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F. Wayne Bell
Ontario Forest Research Institute

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D.G. Pitt, *Canadian Forest Service, 1219 Queen St. East, Sault Ste. Marie, Ontario P6A 5M7;* **C. Stern Krishka,** *British Columbia Ministry of Forests, 4227 Sixth Ave., Port Alberni, British Columbia V9Y 4N1;* **F.W. Bell,** *Ontario Ministry of Natural Resources, Ontario Forest Research Institute, 1235 Queen St. East, Sault Ste. Marie, Ontario P6A 5N5; and* **A. Lehela,** *Plant Community Consultants, Ltd., 11 Country Club Place, Sault Ste. Marie, Ontario P6A 5Z8.*

ABSTRACT: *In May 1987, hexazinone (Velpar® L) was applied by helicopter at 0, 1, 2, and 4 kg active ingredient (a.i.) in 45 L of total solution per ha to a sandy loam site approximately 74 km northwest of Thunder Bay, Ontario. Container (FH408 paper pot) jack pine (*Pinus banksiana *Lamb.) and container (FH408 paper pot) and bareroot (1½ + 1½) black spruce (*Picea mariana *[Mill.] B.S.P.) were hot-planted 1 month and deferred-planted 12 months after herbicide application. Survival, height, and diameter growth were monitored annually, through the fall of 1991. Jack pine container stock planted 1 month after hexazinone treatment at 2 and 4 kg a.i./ha suffered 12% greater mortality than trees planted 1 yr later. However, the benefits of early establishment and herbaceous weed control offset these early losses and hot-planted areas supported equal volumes at age 4, and 2.3-fold more volume per ha than deferred-planted areas 5 growing seasons after herbicide treatment. Black spruce container and bareroot stock exhibited high tolerance to hexazinone throughout the range of rates tested. Overall, a 1 yr delay in planting resulted in stem and stand volumes that were less than half of those observed in hot-planted areas. Growth response was positively related to the level of herbaceous weed control achieved, with 4 kg treated areas supporting volumes 2- to 4-fold greater than those on untreated areas. The data illustrate significant growth advantages associated with early crop establishment and herbaceous weed control. North. J. Appl. For. 16(2):72–81.*

Hexazinone is a water-soluble, soil-applied herbicide that provides pre- and post-emergent control of many grasses, forbs, and woody plants. Like other triazine herbicides, hexazinone is readily absorbed by plant roots and translocated through xylem tissues to the foliage, where it inhibits photosynthesis (W.S.S.A. 1994). Movement in the soil profile is facilitated by moisture and limited by adsorption, which is influenced by soil texture and organic matter content (Ghassemi et al. 1982). Soil adsorption increases with increasing clay and organic matter content (W.S.S.A. 1994), leaving less hexazinone available for plant absorption and/or further movement in the soil (Minogue et al. 1988). Soil half-life of hexazinone is typically 1 to 6 months.

Although hexazinone was first developed for noncrop vegetation control in 1968, the high susceptibility of several key forest competitors, including poplars (*Populus* spp.), raspberries (*Rubus* spp.), and members of the grass (*Poaceae*), sedge (*Cyperaceae*), and aster (*Asteraceae*) families, quickly attracted the attention of foresters. Pre-emergent control capability, coupled with the fact that conifers could be successfully planted shortly after treatment, gave hexazinone the potential of becoming Canada's first forest site-preparation herbicide. Temporary Canadian registration status was granted to liquid hexazinone (Velpar® L) in 1984, for ground-applied site preparation and conifer release treatments in Canadian woodlands (areas < 500 ha). Full registration followed in 1990, with a label expansion to include aerial application in 1991.

The Velpar® L label has always specified that the product not be used on "gravelly soils, rocky soils, or soils which are

NOTE: D.G. Pitt is the corresponding author and can be reached at (705) 759-5740, ext. 2453; Fax: (705) 759-5700; E-mail: dpitt@NRCan.gc.ca. The authors are indebted to Jamie Corcoran and Frank Huston, DuPont Canada Inc., for product contributions and funding of soil analyses. Bill Smith, Abitibi Price Inc., generously provided the study site and accommodations for field crews. Special thanks to Robert Campbell (Canadian Forest Service) for assistance with herbicide applications; Margaret Carruthers, Daphne Wass, and De-Wei Li for their field assistance; Al Wiensezyk and Din Chen for preliminary data analysis; and the University of Guelph for soil analysis.

sandy or coarse textured." Early Canadian experimentation with hexazinone in forestry applications suggested practical efficacy and acceptable crop tolerance on a wide range of soil conditions (Wood et al. 1989, 1992, Deschamps and Mutchmor 1988, Reynolds and Roden 1995a,b). The study reported herein was one of several field trials that were established to generate registration data in support of a label amendment to include uses on coarser textured soils. Unfortunately, environmental problems associated with the off-site movement of hexazinone in coarse-textured soils preclude the data produced by these studies from ever being used for their originally intended purpose (e.g., Ghassemi et al. 1982). Nevertheless, our results offer foresters valuable insights into the importance of early weed control and crop establishment and are presented here for this purpose. These data are particularly relevant to efforts aimed at addressing recent concerns for the steady decline of black spruce (*Picea mariana* [Mill.] B.S.P.) (MacDonald 1991, Hernden et al. 1991), and the early establishment of jack pine (*Pinus banksiana* Lamb.) in the boreal forest, since the growth, survival, and, ultimately, sustainability of these species depend heavily on our ability to reduce competitive pressures from noncrop vegetation.

Methods

Site

The study area is situated approximately 74 km northwest of Thunder Bay, Ontario (Lat. 48°51'N, Long. 89°47'W, Alt. 479 m), near Raith, on Abitibi Freehold Block 3. Geology of the area has been described by Gartner et al. (1981). The site lies at the interface of a ground moraine, deltaic sand, and valley train area, with rolling hills (slopes < 5%), occasional flat areas, and patches of exposed bedrock. The site was classified as an SS5 [shallow to moderately deep (20–100 cm)] soil (Sims et al. 1989), which was confirmed by soil pits in the study area that averaged 10 cm fibrimor-humus over a 60 cm sandy-loam mineral soil layer. Soil analysis indicated sand, silt, and clay contents of 56, 37, and 7%, respectively, with 1.6% organic matter content, CEC of 4.0 meq per 100 g of soil, and a pH of 4.6. The average moisture regimes and drainage classes (Denholm and Schut 1993) are 2 (fresh) and 3 (well drained), respectively.

Preharvest, the Jack Pine Mixedwood/Feathermoss (Sims et al. 1989) forest in the study area, consisted of fire-origin jack pine (60%), black spruce (20%), trembling aspen (*Populus tremuloides* Michx.) (10%), and white birch (*Betula papyrifera* Marsh.) (10%). This forest was clear-felled in the fall/winter of 1986/1987 using a cut and skid, full-tree mechanical harvesting system. No subsequent site preparation was undertaken prior to the installation of the experiment.

Experimental Design and Treatments

The experiment was arranged as a split-plot design, with three blocks of 100 × 200 m "whole-plots" receiving each of four hexazinone (Velpar® L) dosages (0, 1, 2, and 4 kg active ingredient (ai)/ha) (2 to 4 kg ai/ha is the range currently recommended for site preparation). Treatments took place on the morning of May 21, 1987, under overcast skies, light winds (0 to 17 kph), mild temperatures (9 to 10°C), and high humidity (96%). A total (water-based) spray solution of 45 L/ha was applied with a Bell 206B helicopter equipped with a 7 m boom and 16 D10-46 nozzles. At a boom pressure of 152 kpa, this system was calibrated with a swath width of 16 m at a release height of 23 m and airspeed of 80 kph. A total of 4.8 mm of rain fell the day of application.

Each whole plot was subsequently "split" into six 0.036 ha planting areas, each receiving one of six randomly assigned stock-type/planting-date combinations. The stock types evaluated were: (1) jack pine container (over-wintered FH408 paper pot), (2) black spruce container (over-wintered FH408 paper pot), and (3) black spruce bareroot (1½ + 1½). Each of these stock types was planted 1 and 12 months after herbicide treatment (hot-planted June 9–30, 1987, and deferred-planted May 17–22, 1988, respectively). A total of 80 trees of each stock-type × planting date combination were planted per split-plot. At the time of planting, each tree was numbered, tagged, and measured for total height (nearest cm) and root-collar diameter (nearest mm). Repeat measurements were made each fall, through 1991.

To relate observed crop growth responses to vegetation levels following herbicide treatment, noncrop vegetation cover was assessed on 66 1.26 m radius circular plots located within each split-plot area. Cover was visually estimated (to the nearest 5%) for all species present on these plots in August of 1987, 1988, 1989, and 1991.

Data Analysis

Response variables used for crop-tree analysis included *root-collar diameter*, *total height*, *stem volume* (assuming conical form), and *survival*. In addition, stem volume and survival were integrated to form the variable *volume per ha*, assuming an initial planting spacing of 1.8 × 1.8 m [standard operational planting procedure in northwestern Ontario (Bill Towill, pers. comm. Nov. 1998)]. Statistical comparisons were made at the time of planting (age 0), 4 growing seasons after planting (age 4), and 5 growing seasons after herbicide treatment (growing season 5 = age 5 for hot-planted trees; age 4 for deferred-planted trees). For these end-point comparisons, a conventional split-plot analysis of variance was used (Table 1), with separate analyses being conducted for each stock type. Orthogonal polynomials were used to describe the relationship between the quantitative levels of herbicide dose and crop growth and survival (Mize and Schultz 1985). In all cases, model residuals were examined to verify that assumptions of homogeneity of variance and normality were met.

Since measurements were made on the same crop trees over time, a repeated-measures analysis was used to study the nature of the dose-response × planting date relationships through time. For this, polynomial response functions were fit to the means of the repeated measures for each subplot (i.e., each herbicide dose × planting date × stock-type combination) and the estimated orthogonal polynomial coefficients (mean, linear, and quadratic) used as primary data in the ANOVA structure of Table 1 [see Meredith and Stehman (1991) for details]. In this analysis, each of the sources of variation listed in Table 1 was considered as being an interaction term with *time*.

Table 1. General form of analysis of variance.

	Source of variation	df
Whole plot analysis	**Herbicide**	**4 – 1 = 3**
	Linear	(1)
	Quadratic	(1)
	Cubic	(1)
	Blocks	**3 – 1 = 2**
Error	**Herbicide × blocks**	**3 × 2 = 6**
Split-plot analysis	Planting date	2 – 1 = 1
	Planting date × herbicide	**1 × 3 = 3**
	Date × herbicide linear	1 × 1 = (1)
	Date × herbicide quadratic	1 × 1 = (1)
	Date × herbicide cubic	1 × 1 = (1)
Error	**(date × blocks) + (date × herb. × blocks)**	**(1 × 2) + (1 × 3 × 2) = 8**
	Total	**4 × 3 × 2 – 1 = 23**

For example, a significant *herbicide × time* interaction implies that the growth trends over time differ for one or more herbicide doses, either in their overall position (mean), slope (linear), or curvature (quadratic). Further, a significant *herbicide (linear) × time* interaction implies that the growth trends over time differ proportionally (linearly) to herbicide dose. Similarly, significant *planting date × time* interactions imply that the growth trends over time differ for the two planting dates, either in their overall position (mean), slope (linear), or curvature (quadratic). The presence of a significant *planting date × herbicide × time* interaction implies a lack of consistency between the growth trends of hot- and deferred-planted trees in areas treated with different herbicide doses. In such an event, general statements could not be made about herbicide response without reference to planting date, or visa versa. In this manner, the response surfaces defined by herbicide dose and time post-treatment were analyzed and compared for the two planting dates: (a) at equivalent age (0 through 4) and (b) at equivalent time post-treatment (growing seasons 1 through 5) [following recommendations of Borders and Shiver (1989)]. Individual *stem volume* and *volume per ha* were the response variables used for this analysis. As in the end-point comparisons, model residuals were examined to verify that the assumptions of homogeneity of variance and normality were met.

Results

Jack Pine Container Stock

Individual Tree Growth.—In any experiment involving different planting dates, it can be difficult to obtain trees of identical size and vigor to initially equalize treatments. In this experiment, pines planted in May 1988 were 3 cm taller, at the time of planting, than those planted the previous year ($P < 0.01$; Table 2). Although diameter differences were small (< 1 mm; $P = 0.06$), there was an initial 54% volume discrepancy between the two groups of trees ($P < 0.01$; **1**[1], Table 3) (note that data did not meet the assumptions of analysis of covariance). By age 4, however, trees of both planting dates exhibited equivalent

[1] Numbered points reference key portions of the cited tables and/or figures.

Table 2. Summary of mean individual tree dimensions at the time of planting, age 4, and 5 growing seasons after treatment.

				Age 4								Age 5			
				Four growing seasons after treatment				Five growing seasons after treatment							
		At planting		Hot				Deferred				Hot			
Stock	Dimension*	Hot	Deferred	0 kg	1 kg	2 kg	4 kg	0 kg	1 kg	2 kg	4 kg	0 kg	1 kg	2 kg	4 kg
Jack	*H*	9	12	78	95	83	97	74	91	81	106	108	128	111	134
pine	*D*	3	3	15	18	18	24	12	15	16	22	20	24	23	32
container	*V*	0.2	0.3	61	98	108	185	48	76	101	201	158	238	264	446
Black	*H*	11	11	58	63	66	82	45	45	55	66	71	77	81	103
spruce	*D*	3	2	8	9	11	15	6	6	8	10	11	11	14	20
container	*V*	0.2	0.1	14	16	25	61	6	6	14	28	30	31	51	137
Black	*H*	27	25	75	82	88	96	69	78	87	96	90	98	106	118
spruce	*D*	5	6	12	16	17	19	10	13	14	18	15	19	20	23
bareroot	*V*	2.3	2.3	39	64	78	104	26	46	56	107	71	116	143	205

* *H* = total height (cm); *D* = root collar diameter (mm); *V* = stem volume (cm^3).

Table 3. Summary of P-values from ANOVA of the response variables stem volume and volume per ha. Values of interest are shown in bold text; underlined superscript numbers reference points made in the text.

					Volume per ha							
		Stem volume per tree			Age 0 through 4 (× time)				gs 1 through 5 (× time)			
Source of variation	df	Age 0	Age 4	g.s.* 5	Mean	Linear	Quad.	Age 4	Mean	Linear	Quad.	g.s. 5
Jack pine container												
Herbicide	3	0.47	<0.01	<0.01	0.01	0.01	0.02	0.01	0.03	0.04	0.10	0.05
Linear (proportional to dose)	(1)	0.18	**<0.01**[4]	**<0.01**[5]	<0.01	<0.01	**<0.01**[12]	<0.01	**0.01**	0.01	**0.02**[12]	**0.01**
Quadratic (prop. to dose2)	(1)	0.94	0.36	0.44	0.58	0.61	0.69	0.62	0.70	0.71	0.73	0.71
Planting date	1	**<0.01**[1]	**0.70**[2]	**<0.01**[3]	0.25	0.56	**0.44**[9]	0.74	**<0.01**	<0.01	**<0.01**[11]	**<0.01**[8]
Planting date × herbicide	3	0.80	0.86	0.42	0.04	0.07	0.50	0.14	0.83	0.86	0.93	0.88
Date × herb linear	(1)	0.42	0.47	0.12	**0.01**[10]	**0.02**[10]	0.19	**0.04**[7]	0.57	0.54	0.52	0.54
Date × herb quadratic	(1)	0.67	0.75	0.95	0.40	0.42	0.55	0.46	0.83	0.84	0.95	0.86
Black spruce container												
Herbicide	3	0.70	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Linear	(1)	0.63	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Quadratic	(1)	0.34	<0.01	<0.01	0.04	0.05	0.09	0.05	0.02	0.03	0.03	0.02
Planting date	1	**<0.01**[13]	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Planting date × herbicide	3	0.68	0.02	<0.01	0.12	0.09	0.05	0.07	<0.01	<0.01	<0.01	<0.01
Date × herb linear	(1)	0.25	**<0.01**[14]	<0.01	**0.04**	0.03	**0.01**[20]	**0.02**[17]	<0.01	<0.01	<0.02	<0.01
Date × herb quadratic	(1)	0.93	0.14	**0.01**[15]	0.27	0.27	0.32	0.25	**0.03**	0.03	**0.03**[20]	**0.03**[18]
Black spruce bareroot												
Herbicide	3	0.75	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Linear	(1)	0.99	**<0.01**[23]	<0.01	**<0.01**	<0.01	**<0.01**[29]	**<0.01**[26]	**<0.01**	<0.01	**<0.01**[29]	**<0.01**[26]
Quadratic	(1)	0.35	0.99	0.99	0.72	0.58	0.68	0.64	0.73	0.47	0.36	0.48
Planting date	1	**0.93**[21]	**0.02**[22]	<0.01	**0.10**	0.03	**<0.01**[30]	**0.03**[25]	**<0.01**	<0.01	**<0.01**[30]	**<0.01**[25]
Planting date × Herbicide	3	0.06	0.26	0.16	0.38	0.50	0.92	0.62	0.23	0.24	0.36	0.23
Date × herb linear	(1)	0.05	0.18	**0.04**[24]	0.18	0.24	0.84	0.34	0.06	0.06	0.10	**0.05**[27]
Date × herb quadratic	(1)	0.27	0.14	0.38	0.28	0.35	0.61	0.39	0.64	0.77	0.76	0.84

* g.s. = growing seasons after treatment.

stem volumes ($P = 0.70$; **2**, Table 3). When compared 5 growing seasons after herbicide treatment, an additional year provided hot-planted trees with an average gain of 9 mm in diameter and 32 cm in height over deferred-planted trees (2.6-fold difference in volume, Table 2; $P < 0.01$; **3**, Table 3).

Herbicide treatment had a positive influence on jack pine diameter growth, regardless of planting date ($P = 0.01$). Responses were directly proportional to herbicide dose (linear contrast, $P < 0.01$), with age 4 diameters averaging 13 mm in untreated plots and 23 mm in 4 kg treated plots (Table 2). Age 4 seedling heights were not influenced by herbicide treatment ($P = 0.22$). Nevertheless, diameter responses translated into positive stem volume responses ($P < 0.01$; **4**, Table 3). Stem volumes increased in proportion to herbicide dose, from 54 cm^3/seedling in untreated plots, to 193 cm^3/seedling in 4 kg treated plots. Similar trends were evident when trees of the two planting dates were compared 5 yr post-treatment ($P < 0.01$; **5**, Table 3).

Treatment-related trends in noncrop vegetation (Figure 1) suggest that the growth responses observed with jack pine are largely related to herbaceous weed control. The data reflect a typical dose-response pattern of diminishing reduction in herbaceous cover with increasing herbicide dose (Figure 1a). Although cover increased slightly over time, the effects of hexazinone treatment were still evident 5 growing seasons after treatment. In contrast, woody species (except poplar and raspberry) were largely unaffected by the hexazinone treatments (Figure 1b). This result is consistent with the literature (Buse and Bell 1992).

Stand Growth.—Jack pine planted immediately following the highest herbicide dosages (2 and 4 kg) averaged 12% lower age 4 survival than trees planted a year later (**6**, Figure 2; planting date × herbicide linear, $P = 0.08$). An additional growing season resulted in a further 2% mortality in hot-planted trees, irrespective of the herbicide treatments applied (differences between planting dates 5 growing seasons post-treatment, $P = 0.04$). Volume per ha, which integrates tree size and survival, was similar at age 4 in the lower herbicide rates (0 and 1 kg), but greater for deferred-planted areas treated with the higher rates (2 and 4 kg) (planting date × herbicide linear, $P = 0.04$; **7**, Figure 3, Table 3). This difference was a result of increased survival of deferred-planted trees in high-rate areas, rather than differences in individual tree size. However, hot-planted areas supported 2.3 times the volume of deferred-planted areas when compared 5 growing seasons post-treatment (average 623 vs. 271 dm^3/ha, $P < 0.01$, Table 3; maximum 880 vs. 480 dm^3/ha;

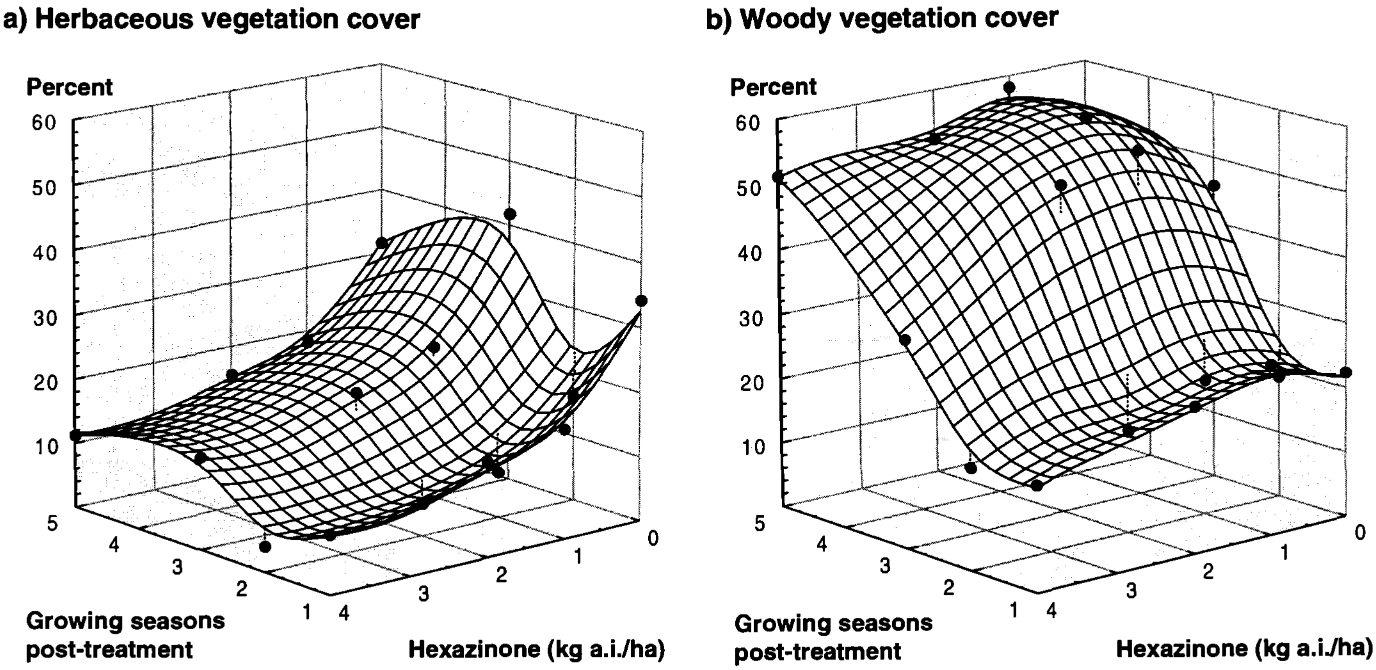

Figure 1. Cover of noncrop (a) herbaceous and (b) woody vegetation through 5 growing seasons after treatment with hexazinone. Each plotted point represents the mean of 66 samples in each of 6 conifer stock-type/planting date areas.

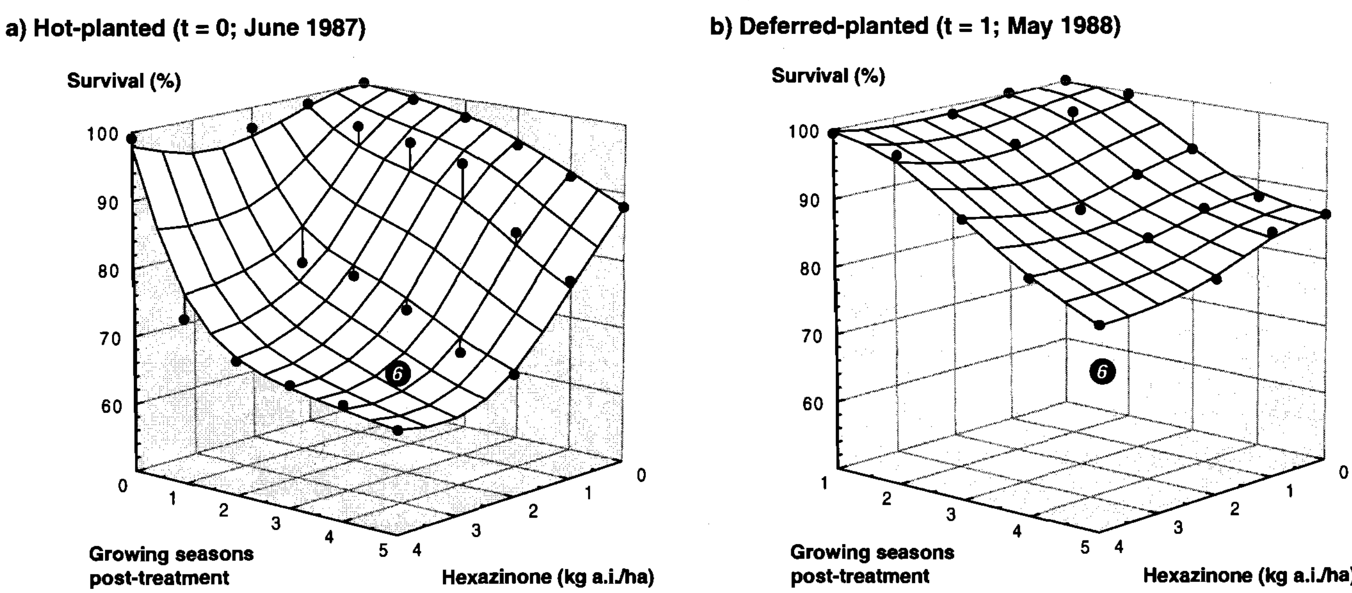

Figure 2. Survival of jack pine container stock (a) hot-planted and (b) deferred-planted following site preparation with hexazinone. Each plotted point represents the mean of 80 trees. Back-lit numbers reference points made in the text.

8, Figure 3). To this point in time, a one-season headstart in growth more than offset any losses associated with planting immediately following hexazinone treatment.

Trends in volume production over time are also illustrated in Figure 3. Viewed in terms of age equivalence, quadratic patterns of increasing growth through time are similar for the two planting dates (planting date × time, quadratic parameter, $P = 0.44$; **9**, Figure 3, Table 3), with the exception that increased survival in the high-rate, deferred-planted areas suggest the potential for accelerated growth (per ha) over time (planting date × herbicide linear × time interaction, $P < 0.02$; **10**, Table 3). Compared over time, post-treatment quadratic increases in growth were greater for hot-planted trees than for deferred-planted trees ($P < 0.01$; **11**, Table 3). In all cases, herbicide treatment resulted in increased growth, with quadratic trends over time being directly proportional to hexazinone dose (age-equivalent comparison, herbicide linear contrast of the quadratic time parameter, $P < 0.01$; growing seasons post-treatment comparison, $P = 0.02$; **12**, Figure 3, Table 3). Again, these growth responses can be attributed to herbaceous vegetation control (Figure 1).

Black Spruce Container Stock

Individual Tree Growth.— Black spruce container stock planted in May 1988 were slightly (< 1 mm) smaller in diameter than those planted the previous year ($P < 0.01$;

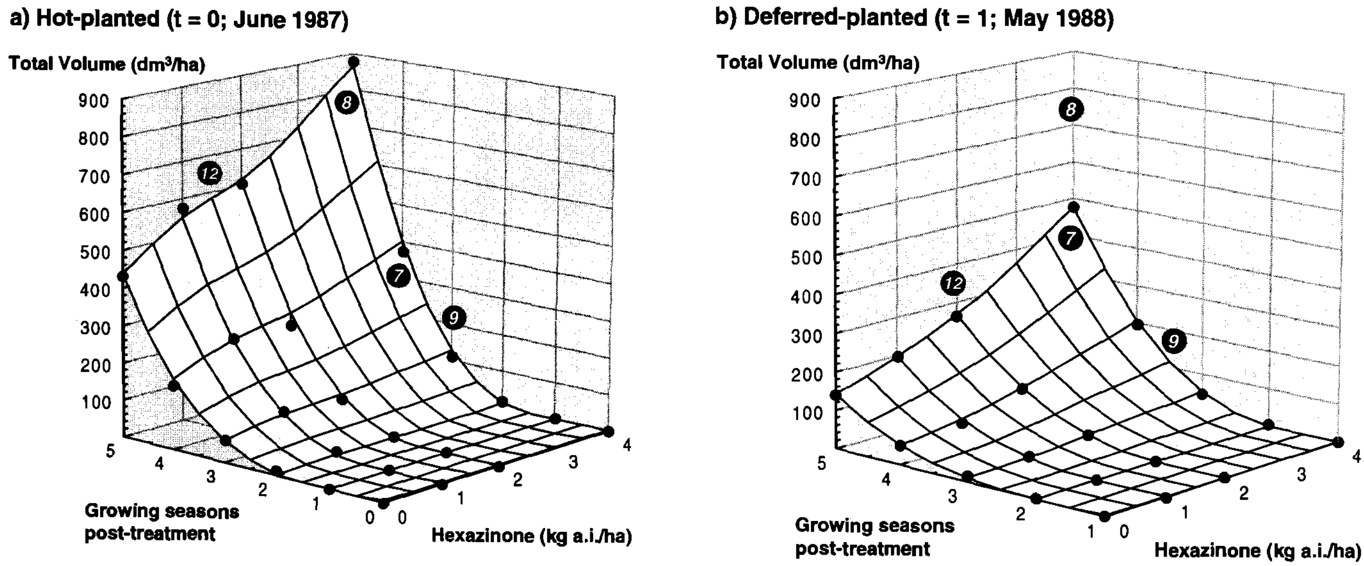

Figure 3. Stand growth (volume/ha) of jack pine container stock (a) hot-planted and (b) deferred-planted following site preparation with hexazinone. Each plotted point represents the mean of 80 trees. Back-lit numbers reference points made in the text.

Table 2). Although height differences were minimal (< 1 cm; $P = 0.53$), initial diameter differences lead to a 51% volume discrepancy between the two groups of trees at the time of planting ($P = 0.01$; **13**, Table 3). This difference increased to 54% by age 4, with individual hot-planted trees averaging 15 cm^3 in untreated and 1 kg areas and 61 cm^3 in 4 kg areas, compared to deferred-planted values of 6 and 28 cm^3, respectively ($P < 0.01$; **14**, Table 3). Although response was greater in hot-planted areas, individual stem volume growth was proportionally related to hexazinone dose (the inverse of herbaceous cover, Figure 1a). When compared five growing seasons after herbicide treatment, hot-planted trees averaged 30 cm^3 in untreated and 1 kg areas and 137 cm^3 in 4 kg areas, with volume increases being curvilinearly related to hexazinone dose (Table 2). In contrast, deferred-planted trees averaged 6 cm^3 in the low-rate areas and only 28 cm^3 in 4 kg areas, responses being proportional to dose (planting date × herbicide quadratic, $P = 0.01$; **15**, Table 3).

Stand Growth.— Unlike jack pine container stock, black spruce container stock did not show signs of hexazinone intolerance. At age 4, hot-planted trees averaged 83% survival, irrespective of hexazinone rate (Figure 4a). Deferred-planted trees in areas treated at the higher rates had similar survival (84%); however, reduced survival (70%) was observed in 0 and 1 kg areas (planting date × treatment linear, $P = 0.01$; **16**, Figure 4b). This result is likely attributable to the smaller diameter trees being more susceptible to higher levels of herbaceous competition on these areas (Figure 1a). An additional growing season resulted in a further 4% mortality in hot-planted trees, irrespective of the herbicide treatments applied, and differences in survival between planting dates or herbicide rates could not be detected ($P = 0.42$ and 0.31, respectively). Integrating tree size and survival, age 4

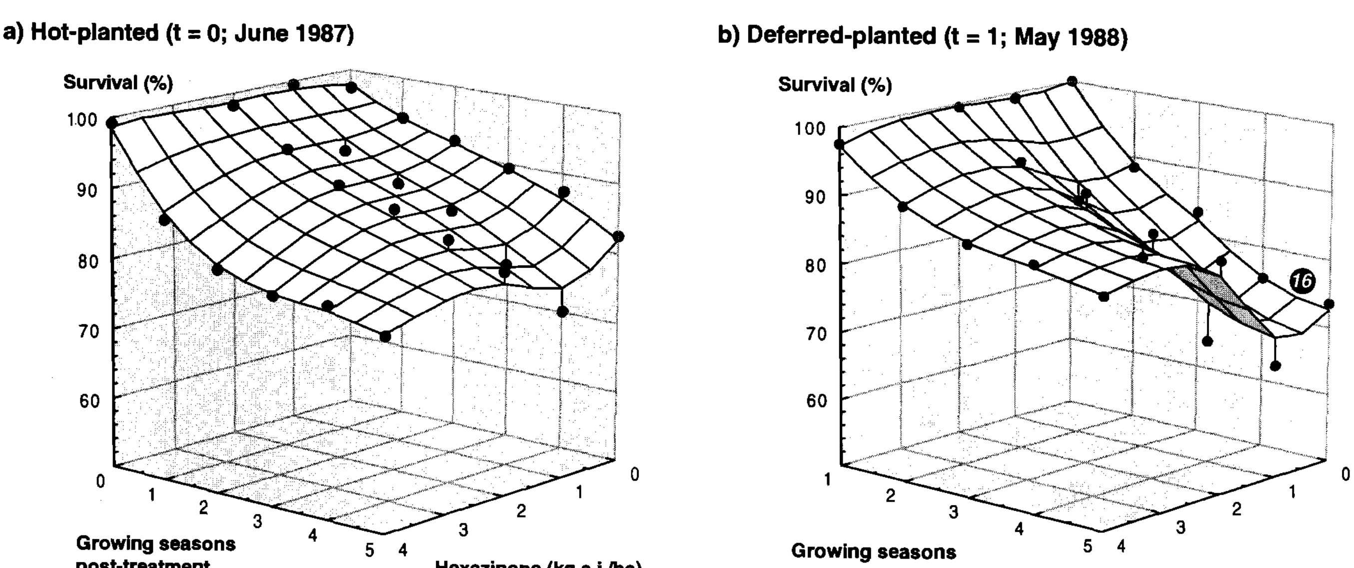

Figure 4. Survival of black spruce container stock (a) hot-planted and (b) deferred-planted following site preparation with hexazinone. Each plotted point represents the mean of 80 trees. Back-lit numbers reference points made in the text.

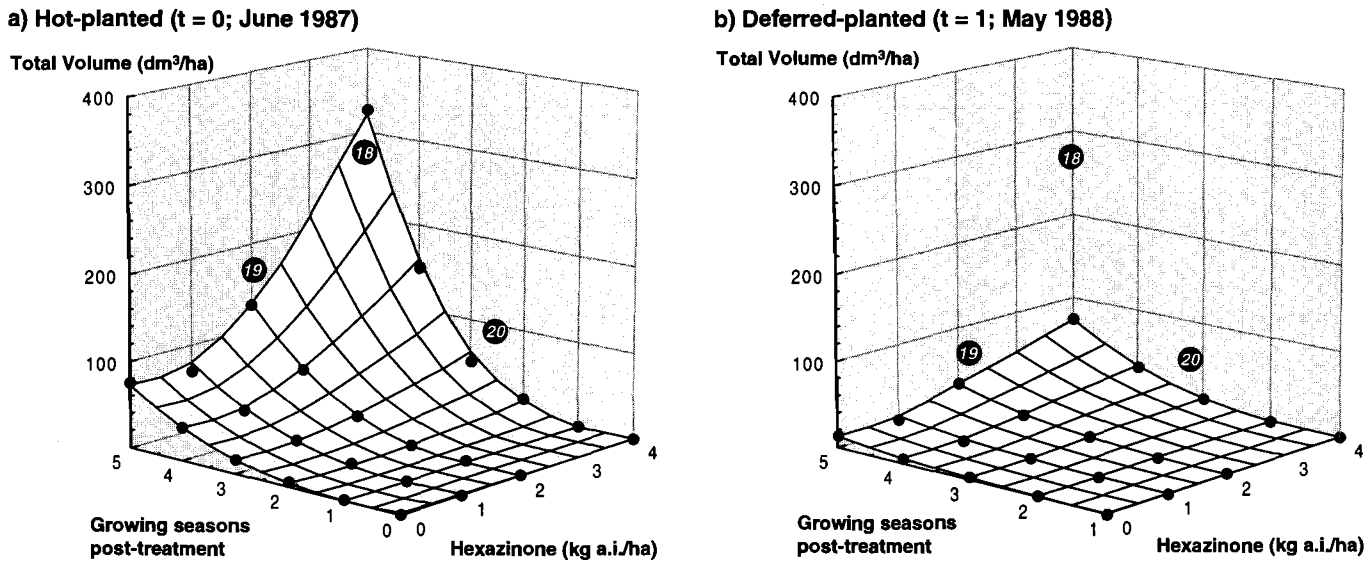

Figure 5. Stand growth (volume/ha) of black spruce container stock (a) hot-planted and (b) deferred-planted following site preparation with hexazinone. Each plotted point represents the mean of 80 trees. Back-lit numbers reference points made in the text.

volume per ha values differed widely between planting dates and herbicide rates ($P = 0.02$; **17**, Table 3). On hot-planted areas, age 4 volumes ranged from 38 dm^3/ha in 0 and 1 kg areas to 150 dm^3/ha in 4 kg areas, response being proportional to dose. In contrast, deferred-planted areas only supported 13 dm^3/ha in low-rate areas and 74 dm^3/ha in 4 kg areas. Compared at the fifth growing season post-treatment, hot-planted areas show dramatic volume advantages over deferred-planted areas (average of 328 vs. 74 dm^3/ha at 4 kg, $P = 0.03$; **18**, Figure 5, Table 3). Growth response of hot-planted trees was curvilinear in relation to hexazinone dose, whereas the relationship for deferred-planted areas is linear (proportional) to dose (**19**, Figure 5).

Trends in volume production over time reinforce the end-point comparisons made above. With no evidence of herbicide intolerance, the volume gains associated with early planting are dramatic, despite the fact that deferred-planted trees were diameter-disadvantaged at the time of planting. Like the relationship for dose-response, volume growth was curvilinear over time in hot-planted areas. A linear relationship could only be ascribed to growth in deferred-planted areas over the same observation period (**20**, Figure 5, Table 3).

Black Spruce Bareroot Stock

Individual Tree Growth.—Trees planted in May 1988 were slightly (< 1 mm) larger in diameter but 2 cm shorter than trees planted the previous year ($P < 0.01$; Table 2). These differences offset each other, such that initial volume differences between the two planting times were negligible ($P = 0.93$; **21**, Table 3). By age 4, hot-planted trees gained an average of 12 cm^3 (21%) more volume than deferred-planted trees ($P = 0.02$; **22**, Table 3). Through increased diameter and height growth, trees of both planting dates responded positively to hexazinone treatment ($P < 0.01$). Volume responses were proportional to herbicide dose in all cases (herbicide linear, $P < 0.01$; **23**, Table 3). When compared 5 growing seasons after herbicide treatment, hot-planted trees averaged 71 cm^3 in untreated areas and 205 cm^3 in 4 kg areas, with volume increases being linearly related to hexazinone dose. In contrast, deferred-planted trees averaged 26 cm^3 in the low-rate areas and only 107 cm^3 in 4 kg areas, with a more subtle linear response to dose (planting date × herbicide linear, $P = 0.04$; **24**, Table 3).

Stand Growth.—Black spruce bareroot survival was not influenced by planting date ($P > 0.42$) or herbicide treatment ($P > 0.95$), regardless of whether comparisons were made at an equivalent age 4 or at the end of the fifth growing season post-treatment (Figure 6). Average survival was 85% at age 4 and 84% at the end of the fifth growing season. Patterns in volume per ha (Figure 7) consequently reflect those of individual stem volume described above (**25**, **26**, and **27**, Table 3).

Viewed in terms of age- or post-treatment equivalence, growth patterns over time were quadratic in nature for both planting dates (**28**, Figure 7). In all cases, the quadratic trends over time increased proportional to hexazinone dose ($P < 0.01$; **29**, Figure 7, Table 3). High tolerance to hexazinone and excellent growth response indicate that hot-planting bareroot back spruce offers significant volume advantages over delaying planting by 1 growing season ($P < 0.01$; **30**, Table 3).

Discussion

Environmental issues aside, the data generated in this study would support a label-extension to include hexazinone applications to fine-grained sandy loams and loamy sands. Whereas several short-term studies have reported increased mortality in jack pine planted immediately following hexazinone site preparation, (Campbell et al. 1982, Wood and Campbell 1983), the longer term data generated in this study suggest that the volume gains associated with hot-planting may outweigh any losses attributable to herbicide intolerance. High tolerance of black spruce (container or bareroot) to hexazinone observed in this study is consistent

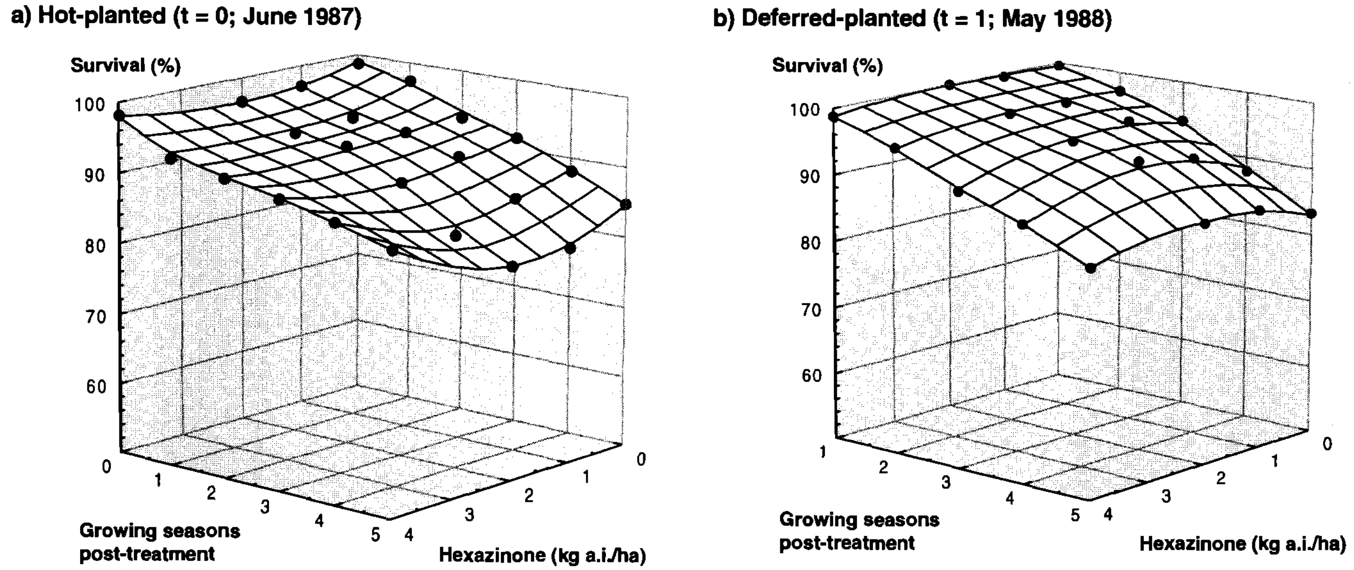

Figure 6. Survival of black spruce bareroot stock (a) hot-planted and (b) deferred-planted following site preparation with hexazinone. Each plotted point represents the mean of 80 trees. Back-lit numbers reference points made in the text.

with other research (Wood *et al.* 1989, 1992; Reynolds and Roden 1995a, 1995b) and label recommendations to plant such stock immediately following rates of up to 2 kg a.i./ha on medium- and fine-textured soils. Any further discussion of these results in relation to soil texture is inconsequential, since the environmental risks associated with off-site movement and vertical leaching preclude the application of hexazinone to sandy soils.

A more pertinent use of these data, however, lies in illustration of the silvicultural advantages of early crop establishment and vegetation control. With the exception of black spruce container stock, growth and survival patterns from the time of planting through age 4 were similar, regardless of whether trees were planted immediately following harvesting or 1 year later. In the case of black spruce container stock, deferred planted trees were slightly diameter-disadvantaged at the time of planting and did not perform as well as hot planted trees of an equivalent age [perhaps because the smaller trees were more susceptible to elevated post-treatment competition levels (Figure 1)]. Nevertheless, a 1 yr headstart allowed hot-planted trees to gain, on average, 1.5 times the girth and height of deferred-planted trees 5 growing seasons after herbicide treatment, regardless of stock type or competition level. More importantly, these size advantages led to at least two-fold differences in stem volume and volume per ha over the same period.

Clearly, there are advantages to planting as soon after harvesting as possible. However, will a delay in planting simply lengthen the rotation age by an equivalent amount? The answer to this question lies in complex weed-crop interactions, for which we have little long-term data. When a decision is made to release these trees from competition (e.g., at age 5), it is likely that deferred-planted trees will respond more slowly and be less able to

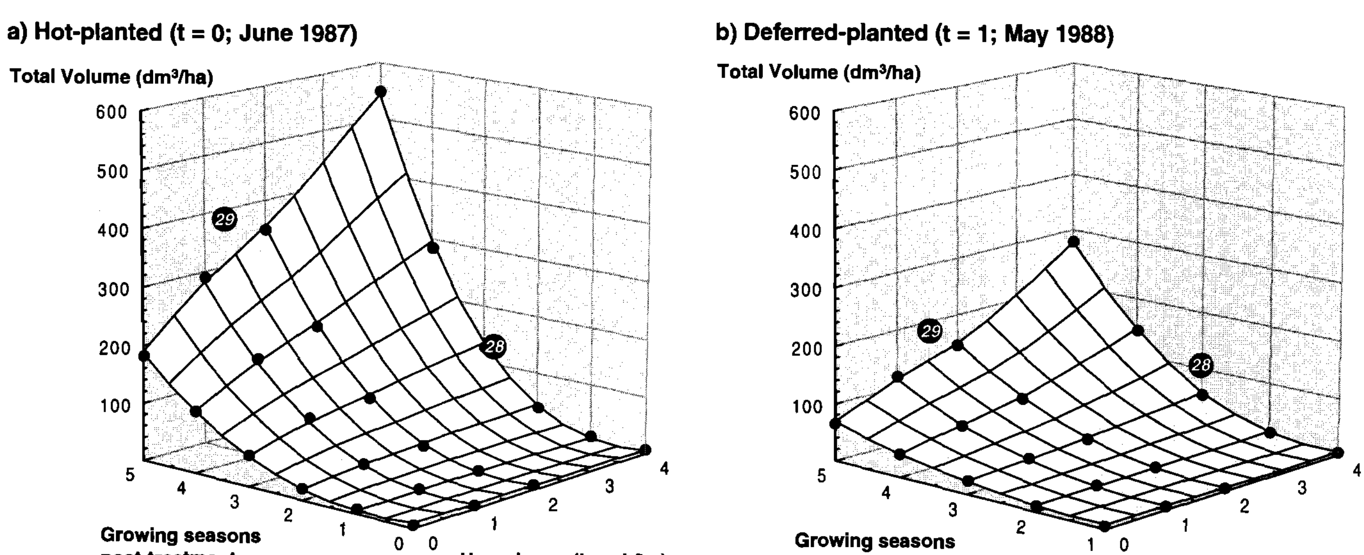

Figure 7. Stand growth (volume/ha) of black spruce bareroot stock (a) hot-planted and (b) deferred-planted following site preparation with hexazinone. Each plotted point represents the mean of 80 trees. Back-lit numbers reference points made in the text.

fully occupy the site before competition rebounds, than their larger hot-planted counterparts (Wagner et al. 1996). Over time, the cumulative effects of competition will likely prolong the age at which the deferred-planted stand reaches target volume. Without long-term data, however, one can only speculate about the length of such a delay. Regardless, forest managers may place high value on the short-term benefits of achieving free-to-grow status in the shortest possible time frame. Doing so may help meet license requirements, reduce potential liability and obligations, and increase harvest opportunities under some provincial regulations and legislation. In British Columbia, for example, forest companies must meet "green-up" standards before they are permitted to harvest adjacent stands.

Although the recommendation to establish a crop at the earliest possible time following harvest seems rather self-evident, the common practice of mechanical site preparation may delay planting for 1 or more growing seasons. Mechanical methods (e.g., trenching, disking, blading, shearing, raking, chopping, scalping, rolling, and crushing) typically reduce planting costs but can have the undesirable effects of stimulating competition and damaging the soil profile (e.g., through compaction, removal of surface organic layers, erosion, and/or puddling) (Sutton 1985, Malik and Vanden Born 1986, Wood and Dominy 1988, Mitchell 1988, Sutherland and Foreman 1995). On some sites, these methods may be obviated by

- harvesting during the snow-free period and dispersing skid trails uniformly throughout the block to maximize disturbance to the duff layer,
- bucking down slash and debris that may impede subsequent planting and tending operations,
- foot scalping during planting, and
- planting the largest, healthiest stock available.

In the short term, the added costs of these efforts will likely be more than offset by avoiding mechanical site preparation. Over the long term, early planting and minimal site disturbance are likely to offer significant volume gains.

On particularly rich sites, or those where cold soils, deep organics, and/or heavy slash necessitate some form of mechanical site preparation, chemical site preparation may also be required for competition control. Data from this study illustrate that early crop response is strongly linked to herbaceous weed levels and that threshold levels may be quite low (< 15% herbaceous cover, Figure 8). With hexazinone, increases in dose appear to result in diminishing reductions in herbaceous cover (Figure 1) and proportional increases in crop growth (Figures 3, 5, and 7), regardless of stock type or planting date post-treatment. In general, herbaceous weed control provided by 4 kg ai/ha of hexazinone resulted in crop trees with 1.6 to 2.0 times the girth of trees planted with no herbaceous weed control (2- to 4-fold increases in stem volume and volume per ha). A more traditionally applied rate of 2 kg ai/ha provided approximately half the growth response of the 4-kg ai/ha

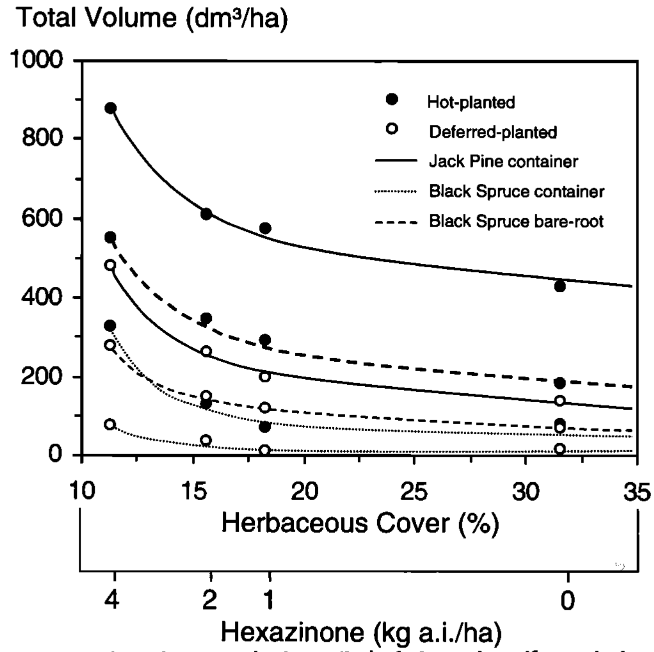

Figure 8. Stand growth (volume/ha) of planted conifers relative to mean herbaceous cover levels 5 growing seasons after treatment with hexazinone. Each plotted point represents the means for 80 crop trees and 66 herbaceous cover samples in each of 6 conifer stock-type/planting date areas.

rate, regardless of the stock type or planting date observed. As discussed above, early volume differences will likely continue to diverge, at least until the point of crown closure, as the smaller trees have an increasingly difficult time gaining site dominance over competing vegetation. Similar responses were observed in noble fir (*Abies pocera* Rehd.) and Douglas fir (*Pseudotsuga menziesii* [Mirb.] Franco) following herbaceous weed control with hexazinone in the pacific northwest (White et al. 1990).

Longer term growth response data are needed to conduct a cost-benefit analysis of vegetation control activities. At this point, it appears as though one unit of input (hexazinone) results in a proportional increase in growth. This observation may not hold true over time or with increasing dosages. Assessment of the marginal rate of return on weed control will depend on a number of factors, including the cost of treatment, future value of the product, how interest rates are viewed, the need for and cost of additional treatments needed to promote the desired product, etc. The data do, however, illustrate the short-term advantages associated with a chemical site preparation method that permits early crop establishment with minimum site disturbance.

Conclusions and Recommendations

Fifth-season post-treatment growth response data for three conifer stock types planted into sandy-loam soils treated with hexazinone (Velpar® L) suggest the following:

1. Applied to coarser textured soils (loamy sands) than permitted under the current Velpar® L registration, hexazinone increased mortality (12%) of jack pine container stock planted the spring of treatment at rates of 2 to

4 kg ai/ha. However, in as few as 5 growing seasons post-treatment, the benefits of herbaceous weed control offset these early losses, and hot-planted areas supported 2.3 times the volume of deferred-planted areas. Black spruce container and bareroot stock exhibited high tolerance to hexazinone through the range of rates tested.

2. Jack pine and black spruce stock planted the spring following harvest generally supported 2-fold greater fifth-year stem and stand volume than similar trees planted 1 year later. With little additional effort during harvesting and planting, it may be possible to avoid mechanical site preparation and capitalize on the volume gains associated with earliest possible crop establishment.

3. Jack pine and black spruce growth were positively related to the level of herbaceous weed control applied, regardless of the stock type tested. Chemical site preparation with hexazinone provided excellent herbaceous control through 5 growing seasons after treatment, permitting early crop establishment with minimum site disturbance. With the exception of poplar and raspberry, hexazinone did not offer measurable control of woody species on the test site. Although interest in the research and development of synthetic herbicides has waned in recent years, there is still need for a broad-spectrum, soil-active site-preparation herbicide in Canadian forestry.

4. There is a significant need for long-term growth response data for cost:benefit analysis and rate optimization.

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