27.9 (±4.9)
Paperpot	16-19/5/83	0.7 (±0.2)	1.8 (±0.3)	8.1 (±3.1)	6.3 (±1.3)	14.4 (±1.8)

[a] Morrison and Armson 1968

[b] Figures within parentheses are standard deviations.

Appendix B. Values for data in tables 5-9 (x ± S.E.M.)

Variables	Application rates (kg a.i./ha)	Stock type/year planted	
		Bare-root/1979	Paperpot/1979
<u>Exp. 1</u>			
SURV5[a] (%)	0.0	87.0 - 95.1	87.8 - 94.3
	4.5	84.0 - 96.0	82.6 - 97.1
	9.0	88.0 - 96.9	77.9 - 89.9
THT5[b] (cm)	0.0	41.0 - 43.9	29.7 - 30.5
	4.5	60.4 - 69.8	49.6 - 53.6
	9.0	64.3 - 71.7	56.6 - 61.1
RGR5[c] (yr^{-1})	0.0	0.158 - 0.171	0.299 - 0.329
	4.5	0.253 - 0.284	0.420 - 0.443
	9.0	0.275 - 0.318	0.424 - 0.463
		Bare-root/1980	Paperpot/1980
<u>Exp. 2</u>			
SURV5[a] (%)	0.0	90.7 - 93.5	74.2 - 89.3
	1.1	96.2 - 99.4	87.8 - 92.9
	2.2	86.0 - 93.5	75.5 - 79.1
	4.5	73.8 - 84.8	62.6 - 70.6
THT5[b] (cm)	0.0	53.2 - 61.3	32.9 - 36.1
	1.1	62.8 - 69.3	45.5 - 49.7
	2.2	62.8 - 65.0	41.7 - 44.2
	4.5	69.7 - 75.1	61.2 - 63.4
RGR5[c] (yr^{-1})	0.0	0.240 - 0.287	0.357 - 0.399
	1.1	0.264 - 0.308	0.400 - 0.424
	2.2	0.266 - 0.286	0.389 - 0.400
	4.5	0.295 - 0.323	0.469 - 0.481

[a] SURV5 = survival five growing seasons after outplanting

[b] THT5 = total height five growing seasons after outplanting

[c] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

(cont'd)

Appendix B. Values for data in tables 5-9 ($x \pm$ S.E.M.) (cont'd)

Experiment 3.

Variables	Application rates (kg a.i./ha)	Stock type/year planted			
		Bare-root/1981	Bare-root/1982	Paperpot/1981	Paperpot/1982
SURV5[a] (%)	0.0	79.8 - 87.6	75.9 - 97.2	43.6 - 52.4	59.8 - 83.6
	1.0	88.5 - 93.1	78.3 - 94.3	57.5 - 68.8	67.0 - 83.3
	2.0	88.1 - 94.1	75.0 - 98.4	76.2 - 81.9	73.2 - 84.8
	4.0	84.8 - 89.2	94.0 - 99.4	30.4 - 46.7	87.5 - 94.4
THT5[b] (cm)	0.0	94.3 - 102.5	81.2 - 89.3	57.1 - 58.9	47.1 - 57.0
	1.0	112.0 - 119.6	92.2 - 99.8	77.9 - 86.8	64.9 - 68.2
	2.0	126.7 - 134.3	103.7 - 118.7	89.7 - 95.4	73.1 - 87.3
	4.0	135.3 - 140.6	123.4 - 137.7	81.4 - 89.7	105.8 - 115.9
DIA5[c] (mm)	0.0	15.1 - 18.4	11.8 - 13.8	8.2 - 10.7	6.8 - 8.0
	1.0	19.9 - 23.0	14.4 - 16.0	12.8 - 14.8	8.6 - 9.6
	2.0	26.1 - 29.6	16.6 - 20.5	16.6 - 18.7	11.2 - 13.8
	4.0	29.0 - 31.9	23.1 - 29.3	16.3 - 19.1	20.4 - 22.9
RGR5[d] (yr^{-1})	0.0	0.348 - 0.440	0.268 - 0.296	0.385 - 0.404	0.325 - 0.384
	1.0	0.387 - 0.410	0.319 - 0.332	0.455 - 0.516	0.370 - 0.384
	2.0	0.403 - 0.411	0.344 - 0.384	0.455 - 0.470	0.419 - 0.458
	4.0	0.415 - 0.433	0.381 - 0.420	0.448 - 0.475	0.476 - 0.491

[a] SURV5 = survival five growing seasons after outplanting

[b] THT5 = total height five growing seasons after outplanting

[c] DIA5 = stem diameter 1 cm above ground level five growing seasons after outplanting

[d] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

(cont'd)

Appendix B. Values for data in tables 5-9 (x ± S.E.M.) (cont'd)

Experiment 4.

Variables	Application rates (kg a.i./ha)	Stock type/year planted			
		Bare-root/1981	Bare-root/1982	Paperpot/1981	Paperpot/1982
SURV5[a] (%)	0.0	94.0 - 98.2	96.4 - 100.0	82.2 - 91.0	96.0 - 99.6
	1.0	93.0 - 97.9	92.0 - 94.8	85.5 - 88.3	100.0 - 100.0
	2.0	91.4 - 92.7	96.0 - 96.0	76.7 - 83.7	100.0 - 100.0
	4.0	76.1 - 86.4	100.0 - 100.0	46.6 - 56.6	83.8 - 98.6
THT5[b] (cm)	0.0	80.5 - 86.4	65.5 - 72.1	50.7 - 55.5	46.2 - 58.3
	1.0	88.0 - 93.3	58.1 - 74.2	57.9 - 70.3	59.6 - 65.7
	2.0	93.3 - 96.2	73.9 - 82.1	63.0 - 69.2	60.9 - 70.6
	4.0	108.3 - 112.1	96.4 - 106.5	72.5 - 80.3	79.3 - 94.7
DIA5[c] (mm)	0.0	11.7 - 13.6	10.2 - 11.4	6.7 - 7.7	7.0 - 8.6
	1.0	14.7 - 17.3	8.9 - 10.9	9.1 - 10.3	9.0 - 9.5
	2.0	15.3 - 16.1	12.7 - 13.2	8.9 - 10.4	9.1 - 11.0
	4.0	21.6 - 23.9	16.4 - 19.0	11.8 - 14.8	15.1 - 18.4
RGR5[d] (yr^{-1})	0.0	0.319 - 0.338	0.296 - 0.306	0.366 - 0.394	0.293 - 0.338
	1.0	0.336 - 0.356	0.243 - 0.294	0.343 - 0.397	0.337 - 0.367
	2.0	0.351 - 0.372	0.291 - 0.322	0.412 - 0.478	0.320 - 0.349
	4.0	0.378 - 0.384	0.370 - 0.400	0.430 - 0.448	0.350 - 0.397

[a] SURV5 = survival five growing seasons after outplanting

[b] THT5 = total height five growing seasons after outplanting

[c] DIA5 = stem diameter 1 cm above ground level five growing seasons after outplanting

[d] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5

(cont'd)

Appendix B. Values for data in tables 5-9 (x ± S.E.M.) (concl.)

Experiment 5.

Variables	Application rates (kg a.i./ha)	Stock type/year planted			
		Bare-root/1982	Bare-root/1983	Paperpot/1982	Paperpot/1983
SURV5[a] (%)	0.0	94.7 - 98.8	73.1 - 87.2	63.9 - 77.3	19.1 - 37.3
	2.0	87.1 - 92.9	92.0 - 98.6	82.4 - 88.0	61.6 - 80.6
	4.0	85.7 - 93.6	90.6 - 98.1	65.0 - 73.3	42.6 - 59.5
THT5[b] (cm)	0.0	74.5 - 82.9	87.9 - 99.2	63.4 - 65.2	37.6 - 49.9
	2.0	114.8 - 120.4	103.6 - 118.8	78.6 - 87.0	76.2 - 81.3
	4.0	100.1 - 115.9	110.7 - 129.1	71.2 - 86.1	76.0 - 93.2
DIA5[c] (mm)	0.0	11.0 - 12.5	13.3 - 15.4	8.6 - 9.2	5.2 - 7.7
	2.0	19.1 - 20.9	15.9 - 20.6	12.2 - 14.6	11.1 - 13.2
	4.0	18.5 - 24.2	20.3 - 27.6	13.5 - 20.6	14.3 - 20.0
RGR5[d] (yr^{-1})	0.0	0.279 - 0.312	0.216 - 0.233	0.338 - 0.374	0.219 - 0.278
	2.0	0.379 - 0.387	0.244 - 0.287	0.418 - 0.442	0.348 - 0.380
	4.0	0.357 - 0.414	0.272 - 0.306	0.418 - 0.474	0.390 - 0.444

[a] SURV5 = survival five growing seasons after outplanting

[b] THT5 = total height five growing seasons after outplanting

[c] DIA5 = stem diameter 1 cm above ground level five growing seasons after outplanting

[d] RGR5 = mean relative growth rate (total height) per annum from year 1 to year 5