NC-281

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United States Department of Agriculture

Forest Service

North Central Forest Experiment Station

Research Paper **NC-281**

Effect of Soil and Vegetation on Growth of Planted White Spruce

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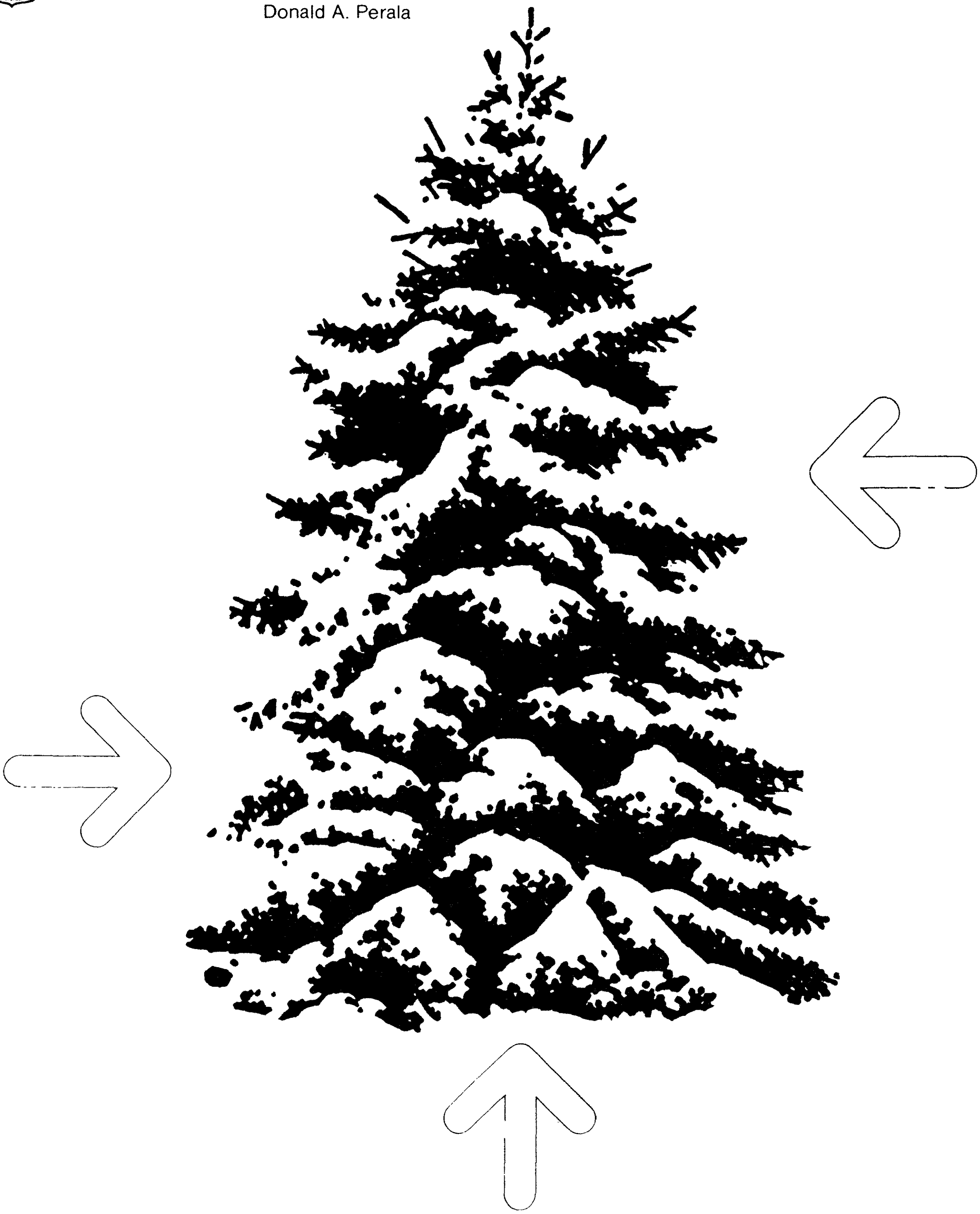

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ACKNOWLEDGMENT

The author thanks the University of Minnesota Cloquet Forestry Center and the Ottawa National Forest for providing the study sites, and Region 9 for providing the white spruce seedlings for this study. This study was partially funded by NAPIAP, appropriation number FS-510(NC-8).

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1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication June 24, 1987
1987

EFFECT OF SOIL AND VEGETATION ON GROWTH OF PLANTED WHITE SPRUCE

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White spruce (*Picea glauca* (Moench) Voss) early survival, and especially growth, are reduced by excessive vegetative competition (Eis 1981), so some weed control is beneficial (Sutton 1972, 1975; Blackmore and Corns 1979; Perala 1982). Herbicides are thought to provide the best vegetation control. Glyphosate—N-(phosphonomethyl) glycine—is a broad spectrum foliar active herbicide used both for site preparation and conifer release. Some research, however, showed that white spruce planted on sites prepared with glyphosate grew in height no more than untreated checks (Blackmore and Corns 1979, Sutton 1984), but suggested that diameter growth and survival might be increased (Sutton 1984).

Glyphosate easily controls suckers of both quaking aspen (*Populus tremuloides* Michx.) and bigtooth aspen (*P. grandidentata* Michx.) as well as most associated woody vegetation (Sutton 1984, Perala 1985), but may cause an undesirable shift in plant community from shrubs/forbs toward grasses (Jordan and Posner 1984). Sod severely competes with newly planted white spruce as well as other conifers (Rudolf 1950, Stiell 1976). White spruce seedlings benefit from some shading (Perala 1982) and protection from late spring frost where cold air drainage is poor (Sutton 1984). Thus, moderate shrub cover with minimal herbaceous competition produces optimum white spruce growth and survival (Baskerville 1961, Jordan and Posner 1984, Nienstaedt and Jeffers 1976, Olson and Perala 1981, Rudolf 1950).

Although the influence of glyphosate on plant succession has been noted on some sites (Jordan and Posner 1984), the role of soil and concomitant plant species in succession in conifer plantations is still poorly understood. Neither do we know much about how white spruce genetics interacts with soils, vegetation, and climate.

We conducted a study to determine the biologic benefits of glyphosate for establishing white spruce plantations, and how glyphosate may alter plant composition. The approach was to contrast plant community development and growth, survival, and genetic/environment interactions of white spruce from nine seed sources on two soils after two stand-conversion treatments.

METHODS

Study Areas

One area is located at the University of Minnesota Cloquet Forestry Center, about 32 km southwest of Duluth. The soil is a Cloquet sandy loam. It supports mature aspen and paper birch (*Betula papyrifera* Marsh.) and has a dense understory of hazel (*Corylus cornuta* Marsh.) and bush honeysuckle (*Diervilla lonicera* Mill.). The other area is on the Ottawa National Forest, 27 km south-southeast of Ontonagon, Michigan. The soil is Ontonagon silty clay. Mature quaking aspen and northern hardwoods dominate with only a sparse shrub layer.

Eight contiguous 1-hectare-square treatment plots were clearcut (4 full-tree logged, 4 tree-length, randomly selected) at both Cloquet (summer 1979) and Ontonagon (March 1980). By late summer 1980, both sites had regenerated abundant aspen suckers and associated woody sprouts. At each site, two replicates of each logging method were randomly selected to convert to white spruce.

Treatments

At each site in late August 1980, glyphosate[1] was foliar broadcast on one plot of each logging method (logging method = blocks) with a powered backpack sprayer at the rate of 4.7 liters per hectare (2 quarts per acre) of product diluted in water to 94 liters per

[1] *Supplied as Roundup™ containing 4 pounds per U.S. gallon of the active ingredient isopropylamine salt of glyphosate. Mention of trade names does not constitute endorsement by the U.S. Department of Agriculture.*

hectare (10 gallons per acre). In June 1981, container-grown (Ray Leach Pine Cells) white spruce comprising nine seedlots from plus trees in the Chippewa and Superior National Forests were planted at Cloquet (on Bracke scarified spots) and at Ontonagon (without further site preparation) in discrete 10 × 10-seedling blocks.

In mid-May 1982, the unsprayed plots at Cloquet were released with soil-active hexazinone (10 percent Velpar™ Gridballs™) hand placed 1 meter from seedlings as needed for shrub control (up to 4 pellets per seedling or 1.5 to 2.0 kg per hectare active ingredient). Spruce lateral root extension averages less than 50 cm at this age (Eis 1970), but asymmetrical root development is common, and some hexazinone uptake by spruce was possible. In mid-July 1982, unsprayed plots at Ontonagon were released with 2,4-D foliar spray at a rate of 3.36 kg acid equivalent in 94 liters total aqueous volume per hectare (3 pounds in 10 gallons per acre). Both hexazinone and 2,4-D were variably effective and left an irregular shrubby cover.

The herbaceous and shrub layers were sampled annually from 1980 through 1982 and in 1984 to determine herbaceous biomass, shrub basal area, and indices of similarity (Appendix A). White spruce were sampled in 1985 to determine growth, vigor, survival, shoot injury, and freedom to grow (Appendix A). These response variables were analyzed in relation to site, glyphosate, seedlot, and time by multiple regression (Appendix B).

RESULTS AND DISCUSSION

Site, or interaction of site with other variables, significantly affected spruce growth and herb layer development but did not affect shrubs (tables 1 and 2). Apparently, shrub component character and treatment response were similar on these two sites. Glyphosate did not affect spruce seedling vigor, survival, or shoot injury, but otherwise affected spruce, herb, and shrub growth. Seedlot, and especially age, were important to spruce seedling growth.

Table 1.--Summary of relations between white spruce dependent and independent variables 1/

Independent variable	Dependent variable: Total height	Biomass	Vigor 2/	Survival	Shoot injury
Site	++	++	--	++	0
Glyphosate	-	0	0	0	0
Age	++				
Site x glyphosate	++	++	0	0	0
Site x age	++				
Genotype	VV	V	V	0	V
Site x genotype	VV	VV	V	0	V
Glyphosate x genotype	0	0	0	0	V
Herb suppression		--	-	0	0
Site x herb suppression		0	--	0	+
Shrub suppression		0	0	0	+
Site x shrub suppression		0	0	0	0
Shoot injury		-	-	0	
Site x shoot injury		0	++	0	
Standard error, percent of $\overline{Y}$	12	6	10	28	33
n	288	72	72	72	72
Adjusted R^2	0.95	0.74	0.29	0.45	0.55

1/ Plus, minus, and zero indicate positive, negative, and no relations, respectively. Variable relations in multiple dummy sets that contrast among seedlots are indicated by "V." Blank = not applicable. Single symbols indicate significant t at $P < 0.05$; double symbols indicate t at $P < 0.01$.

2/ Measured by ratio of leading shoots to mean of lateral shoots.

Table 2.--Summary of relations between competing vegetation dependent and independent variables 1/

Independent variable	Herb biomass	Herb similarity	Shrub basal area	Shrub similarity
Site	++	-	0	0
Glyphosate	0	--	--	--
Year	VV	V	V	0
Site x glyphosate	0	0	0	0
Site x year	V	V	0	0
Glyphosate x year	0	0	V	0
Site x glyphosate x year	V	0	0	0
Standard error, percent of $\bar{Y}$	34	26	58	71
Adjusted R^2	0.80	0.56	0.48	0.24

1/ Plus, minus, and zero indicate positive, negative, and no relations, respectively. Variable relations in multiple dummy sets that contrast among years are indicated by "V." Single symbols indicate significant t at $P < 0.05$; double symbols indicate t at $P < 0.01$. $n = 64$.

White Spruce Environment

Seedlings grew faster on the Cloquet site:

Site	Seedling age, years: 2	3	4	5
		(Height, mm)		
Cloquet	132	252	380	517
Ontonagon	119	181	258	362

Five-year-old spruce were shorter at Ontonagon than 4-year-olds at Cloquet.

Spruce biomass after 5 years at Cloquet was twice that at Ontanagon:

Site	Glyphosate	No glyphosate
	(Biomass index, cm^3)	
Cloquet	33	22
Ontonagon	11	15

With glyphosate, spruce attained 50 percent more biomass at Cloquet but 27 percent less at Ontonagon. The reason is glyphosate increased the proportion of spruce overtopped by herbs at Ontonagon, but decreased the proportion at Cloquet (table 3). Herbs reduced spruce plantation biomass by 22 percent at Cloquet and by 40 percent at Ontonagon. Leading shoot injury caused an additional 12 percent growth loss.

Shrubs were reduced by glyphosate but they affected biomass only by increasing shoot injury rate:

Site	Shrub suppression	Herb suppression	No shrub or herb suppression
		(Shoot injury, percent)	
Cloquet	4.7	6.5	0.6
Ontonagon	3.4	0	0

Shrubs injure shoots indirectly by providing cover for small herbivores, mainly snowshoe hare (*Lepus americanus* Erxleben). Shrubs injure shoots directly by wind-induced whipping. The lush grasses at Cloquet (39 percent cover) accounted for the high shoot injury rate there. Grasses covered only 9 percent of the area at Ontonagon.

The index of biomass, derived from stem caliper and total height, was affected by the seedling environment acting in different ways on these components. For each doubling of stem caliper, total height increased by 60 percent at Ontonagon but by 100 percent at Cloquet. Seedlings suppressed by herbs were 9 percent shorter per unit caliper than open-grown seedlings. Leader injury caused a 12-percent loss in biomass, mostly because of caliper growth loss rather than height growth loss. Seedlings with shoot injury had height: caliper ratios 13 percent higher than uninjured seedlings.

Table 3.--Suppression of and injury to white spruce seedlings by herbs and shrubs

Site	Glyphosate	No glyphosate
	- Herb suppression, percent -	
Cloquet	22	32
Ontonagon	44	22
	- Shrub suppression, percent -	
Cloquet	12	24
Ontonagon	20	27
	- - Injured shoots, percent - -	
Cloquet	3.2	7.9
Ontonagon	0.5	2.3

Seedling density was related only to site. White spruce averaged 1,842 per hectare at Cloquet and 1,094 at Ontonagon. Initial stocking was greater at Cloquet (2,500/ha) than at Ontonagon (1,600/ha), and survival was better at Cloquet (74 percent vs. 68 percent). Even though environmental variables strongly affect seedling growth, their effect on survival is much weaker (Perala 1982).

The ratio of length of leading shoots to lateral shoots in the uppermost whorl increases with seedling vigor (Sutton 1975). Ratios exceeding 1.5 generally indicate sufficient dominance to continue vigorous height growth; ratios less than 1.5 indicate loss of dominance and ability to compete and survive. In this study, each 20-percent improvement in shoot ratio increased height by 1.4 percent, stem caliper by 2.8 percent, and biomass by 4.3 percent.

Leader:lateral ratios were controlled mainly by site, herb suppression, and by leading shoot injury interacting with site:

Site	Herb suppression	Shoot injury	Neither
	(Leader:lateral ratio)		
Cloquet	1.25	2.28	1.70
Ontonagon	1.43	1.67	1.67

Shoot injury improved ratios at Cloquet because laterals were injured more than leading shoots. Shrubs did not significantly affect ratios.

White Spruce Genetics

White spruce is genetically plastic (Nienstaedt and Teich 1972, Stellrecht *et al.* 1974, Khalil 1985) and wide variation in growth among seed sources is common. The most productive seedlots exceeded the least productive seedlots in our study by nearly 80 percent on each site (table 4). Chippewa National Forest seedlots were nearly one-fourth more productive overall than Superior National Forest seedlots. Mohn *et al.* (1976) observed similar variation among seed sources from these two forests.

The least productive Chippewa National Forest seedlot at Cloquet (C44) was the most productive at Ontonagon (table 4). Some white spruce seed sources may be better adapted than others to calcareous soils such as Ontonagon (Cunningham 1971, Nienstaedt and Teich 1972, Nienstaedt 1982).

Seedlot productivity was directly related to ratios of leading shoots to lateral shoots and of total height to stem caliper. Productivity was not related to shoot injury, although Chippewa National Forest seedlots suffered about half as much injury overall as Superior National Forest seedlots:

Site	Seed source: Chippewa	Seed source: Superior
	(Shoot injury, percent)	
Cloquet	2.4	5.3
Ontonagon	.7	.6

Competing Vegetation

Herb biomass production is highly variable because it strongly depends on growing season climate (Zavitkovski 1976):

Year	Cloquet: Glyphosate	Cloquet: No glyphosate	Ontonagon: Glyphosate	Ontonagon: No glyphosate
	– – – – (Herb biomass, kg/ha) – – – –			
1980	2,787	2,303	599	482
1981	838	1,288	835	1,137
1982	2,425	1,558	941	823
1984	3,067	4,026	2,863	2,680

Table 4.--White spruce 5-year biomass index by site and seedlot [1]

Seedlot	Site: Cloquet	Ontonagon	Mean
	- - - Biomass index, cm^3 - - -		
C50	34 a	14 fg	24
C24	34 a	12 g	23
S68	31 b	13 g	22
C23	30 bc	14 fg	22
C29	28 c	14 fg	21
C44	26 cd	16 f	21
S95	25 d	11 h	18
S77	19 e	14 fg	17
S92	20 e	9 h	15
Chippewa mean	30	14	22
Superior mean	24	12	18

[1] Means followed by the same letter are not statistically different ($P < 0.05$).

In 1981, after glyphosate application, herb biomass was significantly less than the ensuing measurement years, but differed significantly by herbicide treatment only at Cloquet. Herb biomass was greater in 1984 than in 1982, except for glyphosate treatment at Cloquet. Herb biomass, regardless of herbicide treatment, was lower in 1980 than in the ensuing years at Ontonagon, but did not differ at Cloquet. Overall, glyphosate had little effect, and site and year (climate) were most important to the production of herb-layer biomass.

Shrub basal area was not affected by site, but was greatly reduced by glyphosate:

Year	Glyphosate	No glyphosate
	(Shrub basal area, m^2 /ha)	
1980	2.2	2.1
1981	1.7	2.6
1982	.9	4.3
1984	1.7	6.2

Shrub basal area in 1982 was reduced by nearly 80 percent by glyphosate and was significantly less than pre-treatment levels throughout the study period. The prolonged activity of glyphosate is apparent: maximum reduction of shrubs did not occur until 2 years after treatment. The release with hexazinone and 2,4-D did not greatly affect shrub basal area.

Neither shrub nor herb indices of similarity were affected by glyphosate.

CONCLUSIONS

Growth of 5-year-old (from seed) white spruce seedlings was largely determined by site quality, with growth on a Cloquet sandy loam much better than on an Ontonagon silty clay soil.

Glyphosate temporarily reduced shrub competition at both sites, but increased herb competition at Ontonagon while decreasing it at Cloquet. Consequently, spruce grew faster with glyphosate at Cloquet (but not at Ontonagon) primarily because fewer seedlings at Cloquet were overtopped by herbs. The possible uptake of hexazinone at Cloquet where glyphosate was not used may also have enhanced the apparent effectiveness of glyphosate. At both sites, spruce suppressed by shrubs had more injuries to leading shoots. Glyphosate did not alter the species mix in the herb layer or in the shrub layer at either site.

Chippewa National Forest seedlots grew better overall than Superior National Forest seedlots, and one seedlot (C50) from the former grew particularly fast. Another seedlot, C44, was site-sensitive. These two seedlots especially deserve continued monitoring to determine their long-term performance.

The 50 percent faster growth of spruce at Cloquet and the 27 percent slower growth at Ontonagon following glyphosate application suggest that this herbicide is site-specific. It may be more prudent on fine-textured soils to use glyphosate for release after the spruce are fully established and prepared to respond to vegetation control.

LITERATURE CITED

Baskerville, G. L. 1961. Response of young fir and spruce to release from shrub competition. Tech. Note 98. Ottawa, ON: Canadian Forestry Branch, Forestry Research Division. 14 p.

Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Canadian Journal of Forest Research. 2: 49-53.

Blackmore, D. G.; Corns, W. G. 1979. Lodgepole pine and white spruce establishment after glyphosate and fertilizer treatments of grassy cutover forest land. Forestry Chronicle. 55: 102-105.

Chambers, J. C.; Brown, R. W. 1983. Methods for vegetation sampling and analysis on revegetated mined lands. Gen. Tech. Rep. INT-151. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 57 p.

Cunningham, R. A. 1971. Genotype × environment interactions in white spruce. Ph.D. thesis. Madison: University of Wisconsin. 8 p. (Abstract and synopsis only.)

Draper, N. R.; Smith, H. 1981. Applied regression analysis. 2d ed. New York: John Wiley & Sons. 709 p.

Eis, S. 1970. Root-growth relationships of juvenile white spruce, alpine fir, and lodgepole pine on three soils in the interior of British Columbia. Publ. 1276. Ottawa, ON: Canadian Forestry Service, Department of Fisheries and Forestry. 10 p.

Eis, S. 1981. Effect of vegetation competition on regeneration of white spruce. Canadian Journal of Forest Research. 11: 1-8.

Jordan, P. A.; Posner, S. 1984. Effects of deciduous shrubs on young planted white spruce, with references to moose, in northeastern Minnesota. Final Report to the Superior National Forest, USDA Forest Service. St. Paul: University of Minnesota. 62 p. (Unpublished)

Khalil, M. A. K. 1985. Genetic variation in eastern white spruce (*Picea glauca* (Moench) Voss) populations. Canadian Journal of Forest Research. 15: 444-452.

Loetsch, F.; Zohrer, F.; Haller, K. E. 1973. Forest inventory, vol. 2. Blv Verlagsgesellschaft Munchen Bern Wien. 469 p.

Mohn, C. A.; Riemenschneider, D. E.; Cromell, W.; Peterson, L. C. 1976. A white spruce progeny test—seedling seed orchard: 12th year progress report. In: Proceedings, 12th Lake States forest tree improvement conference; 1975 August 18-25; Chalk River, ON. Gen. Tech. Rep. NC-26. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 98-107.

Nienstaedt, H. 1982. White spruce in the Lake States. In: Mroz, G. D.; Berner, J. F., comp. Proceedings, Artificial regeneration of conifers in the Upper Great Lakes Region; 1982 October 26-28; Green Bay, WI. Houghton: Michigan Technological University: 142-167.

Nienstaedt, H.; Jeffers, R. M. 1976. Increased yields of intensively managed plantations of improved jack pine and white spruce. In: Intensive plantation culture. Gen. Tech. Rep. NC-21. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 51-59.

Nienstaedt, H.; Teich, A. 1972. The genetics of white spruce. Res. Pap. WO-15. Washington, DC: U.S. Department of Agriculture, Forest Service. 24 p.

Olson, S. P.; Perala, D. A. 1981. Growth of planted white spruce in relation to soil texture, fertilization, and microenvironment. Final report to CANUSA, East Spruce Budworm Program. Grand Rapids, MN: USDA Forest Service. 31 p. (Unpublished)

Perala, D. A. 1982. Early release—current technology and conifer response. In: Mroz, G. D.; Berner, J. F., comp. Proceedings, Artificial regeneration of conifers in the Upper Great Lakes Region; 1982 October 26-28; Green Bay, WI. Houghton: Michigan Technological University: 396-410.

Perala, D. A. 1985. Using glyphosate herbicide in converting aspen to conifers. Res. Pap. NC-259. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 4 p.

Rudolf, P. O. 1950. Forest plantations in the Lake States. Tech. Bull. 1010. Washington, DC: U.S. Department of Agriculture, Forest Service. 171 p.

Stellrecht, F. W.; Mohn, C. A.; Cromell, W. 1974. Productivity of white spruce seed sources in a Minnesota test planting. For. Res. Note 251. St. Paul: University of Minnesota, School of Forestry. 4 p.

Stiell, W. M. 1976. White spruce: artificial regeneration in Canada. Inf. Rep. FMR-X-85. Ottawa, ON: Canadian Forestry Service, Department of Environment, Forest Management Institute. 275 p.

Sutton, R. F. 1972. Constraints on the growth of young white spruce. In: McMinn, R. G., ed. White spruce: ecology of a northern resource: proceedings of a symposium; 1971 June 21; Edmonton, AL. Inf. Rep. NOR-X-40. Edmonton, AL: Canadian Forestry Service, Department of Environment, Northern Forest Research Centre: 24-39.

Sutton, R. F. 1975. Nutrition and growth of white spruce outplants: enhancement by herbicidal site preparation. Canadian Journal of Forest Research. 5: 217-223.

Sutton, R. F. 1984. Plantation establishment in the Boreal Forest: glyphosate, hexazinone, and manual weed control. Forestry Chronicle. 60: 283-287.

Zavitkovski, J. 1976. Ground vegetation biomass, production, and efficiency of energy utilization in some northern Wisconsin forest ecosystems. Ecology. 57: 694-706.

APPENDIX A

VEGETATION SAMPLING

Herbs and Shrubs

On each site we sampled herbs and shrubs using eight systematic sample points located by random starts on each hectare in 1980, 1981, 1982, and 1984. Herbs and woody seedlings less than 15 cm tall were tallied by percent cover by species and total oven-dry weight (by clipping) on 0.5 m^2 plots. Shrubs (including trees less than 2.5 cm d.b.h. but taller than 15 cm) were tallied by species and diameter at 15 cm on 4-m^2 plots to derive shrub basal area. We computed indices of similarity, using Spatz's method (Chambers and Brown 1983) from species cover (herbs) and basal area (shrubs).

White Spruce

Stocking and growth estimates for white spruce were derived from sampling before start of growth in April 1985. Four sample points were systematically located near the center of each seedlot block. The three spruce forming the smallest triangle enclosing each sample point were measured for annual height growth (distance between whorls) in 1981 through 1984; for 1983 interwhorl caliper; and for length of lateral shoots in the uppermost whorl. We also noted whether the seedling was smothered by herbs or overtopped by woody plants, and whether the leading shoot or bud was injured. The distances separating the three sample seedlings were recorded to estimate seedling density according to the method of non-overlapping triangles (Loetsch *et al.* 1973). The 12 subsample estimates of seedling attributes and 4 subsample estimates of stocking were averaged by seedlot, herbicide treatment, replicate (logging method), and site.

APPENDIX B

EXPERIMENTAL DESIGN AND STATISTICAL ANALYSIS

The experimental design was a split-plot replicated twice with herbicide treatments as large plots. Site was an unreplicated fixed effect. The dependent variables comprise three groups (units in parentheses):

1. White spruce cumulative shoot growth (mm), 1981 through 1984 (n = 288)
2. White spruce attributes in spring 1985 (n = 72):
    a. index of biomass [(1983 internode caliper)^2 × (total height)]
    b. vigor (decimal ratio of 1984 leader growth to 1984 laterals)
    c. seedling survival (number per hectare)
    d. shoot injury (percent of leading shoots)
3. Competing vegetation in 1980, 1981, 1982, and 1984 (n = 64):
    a. shrub basal area (m^2 /ha)
    b. Spatz's index of similarity for shrubs (unitless)
    c. herb biomass (kg/ha)
    d. Spatz's index of similarity for herbs (unitless)

The independent variables by group are:

Independent variable	**Group 1**	**2a-c**	**2d**	**3**
Site	X	X	X	X
Glyphosate	X	X	X	X
Seedlot	X	X	X	X
Age	X			
Year				X
Shoot injury		X		
Herb suppression (percent)		X	X	
Shrub suppression (percent)		X	X	

where for site, Ontonagon = 0, Cloquet = 1; for glyphosate, not applied = 0, applied = 1; seedlot = orthogonal contrasts; age = spruce age from seed, years; and year = orthogonal contrasts. Note that shoot injury was studied as both an independent and dependent variable.

The objective of the contrasts was to identify significantly different performances in Group 1 and Group 2 variables among Chippewa National Forest seedlots (C23, C24, C29, C44, C50), among Superior National Forest seedlots (S68, S77, S92, S95), between the Forest seedlots overall, and between C50 and all other seedlots. Similar partitioning contrasted years for Group 3 variables.

The generalized linear model was:

$$y = bo + b1\ \text{site} + b2\ \text{glyphosate} + b3\ \text{seedlot} + b4\ \text{age (or year)} + b5\ \text{shoot injury} + b6\ \text{herb suppression} + b7\ \text{shrub suppression} + \text{(all interactions)} + e_i\ . \quad (1)$$

For spruce shoot growth, biomass, and vigor, log-log transformations were needed to stabilize variance and accommodate nonlinearity. All interaction terms are simply the products of the appropriate dummy and/or real variable columns.

Frequencies of suppression by herbs and shrubs and of shoot injury were transformed as $\sqrt{\text{per cent} + 1}$ for analysis. The analyses were performed by the all possible subsets method (Draper and Smith 1981). Treatment significances were determined by t-test (0.05 level) of regression coefficients. Site was unreplicated, so significance was declared if t-test $p < 0.001$.

The log-log equation for white spruce shoot growth expressed in the nonlinear arithmetic mode is:

$$\text{Predicted height, mm} = 51.7\ \text{age}^{1.21} \times 0.90\ \text{site} \times (\text{site} \times \text{age})^{0.28} \times 0.93\ \text{glyphosate} \times 1.14\ (\text{site} \times \text{glyphosate}). \quad (2)$$

The strong interaction of site with age and with glyphosate is seen by rewriting the equation expressly for each of the two sites.

$$\text{Predicted height (Cloquet), mm} = 46.5\ \text{age}^{1.49} \times 1.06\ \text{glyphosate}, \quad (3)$$

and

$$\text{Predicted height (Ontonagon), mm} = 51.4\ \text{age}^{1.21} \times 0.93\ \text{glyphosate}. \quad (4)$$

The constants are corrected for logarithmic bias according to Baskerville (1972) and are the average for all seedlots. Standard error is $\pm$ 12 percent at mean predicted height.

Casual interpretation of the significant response of the herb index of similarity to glyphosate (table 2) suggests almost 12 points of dissimilarity in the species mix in the herb layer. But the lack of a significant interaction of glyphosate with the year contrasts (especially the contrast between pre-treatment and post-treatment years), means great dissimilarity existed before herbicide treatment and persisted unchanged throughout the study period. Similarity is high (Chambers and Brown 1983) and tended to be higher overall at Ontonagon than at Cloquet:

Year	**Cloquet**	**Ontonagon**
	Index of similarity	
1980	26	30
1981	27	34
1982	30	36
1984	30	25

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1987. Effect of soil and vegetation on growth of planted white spruce. Res. Pap. NC-281. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 8 p.

White spruce container stock grew better on a sandy loam soil than on a silty clay, and much better without herbaceous competition. Herbaceous competition was less vigorous on the sandy loam soil following glyphosate treatment, but was more vigorous on the silty clay. Certain spruce genotypes excelled under different field environments.

KEY WORDS: Roundup™, glyphosate, *Picea glauca*, genotype, height growth, biomass, productivity.