PLANTATION ESTABLISHMENT IN BOREAL ONTARIO: A STUDY OF SPRING PLANTING AND MECHANIZATION

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ABSTRACT

Bare-root jack pine *(Pinus banksiana* Lamb.), black spruce *(Picea mariana* [Mill.] B.S.P.), and white spruce *(P. glauca* [Moench] Voss), each of two provenances, were planted manually or by machine in boreal Ontario in 1971, 1972, and 1973. Three levels of fertilization were applied soon after planting: none, low (nominally 43, 19, and 36 kg/ha of N, P, and K, respectively) and high (double the low rate). For each site-species combination, a completely randomized factorial design was used, with 2 provenances x 3 levels of fertilization, in 25-tree plots with 15 replications, i.e., 2,250 trees per species per site. Performance was monitored for 4 years. Provenance had no effect. Jack pine outperformed the spruces on both clearcut outwash and corridored mixedwood sites. White spruce showed no potential for successful plantation establishment on clearcut outwash sites. None of the three species showed potential for conversion of shrubby, overmature mixedwoods by underplanting without weed control. With similar soil conditions and comparable site preparation, planting by machine and planting by hand gave essentially identical results; in dry soil that was difficult to firm, machine planting was superior. The positive response to low fertilization as a surface dressing at or soon after the time of planting was small and unlikely to be economic. High fertilization was detrimental.

RÉSUMÉ

En 1971, 1972 et 1973, des plants à racines nues de pin gris *(Pinus banksiana* Lamb.), d'épinette noire *(Picea mariana* [Mill.] B.S.P.) et d'épinette blanche *(Picea glauca* [Moench] Voss), chaque essence venant de deux provenances différentes, ont été plantés à la main et à la machine dans la région forestière boréale de l'Ontario. Peu de temps après leur mise en terre doses d'engrais ont été épandues: une dose nulle, une faible dose (soit 43, 19 et 36 kg/ha de N, P et K respectivement) et une forte dose (le double de la faible dose). Pour chaque combinaison station-essence, un plan d'expérience factorielle complètement randomisé a été utilisé, avec deux provenances recevant 3 doses d'engrais, dans des parcelles de 25 arbres avec 15 répétitions, pour un total de 2,250 arbres d'une même essence par station. Le rendement a été surveillé pendant quatre ans. La provenance n'a eu aucun effet. Le pin gris a surpassé les épinettes dans les stations coupées à blanc situées dans des sols d'épandage fluvio-glaciaire et dans des bandes déboisées de forêt mixte. L'épinette blanche n'offrait aucun potentiel d'implantation dans les stations coupées à blanc à sol d'épandage fluvio-glaciaire. Aucune des trois essences ne semblait convenir à la plantation en sous-étage sans désherbage pour convertir une forêt mixte surâgée et arbustive. La plantation mécanique et la plantation manuelle ont donné des résultats essentiellement identiques dan des sols similaires préparés de façon comparable; la machine à planter a donné de meilleurs résultats dans des sols secs difficiles à compacter. La réaction des plants à la faible dose d'engrais épandue en surface au moment de la plantation ou peu de temps aprés était négligeable et vraisemblablement peu économique. L'épandage d'une forte dose d'engrais a été nuisible.

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Cover photo: Aerial view of parts of the P72 and P73 experimental areas, Fawn Township, November 1978. (photo courtesy of Ontario Ministry of Natural Resouces)

INTRODUCTION

Outplantings were carried out in boreal Ontario in 1971 (P71), 1972 (P72), and 1973 (P73), to provide biological assessments of the effectiveness of planting machines then being evaluated in Ontario (cf. Riley 1975; Cameron 1975a, 1975b, 1976; Scott 1975). First- through fourth-year results from those plantings are presented here.

The objectives were to identify and evaluate the major factors controlling the field performance of bare-root stock outplanted in spring by machine in some typical cutovers in boreal Ontario. Emphasis was on those factors that could be modified readily in mechanized planting operations, whether by machine attachment, machine design, or machine operation.

Initially, the aim was to evaluate the performance of operational, shipping-run jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* [Mill.] B.S.P.), and white spruce (*P. glauca* [Moench] Voss) as affected by:

- provenance or lot,
- year of planting (variation from year to year),
- planting machine model,
- site,
- fertilization at time of planting,
- weed control.

Various impediments materialized to subvert the full realization of some of these aims.

A succession of problems incidental to the experimentation exerted considerable, uncontrolled influence on the results obtained, notably in the P71 and P72 plantings. For example:

- the black spruce planting stock supplied in 1971 had been overheated in storage or transit, much of the remaining foliage had become blackened, and some of it was mouldy; the root:shoot ratio of this stock was exceptionally poor.
- some of the baled jack pine supplied in 1971 was found submerged in water when collected from the nursery root cellar where it had been stored.
- mechanical problems delayed planting for 5.5 weeks in the unusually dry spring of 1972, during which the field-stored planting stock flushed and the soils of the P72 sites in the Manitouwadge area became excessively dry.

- only one of the three planting machines originally scheduled for evaluation in the federal/provincial program was available for the P71 and P73 plantings, and although two machines were used in the P72 plantings they could not be operated on sites closer than 300 km apart; consequently, direct comparison was impossible (Sutton 1975a).

These planting machines predated the more recent intermittent planters (Stjernberg 1985).

Recognition of these problems is important because they have certainly influenced the results; nevertheless, the results are worth reporting. They would be obtainable even with unusually poor operational practice, but could readily be improved upon in normal practice. The trends reflected by the data could have been strengthened only in the absence of the problems encountered.

The philosophy governing these and related (cf. Sutton 1982) biological studies was that field experiments with shipping-run stock on what approaches the operational scale could provide information of particular operational relevance (Sutton 1975a). If planting stock is specially grown or specially handled, field performance can be dramatically superior to that achieved in operational practice (cf. Anon. 1981, Pierpoint et al. 1981).

MATERIALS AND METHODS

Species

Virtually the whole of the planting program in the boreal forest of Ontario is with jack pine, black spruce, and white spruce. All three species were used on all sites in the investigation reported here, notwithstanding the fact that white spruce were apparently unsuited to some of the outwash sites. This was done both to secure statistical orthogonality and to provide data for ecologically informative comparisons among species.

Provenance

With the exception noted below, planting stock of two provenances, Site Regions 3E (Lake Abitibi) and 4E (Lake Timagami) (Hills 1960), was used. Site Region 3E is the more northerly. Black spruce of one provenance only, 4E, could be obtained for the P71 plantings; this stock was divided into "lot 1" and "lot 2", the former designating stock as received, the latter referring to stock that was regraded after receipt to remove damaged plants together with those that were excessively large or small. The point in using two different planting stock lots was to determine whether field performance was sufficiently similar to support predictive use of the results, or so dissimilar as to demonstrate the unwisdom of extrapolation. If provenance were found to influence results substantively, the forest manager would be alerted to the need to take account of this factor.

Year of Planting

Plantings were carried out in 1971, 1972, and 1973. In plantation establishment research, weather is only one of several uncontrolled factors that vary from year to year. The effect of weather, therefore, cannot be isolated and evaluated by itself. Nevertheless, the predictive value of results from field experiments initiated in each of three years is much greater than that from more limited plantings.

Type of Machine

The Reynolds-Lowther Heavy Duty Crank Axle Planter (formerly the Beloit) was used in all three years of plantings, the Taylor Drum Tree Planter in 1972 only. Details of these machines and their operating characteristics, including the requisite prime movers, are given by Riley (1975) and Cameron (1975a, 1975b, 1976, 1980).

Manual vs Machine Planting

In 1973, three plantings were established by:

- Reynolds-Lowther machine (Site 1),
- hand planting among Site 1 trees, along the line of machine planting, with, therefore, the same kind and degree of site preparation (physically Site 1, but designated Site 2 to distinguish the planting method),
- hand planting on untreated ground adjacent to Site 1 (Site 3).

In 1971 and 1972, no directly comparable hand planting was carried out in association with the machine plantings.

Two mixedwood sites were planted by hand in 1972 to employ otherwise idle support staff during the prolonged delay that preceded the onset of the machine trials.

All manually planted trees were planted by the operational slit method.

Site

The choice of sites was dictated by the locations selected for the work study tests of mechanized planting described by Riley (1975) and Cameron (1976). Most of the sites are within 80 km of Chapleau, Ontario, but P72 sites 1, 2, and 3 are about 26 km northeast of Manitouwadge, Ontario, some 300 km northwest of Chapleau (Table 1, Fig. 1). The Manitouwadge and Chapleau groups of sites lie, respectively, in the eastern part of the Central Plateau (B.8) and the western part of the Missinaibi-Cabonga (B.7) portions of Rowe's (1972) Boreal Forest Region. All sites are on outwash soils except P72 sites 1 and 2, which are on more fertile till.

Fertilization

Three levels of fertilization were applied: none, "low", and "high". For the low rate, approximately 12 g of 15-15-15 or 25 g of 7-7-7 agricultural-grade NPK fertilizer were hand broadcast on a 70-cm-diameter patch centered on each fertilized tree. This rate was nominally 43 kg/ha N, 19 kg/ha P, and 36 kg/ha K. The high rate was double the low rate.

In 1973 the fertilizer was applied immediately after planting, as originally intended, to simulate an application possible with a planting machine if such were found to be desirable. In 1971 and 1972 the fertilizer application was delayed between three and five weeks.

Table 1. Main characteristics of the study sites

Year of planting	Site No.	Designation	Planting mode	Township	Mean elevation (m)	Latitude N	Longitude W	Soil texture and origin
1971	1	Fawn	Reynolds	Fawn	400	47° 39'	82° 30'	sand, outwash
	2	Budd	Reynolds	Recollet	440	47° 55'	84° 05'	gravelly sand, outwash
1972	1	mixedwood slope	hand	-	380	49° 14'	84° 33'	bouldery, loam, till
	2	mixedwood flat	hand	-	360	49° 13'	84° 33'	till, colluvium
	3	block C	Taylor	Nickle	340	49° 09'	85° 36'	gravelly sand, outwash
	4	Fawn	Reynolds	Fawn	400	47° 39'	82° 30'	sand, outwash
1973	1	Fawn	Reynolds	Fawn	400	47° 39'	82° 30'	sand, outwash
	2	Fawn	hand twin[a]	Fawn	400	47° 39'	82° 30'	sand, outwash
	3	Fawn	hand	Fawn	400	47° 39'	82° 30'	sand, outwash

[a]Hand-planted trees interspersed among P73 Site 1 trees.

Weed Control

In the machine plantings, the passage of the planting machines and their prime movers had the effect of isolating the outplants in a nutrient-poor, vegetation-free swath (Sutton 1979). Since this strip remained relatively free of vegetation for several years, the provision for weed control in the experimental design could not be exploited. Hence, there was no opportunity of using herbicide to enhance fertility indirectly (cf. Sutton 1975b). Lack of resources prevented the application of weed control treatment on the two mixedwood sites.

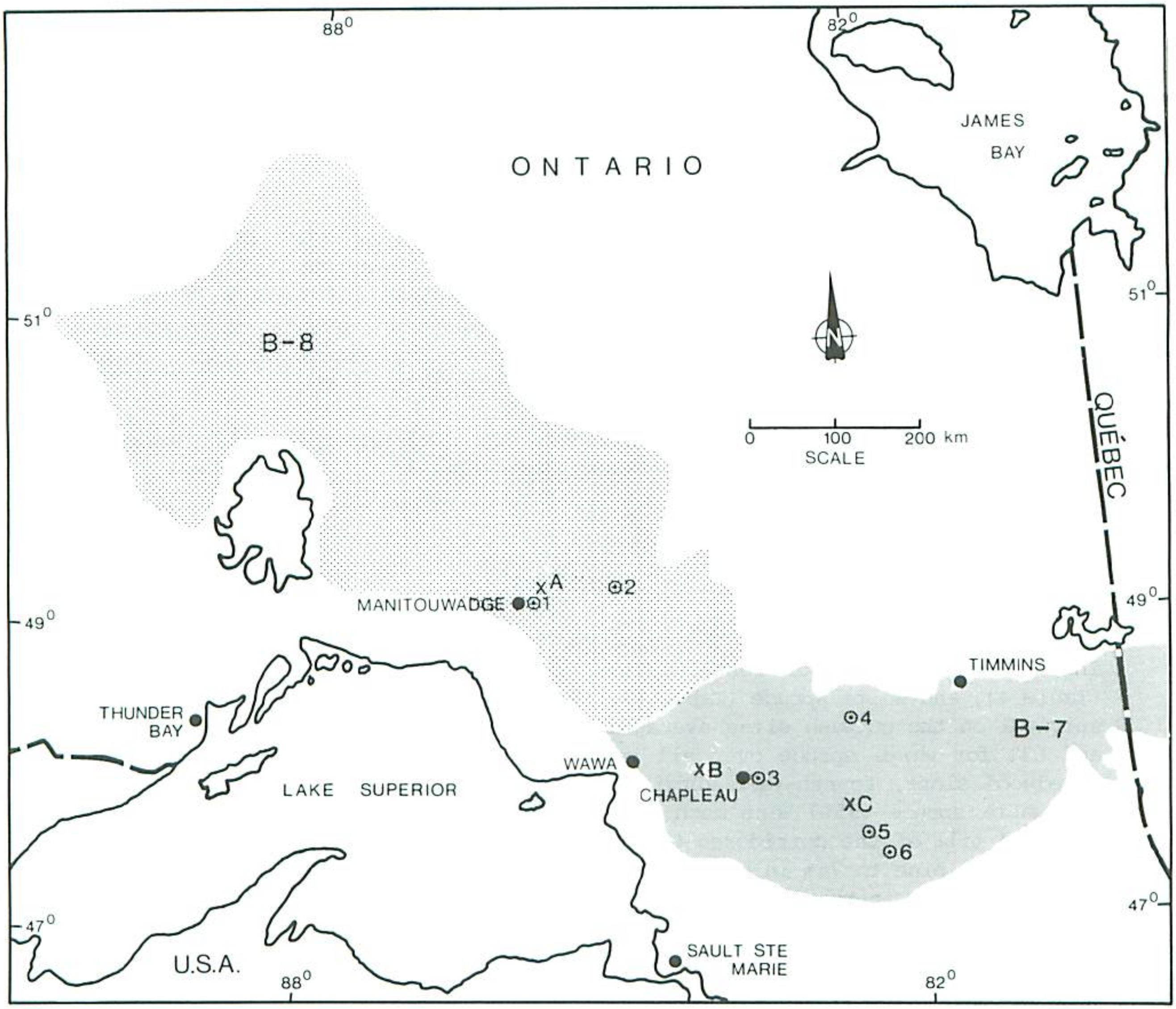

Figure 1. Locations of study sites (XA = P72 sites 1, 2, and 3; XB = P71 Site 2; and XC = P71 Site 1, P72 Site 4, and P73 sites 1, 2, and 3) and weather stations (01 = Manitouwadge, 02 = Hornepayne, 03 = Chapleau, 04 = Foleyet, 05 = Ramsay, 06 = Biscotasing) used in weather data calculations *in* Sutton (1982). B-7 (shaded) and B-8 (stippled) areas identify sections of Rowe's (1972) Boreal Forest Region.

Experimental Design

For each site-species combination, a completely randomized factorial design was used, with two provenances (or, in the case of P71 black spruce, lots) x three levels of fertilization x three degrees of weed control, in 25-tree plots and, except for the P72 mixedwood flat planting with four replications, five replications. Thus, with the exceptions noted, each study site received a total of 2,250 trees of each species. Randomizations were done separately for each study site-P year-species combination.

Planting Stock

Shipping-run, spring-lifted, bare-root seedlings (2+0 jack pine, 3+0 black spruce, and 3+0 white spruce) of provenances 3E and 4E (Hills 1960) were supplied by provincial government nurseries at Chapleau and Swastika. The size of the stock can be inferred from data on planting heights included under **RESULTS** and, for the P72 and P73 stock, from the dimensions of trees used in root-growth capacity tests previously reported by Sutton (1982).

Foliar nutrient concentrations were not determined for the P71 stock, but those of the P72 and P73 4E stocks were similar to one another in most respects (Table 2).

RESULTS

Survival rates (Fig. 2) varied with year of planting, time since planting, site, and level of fertilization, in jack pine (Table 3), black spruce (Table 4), and white spruce (Table 5). By the end of the fourth growing season, survival on the outwash sites averaged 87% for jack pine, 70% for black spruce, and 63% for white spruce over all years of planting. On the till soil of the mixedwood slope, fourth-year survival rates of underplanted black spruce (61%) and white spruce (55%) were much greater than that of jack pine (33%). On the modified till of the corridored mixedwood flat, survival rates varied only from 81% in jack pine to 74% in black spruce. In general, survival rates were higher in the P73 than in the P71 and P72 plantings.

Over all, provenance made a negligible difference to survival rates, but in the P73 plantings survival rates at the various levels of fertilization were influenced by provenance, especially in jack pine but also in the spruces.

Growth rates (Fig. 2) varied with species, time since planting, site, and, to some extent, level of fertilization in jack pine (Table 6), black spruce (Table 7), and white spruce (Table 8). Growth of all three species in underplantings was very poor.

Table 2. Foliage nutrient concentrations in P72 and P73 provenance 4E planting stock.

Year of planting	Species	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1972[a]	jack pine	1.93	--[c]	0.47	0.42	0.057
	black spruce	1.58	--	0.44	0.58	0.060
	white spruce	1.67	--	0.34	0.64	0.047
1973[b]	jack pine	1.90	0.17	0.72	0.39	0.092
	black spruce	1.33	0.13	0.48	0.59	0.068
	white spruce	1.56	0.14	0.37	0.97	0.072

[a]Values for P72 stock are means of four samples each composited from five randomly selected plants.

[b]Values for P73 stock are means of 10 individual sample determinations.

[c]not available

In jack pine, the best growth was on the P72 corridored mixedwood flat where fourth-year total height averaged 108 cm; the poorest growth was in the P72 underplanting on the mixedwood slope, where fourth-year total height averaged 45 cm. In black spruce, fourth-year total height growth was greatest (86 cm) on outwash sites 1 and 2 of the P73 plantings, in which trees had been machine- or hand-planted into site-prepared ground. Black spruce total height after four growing seasons was least on the P72 mixedwood slope underplanting, where it averaged 40 cm. White spruce growth was poor in all plantings; in the P72 mixedwood flat planting, total height after four growing seasons averaged 45 cm; in other plantings, fourth-year total height averaged less than 34 cm and was only 26 cm in the P73 plantings.

DISCUSSION

Survival rates in the study plantings do not differ markedly from those reported by MacKinnon (1974) and Carlson (1977) for operational plantings in boreal Ontario from the mid-1960s through the mid-1970s. Growth rates over the first four growing seasons after outplanting would also seem to be comparable with those achieved operationally.

In Mullin's (1978a, 1979) jack pine and white spruce research plantings, mean total heights after four growing seasons were substantially greater than those in the study reported here; however, his black spruce (1978b) reached about the same fourth-year mean total height as did the black spruce in the present study. Research plantings, typically small scale, often show field performance superior to that in operational plantings (cf. Anon. 1981, Pierpoint et al. 1981), probably reflecting superior stock handling and planting practice and, sometimes, superior planting stock; Mullin's plantings were mostly small scale and located in parts of Ontario more climatically favored than those of the present study.

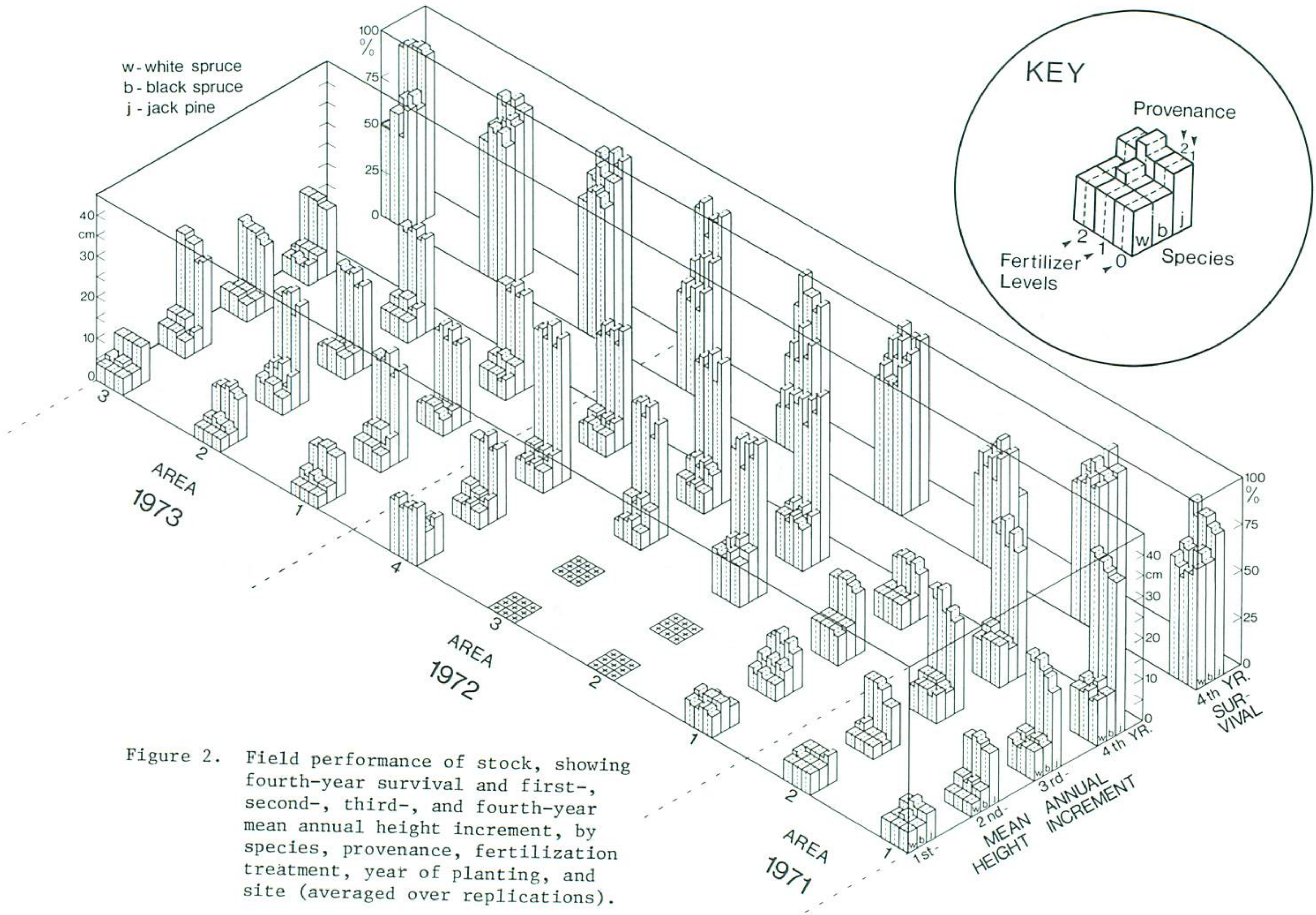

Figure 2. Field performance of stock, showing fourth-year survival and first-, second-, third-, and fourth-year mean annual height increment, by species, provenance, fertilization treatment, year of planting, and site (averaged over replications).

Table 3. Jack pine survival rates, by year of planting, site, time since outplanting, and fertilization treatment.

Year of planting	Site	Growing seasons after out-planting	Fertilization None (%)	Fertilization Low (%)	Fertilization High (%)	Chi-square (%)	Survival, treatments over all
1971	1	1	92	95	95	ns[a]	94
		2	85	90	90	**[a]	88
		3	79	85	86	**	83
		4	79	84	86	**	83
	2	1	96	96	96	ns	96
		2	84	87	83	ns	85
		3	80	83	79	ns	81
		4	80	83	79	ns	81
1972	1	1	75	70	73	ns	73
		2	51	41	45	**	46
		3	37	32	33	ns	34
		4	35	32	32	ns	33
	2	3	87	82	89	**	86
		4	83	77	84	**	81
	3	3	74	77	78	ns	76
		4	74	77	77	ns	76
	4	1	97	94	96	*[a]	96
		2	93	85	90	**	89
		3	92	85	90	**	89
		4	92	83	88	**	88
1973	1[b]	1	96	95	90	**	94
		2	95	95	90	**	93
		3	94	95	88	**	93
		4	93	95	88	**	92
	1[c]	1	92	93	92	ns	92
		2	92	93	92	ns	92
		3	92	93	92	ns	92
		4	90	90	92	ns	91
	2[b]	1	92	96	90	**	93
		2	92	95	89	**	92
		3	91	95	88	**	91
		4	89	93	87	*	90
	2[c]	1	91	91	92	ns	91
		2	91	91	91	ns	91
		3	91	91	91	ns	91
		4	90	90	91	ns	90
	3[b]	1	96	97	97	ns	97
		4	90	91	90	ns	90
	3[c]	1	97	96	93	*	95
		4	91	90	86	ns	89

[a]ns = not significant; ** and * = significant at the P 0.01 and 0.05 levels, respectively.
[b]provenance 3E
[c]provenance 4E

Table 4. Black spruce survival rates, by year of planting, site, time since planting, and fertilization treatment.

Year of planting	Site	Growing seasons after out-planting	Fertilization: None (%)	Fertilization: Low (%)	Fertilization: High (%)	Chi-square	Survival, treatments over all (%)
1971	1	1	80	78	80	ns[a]	79
		2	73	66	73	**[a]	71
		3	66	62	67	ns	65
		4	66	62	67	ns	65
	2	1	88	88	88	ns	88
		2	83	85	84	ns	84
		3	79	82	79	ns	80
		4	78	82	79	ns	80
1972	1	1	73	75	65	**	71
		2	68	71	63	*[a]	67
		3	61	65	59	*	62
		4	60	65	57	*	61
	2	3	85	85	82	ns	84
		4	82	83	81	ns	82
	3	3	54	55	50	ns	53
		4	53	54	49	ns	52
	4	1	86	83	85	ns	85
		4	61	53	57	*	57
1973	1[b]	1	93	92	87	*	91
		2	91	90	87	ns	89
		3	89	87	85	ns	87
		4	84	84	79	ns	82
	1[c]	1	92	94	89	ns	91
		2	91	93	87	*	91
		3	89	91	85	*	88
		4	85	89	83	*	85
	2[b]	1	92	92	88	ns	90
		2	92	90	86	*	89
		3	90	88	83	*	87
		4	85	84	80	ns	83
	2[c]	1	93	88	83	**	88
		2	92	86	82	**	87
		3	90	84	79	**	85
		4	87	81	77	**	82
	3[b]	1	78	76	65	**	73
		4	62	60	47	**	56
	3[c]	1	86	77	64	**	76
		4	68	65	50	**	61

[a]ns = not significant; ** and * = significant at the P 0.01 and 0.05 levels, respectively.
[b]provenance 3E
[c]provenance 4E

Table 5. White spruce survival rates, by year of planting, site, time since planting, and fertilization treatment.

Year of planting	Site	Growing seasons after out-planting	Fertilization None (%)	Fertilization Low (%)	Fertilization High (%)	Chi-square	Survival, treatments over all (%)
71	1	1	85	86	89	ns	87
		2	72	68	74	ns	72
		3	67	63	69	ns	66
		4	62	58	63	ns	61
	2	1	94	91	91	ns	92
		2	82	83	82	ns	82
		3	77	78	75	ns	77
		4	77	78	75	ns	76
72	1	1	68	70	66	ns	68
		2	63	66	61	ns	64
		3	57	58	55	ns	57
		4	55	57	53	ns	55
	2	3	75	69	73	ns	72
		4	74	67	71	ns	71
	3	3	21	27	26	*	25
		4	20	27	25	**	24
	4	1	69	70	70	ns	70
		4	52	53	54	ns	53
73	1[b]	1	92	89	85	**	89
		2	90	89	83	**	88
		3	89	87	80	**	85
		4	74	79	70	*	74
	1[c]	1	95	89	82	**	89
		2	95	88	81	**	88
		3	92	86	79	**	86
		4	78	78	70	**	75
	2[b]	1	94	93	91	ns	93
		2	91	91	88	ns	90
		3	88	89	84	ns	87
		4	72	81	74	*	77
	2[c]	1	97	95	89	**	94
		2	96	93	87	**	92
		3	93	91	84	**	89
		4	83	82	73	**	79
	3[b]	1	90	87	80	**	86
		4	65	59	48	**	57
	3[c]	1	92	90	86	*	90
		4	50	62	48	**	53

[a]ns = not significant; ** and * = significant at the P 0.01 and 0.05 levels, respectively.

[b]provenance 3E

Table 6. Jack pine: summary of growth performance by year of planting, site, and fertilization treatment (F1 = none; F2 = low; F3 = high), through four growing seasons after outplanting as 2+0 stock. Values are means of plots, n = 30.

Year of planting	Site	Fert. treatment	Height of tree after planting[a] (cm)	Height increment[a] 1st yr (cm)	2nd yr (cm)	3rd yr (cm)	4th yr (cm)	Total height after four growing seasons[a] (cm)
1971	1	F1	13	7	13^{a}	21^{a}	37^{a}	85^{a}
		F2	13	7	14^{b}	24^{b}	39^{b}	92^{ab}
		F3	14	7	14^{b}	24^{b}	40^{b}	94^{b}
		ANOVA[b]	ns	**	**	**	**	**
	2	F1	12	7	10^{a}	23a	32	79^{a}
		F2	13	6	13^{b}	26^{b}	33	86^{b}
		F3	12	6	14^{b}	26^{b}	33	87^{b}
		ANOVA	ns	ns	**	**	ns	**
1972	1	F1	13	5	10	15	12	45
		F2	13	4	10	16	12	46
		F3	13	5	10	16	12	45
		ANOVA	ns	ns	ns	ns	ns	ns
	2	F1	13	12	9	34	37	111
		F2	14	12	8	32	33	104
		F3	16	17	13	33	35	109
		ANOVA	ns	ns	ns	ns	ns	ns
	3	F1	16	7	11	26^{a}	32	87^{a}
		F2	15	7	13	30^{b}	33	95^{b}
		F3	16	7	13	30^{b}	32	94^{b}
		ANOVA	ns	ns	ns	**	ns	*
	4	F1	14	9	17	33	26	97
		F2	13	8	19	35	26	99
		F3	14	9	18	35	25	98
		ANOVA	ns	ns	ns	ns	ns	ns
1973	1	F1	12	10	21^{a}	20	22	82^{a}
		F2	11	11	24^{b}	21	23	89^{b}
		F3	12	10	23^{ab}	21	23	87^{ab}
		ANOVA	ns	ns	**	ns	ns	**
	2	F1	9	11	22^{a}	20	23	84^{a}
		F2	10	12	25^{b}	21	23	91^{a}
		F3	11	11	24^{ab}	21	23	87^{ab}
		ANOVA	ns	ns	*	ns	ns	**
	3	F1	9	9	20^{a}	16	16	70^{a}
		F2	9	9	24^{b}	18^{a}	17	76^{b}
		F3	10	9	25^{b}	18^{a}	17	76^{b}
		ANOVA	ns	ns	**	**	ns	**

[a]Within year of planting and site, significant differences among columnar values are indicated by following letters not shared in common.
[b]Analysis of variance; ns = not significant, and * and ** indicate significance at the P 0.05 and P 0.01 levels, respectively.

Table 7. Black spruce: summary of growth performance, by year of planting, site, and fertilization treatment (F1 = none; F2 = low; F3 = high), through four growing seasons after outplanting as 3+0 stock. Values are means of plots, n = 30.

Year of planting	Site	Fert. treat-ment	Height of tree after plant-ing[a] (cm)	Height increment[a] 1st yr (cm)	2nd yr (cm)	3rd yr (cm)	4th yr (cm)	Total height after four growing seasons[a] (cm)
1971	1	F1	27	5	5	7	11	48
		F2	26	5	6	7	12	47
		F3	28	5	6	7	11	48
		ANOVA[b]	ns	ns	ns	ns	ns	ns
	2	F1	26	5a	2a	7a	8a	40a
		F2	27	5a	3b	8b	9a	44b
		F3	25	5b	4c	8b	11b	45b
		ANOVA	ns	**	**	**	**	**
1972	1	F1	22	7	6	8	5	40
		F2	21	7	6	8	5	40
		F3	22	7	6	8	5	40
		ANOVA	ns	ns	ns	ns	ns	ns
	2	F1	18	6		12	12	55
		F2	18	6		12	12	57
		F3	18	6		12	12	57
		ANOVA	ns	ns		ns	ns	ns
	3	F1				8	8	44
		F2				8	9	46
		F3				9	10	45
		ANOVA				ns	ns	ns
	4	F1	21	7	6	7	7	42
		F2	21	8	6	7	6	43
		F3	20	9	7	8	7	45
		ANOVA	ns	ns	ns	ns	ns	ns

(cont'd)

Table 7, (concl.) Black spruce: summary of growth performance, by year of planting, site, and fertilization treatment (F1 = none; F2 = low; F3 = high), through four growing seasons after outplanting as 3+0 stock. Values are means of plots, n = 30.

Year of planting	Site	Fert. treatment	Height of tree after planting[a] (cm)	Height increment[a] 1st yr (cm)	2nd yr (cm)	3rd yr (cm)	4th yr (cm)	Total height after four growing seasons[a] (cm)
1973	1[c]	F1	11	10	21a	20	22	84a
		F2	11	11	25b	22	24	92b
		F3	11	10	22ab	22	23	87ab
		ANOVA	ns	ns	*	ns	ns	*
	1[d]	F1	12	10	20a	19	21	81a
		F2	13	11	23b	19	22	85ab
		F3	12	10	23b	21	23	87b
		ANOVA	ns	ns	*	ns	ns	*
	2[c]	F1	9	11	23	20	23	85ab
		F2	10	12	26	22	24	92b
		F3	9	11	24	21	22	84a
		ANOVA	ns	ns	ns	ns	ns	*
	2[d]	F1	10	11	21a	19	22	82a
		F2	11	11	24a	21	23	89b
		F3	11	10	24a	22	23	89b
		ANOVA	ns	ns	*	ns	ns	*
	3[c]	F1	15	3[a]	5[a]	4	5	29[a]
		F2	16	5[b]	7[b]	4	5	32[ab]
		F3	15	4[b]	7[b]	5	6	34[b]
		ANOVA	ns	**	**	ns	ns	*
	3[d]	F1	23	5	4a	4a	6a[b]	36a
		F2	23	5	7b	5b	6[b]	40b
		F3	24	5	7[b]	4[a]	5[a]	36[a]
		ANOVA	ns	ns	**	**	*	*

[a]Within year of planting and site, significant differences among columnar values are indicated by following letters not shared in common.

[b]Analysis of variance; ns = not significant, and * and ** indicate significance at the P 0.05 and P 0.01 levels, respectively.

[c]provenance 3E

[d]provenance 4E

Table 8. White spruce: summary of growth performance, by year of planting, site, and fertilization treatment (F1 = none; F2 = low; F3 = high), through four growing seasons after outplanting as 3+0 stock. Values are means of plots, n = 30.

Year of planting	Site	Fert. treatment	Height of tree after planting (cm)	Height increment[a]				Total height after four growing seasons[a] (cm)
				1st yr (cm)	2nd yr (cm)	3rd yr (cm)	4th yr (cm)	
1971	1	F1	16	5	2a	7	10	32
		F2	15	5	3ab	7	11	33
		F3	16	5	3b	7	11	32
		ANOVA[b]	ns	ns	*	ns	ns	ns
	2	F1	15	5	3	6	10	32
		F2	16	5	3	7	10	32
		F3	15	5	2	6	9	31
		ANOVA	ns	ns	ns	ns	ns	ns
1972	1	F1	22	5	4	7	6	34
		F2	21	5	4	7	6	34
		F3	21	5	4	7	6	34
		ANOVA	ns	ns	ns	ns	ns	ns
	2	F1	17	5		10	10	43
		F2	16	4		11	11	47
		F3	17	4		10	10	44
		ANOVA	ns	ns		ns	ns	ns
	3	F1				4	5	28a
		F2				5	6	33b
		F3				4	6	30ab
		ANOVA				ns	ns	*
	4	F1	9	13	4	5	5	30
		F2	9	13	4	5	5	30
		F3	9	13	4	5	6	30
		ANOVA	ns	ns	ns	ns	ns	ns
1973	1	F1	13	3	4a	5a	5	26a
		F2	14	3	5b	6b	5	28b
		F3	14	3	5b	6b	5	28b
		ANOVA	ns	ns	**	**	ns	*
	2	F1	14	3	4a	5a	5	26a
		F2	14	3	6b	6b	5	29b
		F3	13	3	6b	6b	5	27ab
		ANOVA	ns	ns	**	**	ns	*
	3	F1	11	4	4a	4a	4	21a
		F2	11	4	5b	5a	4	23b
		F3	10	4	5b	5b	4	22ab
		ANOVA	ns	ns	**	**	ns	*

[a]Within year of planting and site, significant differences among columnar values are indicated by following letters not shared in common.

[b]Analysis of variance: ns = not significant, and * and ** indicate significance at the P 0.05 and P 0.01 levels, respectively.

In general, field performance in the P71, P72, and P73 plantings was much better than might have been expected in view of the poor condition of some of the planting stock, the prolonged field storage of stock prior to the P72 mechanized plantings, and the droughtiness of the 1972 planting and growing season in the Manitouwadge area, and of the 1973 planting and growing season in the Chapleau area.

This level of success in the face of serious problems should not be used to justify any slackening of efforts to improve plantation establishment practice. Some problems, e.g., drought, are not remediable, but to incur reduced stocking, reduced growth rates, and delayed harvest because of avoidable problems is a sheer waste of resources.

After some general limitations to the study have been considered, further discussion will be by species.

Limitations to Study

Planting year: The fate of any given planting can be determined by chance peculiarity of weather. Equally, any peculiarity of planting stock, either in the stock itself initially or in the way it is handled or planted, can determine the outcome of a planting.

The effect of any given sequence of weather on the outcome of an attempt to establish a plantation will depend not only on the nature of that sequence but also on the site factors and the planting stock with which it interacts. The study was conducted on a variety of sites with plantings in each of three consecutive years. Comparisons among results from plantings in the three years definitely pose difficulties: the planting stock used in one year must necessarily differ from that used in another; experimental sites differ among years; and site condition varies with time since harvesting, time since site preparation, and weather during the post-harvest period. These and other factors would have to be controlled before the effect of weather could be evaluated unequivocally.

Nevertheless, even though rigorous comparison among results from plantings in the different years is not possible, their combined predictive value is much greater than would be that of results from plantings in a single year of plantings (Sutton 1982). To the extent that multi-year plantings yield results that point in the same direction, this is persuasive evidence that the effect is strong enough to exert detectable influence in spite of the "noise" of uncontrolled interference. If the several years' results are not mutually supportive, however, this, too, is important information for the forest manager.

In the present study, some major influences on field performance differed among the three years of planting. In 1971, for instance, the performance potential of some of the planting stock had been compromised by faulty storage, faulty handling, or suspect morphology. Age of cutover was also uncontrolled; the condition of slash, roots, and residual stems changes with time. The propensity of this material to spring back after the passage of the planting machine and its prime mover is greatest during the first year after harvest; at this stage, as many as 10% of the trees planted may be obliterated in subsequent adjacent passes of the machine (Sutton 1975a). Older, more brittle slash has less tendency to spring back, and therefore causes less damage to stock planted in a previous adjacent pass. Vagaries of weather in the area of the P71 plantings resulted in less than normal precipitation in every month from June through September 1971 by an amount totalling 21% for the period (Sutton 1982). Precipitation in the Manitouwadge area was much below normal every month from April through October 1972, except for July; already by 13 June, the soil moisture level on the P72 Site 3 was only 12% throughout the uppermost 37.5 cm of soil, and no rain of consequence fell thereafter until the 12 mm rain of 9 July, 1972 (Sutton 1979, 1982). Further vitiating inter-year comparisons was the fact that an epidemic of spruce budworm *(Choristoneura fumiferana* [Clem.]) became intense in the Chapleau area in 1973, and for several years seriously affected spruces of both species in the Fawn Township plantings.

To reiterate, in spite of the difficulties introduced by this uncontrolled variation among years, "replication" (repetition) in time is useful. If, on the one hand, this variation fails to obscure effects that can be attributed to treatments or controlled factors, the predictive value of the results is enhanced. On the other hand, if the effects of treatment are hidden by uncontrolled variation, the dangers of extrapolation are immediately apparent.

Machine planting evaluation: The study illustrates one of the major problems to which mechanized planting of bare-root stock is subject. Delays in planting operations caused by mechanical problems can be accompanied by rapid deterioration of planting stock held in readiness in field storage at the planting site. Flushing of stock in field storage accelerates the deterioration. In fairness, however, it must be acknowledged that an in-place system of mechanized planting would not likely be subject to delays as prolonged as those experienced in the P72 plantings. The point is that bare-root stock, once readied for planting, has a short shelf life. Machine planting operations are particularly vulnerable to the problems caused by delays because the fate of *many* seedlings depends on the proper functioning of one or a few machines, whereas hand planting spreads the risk. Unforeseen delays are probably less common in normal manual planting operations than in mechanized planting.

Jack Pine

Provenance: Fourth-year survival over all years of planting and all sites (except for the P72 Site 1 mixedwood slope underplanting) averaged 86%, with little difference between the two provenances. In the P73 plantings, however, survival rates of provenance 3E stock were influenced significantly by interaction with fertilizer treatment, whereas survival rates of provenance 4E stock were independent of fertilizer treatment. Nor did growth during the first four years after outplanting vary with provenance. Provenance, therefore, could be dispensed with as a variable, and the replication available for the analysis of other factors would thereby be doubled.

Site: Jack pine performance, both survival and growth, was poorest in the P72 mixedwood slope underplanting; two thirds of the outplants were dead within three years, and total height of the survivors after four years was only half that of jack pine on most of the other sites. This is not to be wondered at, for, although conifers had been selectively harvested, there remained a moderate overstorey of mature trembling aspen *(Populus tremuloides* Michx.) and a moderate-to-dense understorey of balsam fir *(Abies balsamea* [L.] Mill.) and shrubs dominated by mountain maple *(Acer spicatum* Lam.), hazel *(Corylus cornuta* Marsh.), alder *(Alnus rugosa* [Du Roi] Spreng.), and mountain ash *(Sorbus americana* Marsh.). This vegetation cover reduced average light incidence (as determined by Brockway light meters) at outplant level to 83% of full light in the open in the prevernal aspect and 23% in the estival, clearly too shaded for jack pine. Plantation establishment by underplanting jack pine through untreated, shrubby, overmature mixedwoods is plainly not feasible.

In corridored mixedwood of P72 Site 2, jack pine had a survival rate of 81% after four growing seasons in spite of the droughtiness of the first growing season after outplanting, the presumed cause of unusually small second-year height increments in this planting. Nevertheless, total height after four growing seasons exceeded 1 m, the greatest of any planting. Good performance on the mixedwood flat is attributable both to soil of greater fertility than that of the outwash soils and relative freedom from competition within the corridored strips, notwithstanding the reduction of light, estimated at 10%, to the outplants by inter-corridor vegetation.

On the outwash sites, with excessively drained sands and gravels of low fertility, but with full light and limited competition, differences in jack pine survival rates would seem to reflect differences in both the performance potential of planting stock and the soil moisture conditions experienced during the first growing season. Even in the very dry P72 Site 3 soils, however, cumulative fourth-year mortality (24%) was only half that of black spruce and less than one third that of white spruce on the same site. Survival of jack pine was undoubtedly helped by rooting vigor. One jack pine, 35.8 cm tall (including 2.8 cm of "interrupted" current-year candelling) and 5 mm in stem diameter at ground level when planted on P72 Site 3, was excavated just 6 weeks later: its tap root was only 15 cm long, but eight main lateral roots averaged 23.4 cm, and one 20-cm lateral bore 34 new roots of 453 cm aggregate length. In total, the root system bore 110 new roots longer than 1 mm, averaging 2.4 cm but up to 24.6 cm long.

<u>Machine planting vs manual planting</u>: With comparable planting stock and similar conditions of soil and site preparation, first- through fourth-year performance of jack pine outplants was essentially independent of whether planting was mechanized or manual. Survival and growth rates through the first four years after planting are virtually identical on sites 1 and 2 in the P73 plantings in which jack pine in good condition was planted by Reynolds-Lowther (Site 1) or manually (Site 2) after identical site/soil preparation. These results accord with those reported by Sirén (1974) from Sweden; first- through sixth-year survival among Scots pine- *(Pinus sylvestris* L.) was virtually identical whether planting was by hand or by Beloit (Reynolds-Lowther) planting machine, although fourth-year height increment was "somewhat better" among trees planted by machine than in those planted manually. In other reports it is claimed that "the survival rate for machine-planted seedlings is generally higher than that for hand-planted seedlings" (Sturos and Miyata 1984). The generalization is to some degree suspect because of the variety among planting machines, but machine wheels may be supe-

rior to human heels for firming outplant root systems into soils that are difficult to pack around outplant root systems. An incomplete portion of the present study provides some indication of this: root growth among outplants in dry sandy loam was somewhat more vigorous in machine-planted trees than among hand-planted trees, probably because capillarity was better reinstated by machine than by manual planting (Sutton 1975a).

Whether planting is mechanized or manual, root system deformation in outplants is virtually inevitable (Sutton 1978). Toppling (Sutton and Tinus 1983), common among outplanted pines, generally affects trees whose crowns are larger than those developed by jack pine during the first 4 years in the present study. To what extent toppling will occur in the study, and whether toppling will affect mechanically and manually planted trees differently, remains to be seen.

Planting machine: The study yielded no data that would permit reliable comparison of the two planting machines involved. From the biological standpoint, all that can be said is that both the Reynolds-Lowther and the Taylor Drum gave results that would seem to be generally similar to those obtainable with good manual planting.

Fertilization: On the outwash soils, fertilization tended to increase survival; in both P71 plantings, in P72 Site 3, and in all three of the P73 plantings, survival rates were higher for trees in the "fertilized" treatments than in the non-fertilized treatment. On these soils, fertilization effected a modest but significant growth response without increasing mortality. Total height after four growing seasons was 7% greater in trees fertilized at either the low or the high level than in non-fertilized trees. However, the level of response obtained would hardly justify using fertilizers on outwash soils in the manner of this study.

On till soils, the mixedwood P72 Site 1 showed first-, third-, and fourth-year survival rates that were independent of fertilization level; the significant depression of second-year survival rates among the fertilized in comparison with the unfertilized plantings would seem to be aberrant, especially as survival rates do not differ significantly (by chi-square test) between the high fertilizer treatment and the non-fertilized. Similarly, the significant differences in survival associated with level of fertilization that occurred in the P72 Site 2 corridored mixedwood flat planting are hard to explain other than on the basis of chance; survival was lower in the low fertilization treatment than in either the non-fertilized or the high fertilization treatment. Fertilization level had no effect on growth of jack pine on the relatively fertile till soils.

The idea that applications of fertilizer as described might be used to promote early root growth in outplants and thus improve field performance of jack pine seems not to be supported by the evidence, either from exploratory excavations of root systems or from the performance data. In general, fertilization level was associated with few significant differences in survival. In some instances, survival rates were lower in the low fertilizer treatment than with either more fertilizer or none, and the high fertilizer treatment never reduced survival significantly, a result that is remarkable in view of the detrimental effect that fertilization can have on stressed outplants (cf. Sutton 1982). Growth, however, was promoted by fertilization on the outwash soils, not on the tills, which are more fertile.

Black Spruce

Provenance: In terms of early plantation establishment, the effect of black spruce provenance in this study was inconsequential. Of little or no effect in the P71 and P72 plantings, provenance was significant in the P73 plantings. This significance was expressed both in minor differences in total height at the end of the fourth growing season after outplanting and in differential survival responses to fertilization treatments (cf. Table 4). However, notwithstanding the significance of some of the differences, performance was very similar between provenances. For example, the mean fourth-year height increment of provenance 3E trees differed from that of provenance 4E by 1 cm or less on each of P73 sites 1, 2, and 3.

Site: Black spruce survival and growth were poorest where trees of this species were planted manually without site preparation (P73 Site 3). When planted after the kind of site preparation effected by the Reynolds-Lowther planting machine together with its prime mover, P73 black spruce, whether planted by machine (Site 1) or by hand (Site 2), performed far better than stock planted without site preparation.

Comparisons among sites planted in different years are of doubtful validity, as discussed earlier. Reservations in regard to black spruce are particularly justified because of the great variation among years in the initial condition of the planting stock.

Field performance varied remarkably little among black spruce on outwash soils on P71 sites 1 and 2 and P72 sites 3 and 4, where growth was similar to that reported by Mullin (1978a) as the mean of 11 research plantings. In the P71 and P72 plantings, black spruce performed best on the corridored mixedwood P72 Site 2, where survival was 82% after four growing seasons and total height averaged 57 cm, 27% more than that in Mullin's (1978a) plantations.

In the P73 plantings, the only year in which initially good planting stock was planted without prolonged delay in soils that did not develop prolonged soil moisture deficiencies during the growing season of the year of outplanting, total height, after four growing seasons, of black spruce planted with "Reynolds-Lowther" site preparation (sites 1 and 2) was 81-92 cm. This is about twice that of the mean reported by Mullin (1978a) for his research plantings of black spruce.

Performance of black spruce on the P72 Site 1 mixedwood underplanting was poor but not the poorest among the plantings; fourth-year survival was 61% but the fourth-year height increment of only 5 cm in comparison with 8 cm the third year suggested that performance might continue to deteriorate. Insufficient light would probably be the main cause.

In plantings other than those on P72 Site 1, the factors most strongly detrimental to black spruce performance would therefore seem to have been poor initial condition of P71 planting stock, prolonged field storage followed by severe and sustained soil moisture stress in the P72 plantings and lack of site preparation in the P73 Site 3 planting.

<u>Machine planting vs manual planting</u>: The Reynolds-Lowther machine and manual planting gave essentially indistinguishable results over the first four growing seasons in the P73 black spruce plantings on sites 1 and 2.

<u>Planting machine</u>: As with jack pine, there are no data suitable for comparison of the two planting machines used in the study.

<u>Fertilization</u>: Growth responses to fertilization of the kind described here were obviously insufficient to justify the cost, especially in view of the increased mortality associated with fertilization.

In all three P73 plantings, and for both provenances, first- through fourth-year survival was lower in the "high fertilization" than in the "low fertilization" treatment, or with no fertilization at all. Differences were significant in many cases. In view of the fact that apparently unstressed planting stock was planted without prolonged field storage in soil that was not thereafter excessively dry for long periods, and in view of the fact that fertilization was carried out very soon after planting, the reduced survival among heavily fertilized black spruce is considered to be a real effect caused by high ion concentrations in the soil solution.

In contrast, fertilization in 1971 and 1972 was not carried out until some weeks after planting and, consequently, there was time for some development of root systems before they faced the fertilizer challenge. In the P71 plantings, and in the P72 plantings other than the Site 1 underplanting, survival rates were virtually unaffected by level of fertilization.

Fertilization increased growth significantly in only one of the P71 and P72 plantings; in terms of total height after four growing seasons, fertilization increased growth significantly in the P71 Site 2 planting, about 12.5% over the unfertilized planting. This response to fertilization was peculiar in that it began in the first growing season (in spite of the delay in applying the fertilizer) and continued through each of the following three years. It may have been a chance effect.

In the P73 plantings, the significant responses to fertilization in terms of growth were generally confined to the second growing season, although in all six site/provenance combinations total height after four growing seasons was significantly affected. In the P73 plantings, fertilization was generally more effective at the low rate than at the high; low and high rates gave 8% and 5% more total height, respectively, after four years than did the non-fertilized treatment. Persistence of significant differences in total height beyond, at most, a further 1 or 2 years would appear unlikely.

White Spruce

Provenance: The two provenances performed in very similar fashion, notwithstanding the statistical significance of minor differences in the interaction of fertilization level and provenance on survival in the P73 Site 2 planting (cf. Table 5).

Site: The results fully substantiate the assessment (Sutton 1969) that white spruce cannot be expected to succeed on droughty, infertile soils, especially when the trees are fully exposed annually to damaging spring hosts. Only the two mixedwood sites (P72 sites 1 and 2) had carried a component of white spruce prior to harvesting. In the other plantings, white spruce was obviously "off site".

In the P72 Site 1 underplanting on the mixedwood slope, shading was a major constraint, as it was with the other species. The unusually dry growing season in the year of planting seriously affected all three P72 plantings in the Manitouwadge area, but moisture stresses were judged to be considerably lower in the tills than in the outwash soils.

On the outwash soil of P72 Site 3, the combination of severe moisture stress and the use of flushed stock after prolonged field storage was devastating; three out of four white spruce outplants died within 3 years, and the miserable survivors averaged only about 30 cm in total height after four growing seasons. Even where fourth-year survival was 74-79% (cf. Table 5), as in the P73 plantings on sites 1 and 2, fourth-year height increments of 5 cm and fourth-year total heights of 26-29 cm (cf. Table 8) emphasize the need to cater to the biological requirements of species. The budworm merely exacerbated an already untenable situation for white spruce.

Machine planting vs manual planting: Problems with machine planting through logging debris include the obvious difficulty of operating the planting machine properly. A less obvious problem is that of having some of the successfully planted trees smothered, uprooted, or otherwise damaged by debris that is disturbed and redistributed during a subsequent adjacent pass of the equipment. Survival among P73 white spruce was less than 4% higher among those planted by hand (Site 2) than among those planted by the Reynolds-Lowther machine (Site 1). The difference may be attributed to losses among machine-planted trees damaged or smothered by slash disturbed and redistributed during a subsequent adjacent pass of the prime mover and planting machine. In the P71 plantings, where slash, 2 years fresher than on the P73 sites, was springier and less brittle, losses from smothering, etc., were as high as 10% (Sutton 1975a). In other respects, mechanized planting and manual planting gave essentially identical results under the same soil/site preparation conditions.

Planting machine: The study generated no data suitable for comparison of the two planting machines used in the study.

Fertilization: The inability of severely stressed planting stock to respond to fertilizer treatment (as described) is indicated by the results of the P71 and P72 plantings. In both years, fertilization had no effect on survival or growth during the first four years after outplanting. That the high level of fertilization did not further depress survival is surprising, even when one takes account of the delays in applying fertilizer in 1971 and 1972. This exemplifies the ability of white spruce to survive under extreme adversity.

In the P73 plantings, fourth-year survival on sites 1 and 2 was significantly higher in the "low fertilization" treatment than in the other treatments, and significantly lower in the "high fertilization" treatment than in the others. However, the gain associated with low fertilization was only 3% more than that in unfertilized plantings, and the growth response to fertilization was only 1 cm in mean annual height increment in each of the second and third growing seasons after treatment, while the best fourth-year mean total height of white spruce in any site/fertilization level combination in the P73 plantings amounted to a mere 29 cm.

Fertilization of this type on these kinds of sites does nothing worthwhile for white spruce.

CONCLUSIONS

The following conclusions can be drawn from the first- through fourth-year results from outplantings of bare-root jack pine, black spruce, and white spruce shipping-run stock in boreal Ontario in 1971, 1972, and 1973.

- Jack pine clearly outperformed black spruce during the first 4 years after outplanting on clearcut outwash sites in the Chapleau and Manitouwadge areas of boreal Ontario.

- Jack pine also outperformed black spruce on corridored mixedwood till sites during the period of assessment.

- White spruce has no potential for successful plantation establishment on clearcut outwash sites in the conditions exemplified by the study areas.

- Neither jack pine nor black spruce nor white spruce has potential for converting shrubby, overmature mixedwoods by underplanting in the absence of weed control.

- Different stock lots, with comparable stock parameters and comparable handling, etc., did not vary greatly in field performance.

- With comparable site preparation, at least on outwash soils, planting by machine gave the same results as planting by hand, in terms of field performance over the first four years after planting. With machine planting, however, site preparation was accomplished as part of the planting operation at no extra cost.

- In dry soil that is difficult to firm, machine planting was superior to manual planting.

- Machine planting through logging debris reduced survival by smothering, uprooting, or otherwise damaging trees, successfully planted during one pass of the equipment, with debris redistributed during a subsequent adjacent pass. Mortality from this cause was a function of the blade and configuration of the prime mover and planting machine, the amount and age (brittleness) of the debris, and the distance between planting lines.

- Site preparation was required for vigorous growth of jack pine, even on outwash soils carrying no more than moderate amounts of other vegetation. For the spruces, planting without site preparation significantly reduced both survival and growth.

- Fertilization with agricultural-grade NPK applied as a surface dressing at, or soon after, the time of planting, generated a positive but small and almost certainly uneconomic response in young outplants. Negative responses, e.g., depression of survival rate, and reduced growth rate, occurred among outplants whose root systems were small and non-vigorous.

- Degrade of planting stock during storage and handling was a major determinant of field performance of outplants.

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