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FACTORS AFFECTING NATURAL WHITE SPRUCE REGENERATION ON PREPARED SEEDBEDS AT THE RIDING MOUNTAIN FOREST EXPERIMENTAL AREA, MANITOBA

by
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Sommaire en français

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ABSTRACT

Factors affecting natural white spruce regeneration on artificially prepared seedbeds in mature white spruce-trembling aspen stands on fresh to wet clay loam soils have been studied at the Riding Mountain Forest Experimental Area in Manitoba for the past twenty years. Results showed that weather, seedbed, litter, crown cover, site, lesser vegetation, and animals played important roles in the germination, early survival and growth of white spruce. It was apparent from these results that shelterwood cutting in accompaniment with the preparation of mineral soil seedbeds on the fresh to moist sites using a bulldozer and straight blade can be used to create conditions suitable for the establishment of natural white spruce regeneration.

ACKNOWLEDGEMENTS

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by

R.M. Waldron[1]

INTRODUCTION

Early regeneration surveys in Manitoba and Saskatchewan showed that white spruce (Picea glauca (Moench) Voss) was not present in sufficient quantities in either cut-over or burned-over mixed white spruce-trembling aspen (Populus tremuloides Michx.) stands to form future well-stocked stands[2,3,4,5] (Candy 1951). Subsequent research indicated that the scarcity of white spruce regeneration was attributable to lack of seedbeds suitable for germination and early survival and to the presence of severe vegetative competition (Bedell 1948; Phelps 1948; Rowe 1955). Since the early 1940's the Department of Forestry and Rural Development has been studying the silvics and ecology of white spruce at the Riding Mountain Forest Experimental Area in Manitoba with particular emphasis on the development of natural regeneration on artificially prepared seedbeds. This report brings together the results of these studies.

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[1] Forestry Officer, Department of Forestry and Rural Development, Manitoba-Saskatchewan Region, Winnipeg, Manitoba.

[2] Pike, R.T. 1926. Investigation of cut-over timber sales. Canada, Dept. of the Interior, Forestry Branch, Unpublished MS.

[3] Best, A.L. 1937. Report on survey of cut-over lands 1936 -- Carrot River, Saskatchewan. Canada, Dept. Mines and Resources, Lands, Parks and Forests Branch, Dom. For. Ser., Unpublished MS.

[4] Phelps, V.H. 1938. Growth and reproduction of white spruce on cut-over areas of The Pas Lumber Company in northern Saskatchewan. Canada, Dept. Mines and Resources, Lands, Parks and Forests Branch, Dom. For. Ser., Unpublished MS.

[5] Phelps, V.H. 1940. Cut-over and burned-over white spruce lands, northern Saskatchewan survey, 1938. Canada, Dept. Mines and Resources, Lands, Parks and Forests Branch, Dom. For. Ser., Unpublished MS.

DESCRIPTION OF THE EXPERIMENTAL AREA

The forest experimental area is located within the Riding Mountain National Park approximately 140 miles northwest of Winnipeg. The experimental area, 25 square miles in area, is situated at approximately 100° west longitude and 50° 45' north latitude and lies at an elevation of 2,200 to 2,300 feet above mean sea level.

The forest experimental area is within the Humid Microthermal Climatic zone as recognized by Köppen and is characterized by a rain-snow climate with cold winters and warm summers (Anon. 1957). Long-term records from weather stations located to the north, south and west[6] of the experimental area indicate an annual precipitation of between 16 and 18 inches; fifty per cent of which falls between June and August. Mean annual air temperature ranges between 33° and 37°F. Mean daily air temperature is between 0° and 5° in January, and between 65° and 70°F in July. Mean annual length of the growing season (based on 42°F) is between 160 and 180 days (Anon. 1959). Potential evapotranspiration for the region is about 18.7 inches with an average moisture deficit of 3.4 inches during the summer months and an average moisture surplus of 0.5 inches during the winter (Weir 1960). Records obtained from the forest experimental area between 1951 and 1959 indicate slightly lower mean air temperatures (4°F) and higher precipitation (1.2 inches) during the growing season[7].

Soils on the study areas are grey wooded (Anon. 1960) and have developed on moderately calcareous loam to clay loam boulder tills (Figure 1). Sites range from fresh to wet in moisture regimes[8]. Fresh sites predominate and occur on upper slopes, moderately moist and moist sites on middle and lower slopes, and very moist and wet sites in small depressions.

The forest, which forms the extreme southeastern portion of the

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[6] Dauphin, Minnedosa and Russell, respectively.

[7] Waldron, R.M. 1962. The effects of certain climatic factors on the terminal growth of white spruce at the Riding Mountain Forest Experimental Area in Manitoba. Thesis submitted to the University of Toronto.

[8] Rowe, J.S. 1957. Forest site description. Canada, Dept. Northern Affairs and National Resources, Forestry Branch, For. Res. Div. Unpublished MS.

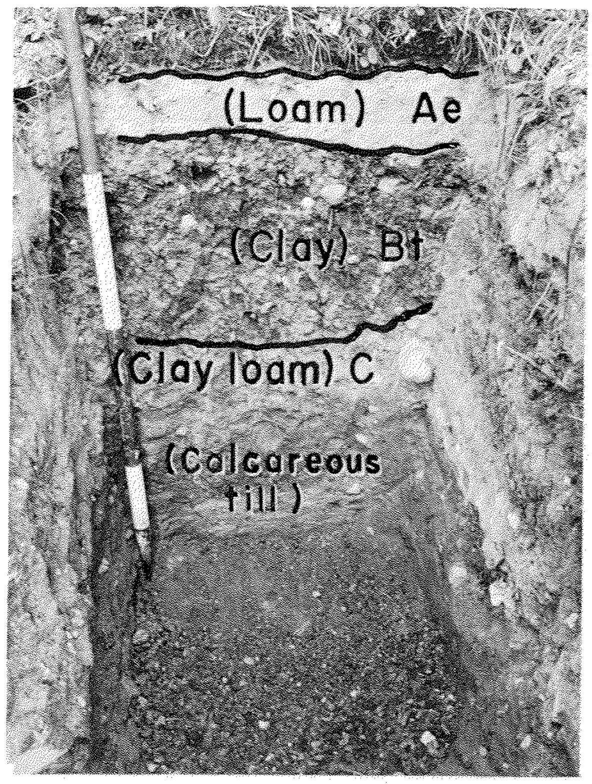

Figure 1. Typical soil profile development on a fresh site.

Mixedwood (B. 18a) Section of the Boreal Forest Region of Canada (Rowe 1959), is characterized by mixedwood stands of white spruce and trembling aspen[9] on the fresh and moderately moist sites (Figure 2) and white spruce and balsam poplar (Populus balsamifera L.) on the moist sites. The very moist and wet sites are treeless.

In the mixed stands the aspen originated after fire; it is even-aged and approximately 120 years old. The white spruce component is uneven-aged with the oldest trees the same age as the aspen. White birch (Betula papyrifera (Marsh.)), black spruce (Picea mariana (Mill.) BSP.), balsam fir (Abies balsamea (L.) Mill.), and jack pine (Pinus banksiana Lamb.) are scattered throughout the stands. The dominant understorey type is hazel (Figure 3).

Typical forest, lesser vegetation, and soil profile development[10] on the various sites are schematically shown in Figure 4. An actual

[9] Pertinent stand data may be found in Appendix I.
[10] Soil horizon designations follow Bowser (1960).

Figure 2. A typical undisturbed white spruce-trembling aspen stand on a fresh site at the Riding Mountain Forest Experimental Area.

Figure 3. Hazel (Corylus cornuta Marsh.) development under an undisturbed, partially open, hardwood stand on a fresh site. Hazel in the foreground was cut the previous summer.

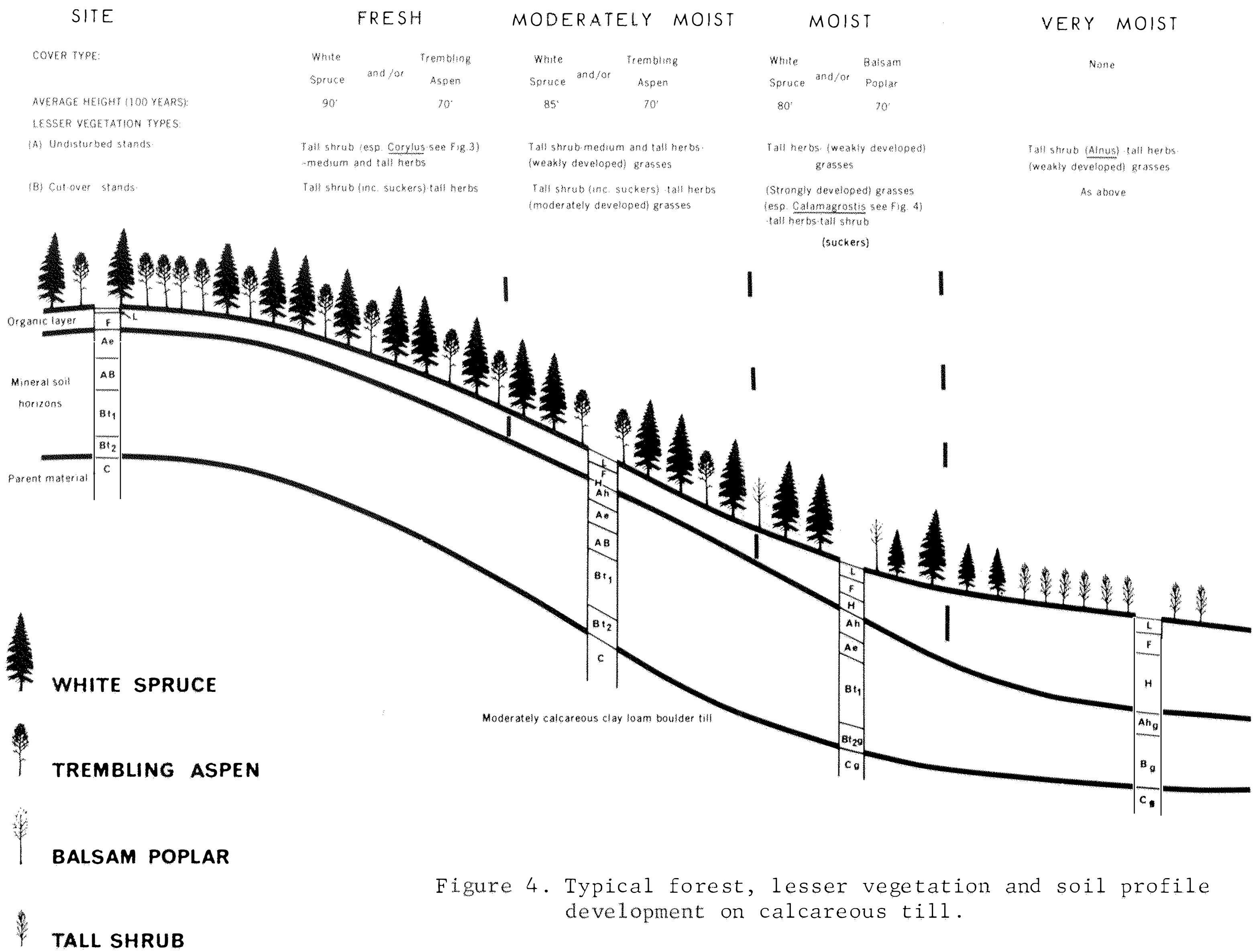

Figure 4. Typical forest, lesser vegetation and soil profile development on calcareous till.

Figure 5. Grass (Calamagrostis canadensis (Michx.)Beauv.) development following clear cutting on a moist site.

forest and terrain profile depicting the occurrence and relative importance of the various forest cover and site types is shown in Figure 6.

EXPERIMENTAL METHODS

A total of nine studies (see Appendix II for brief descriptions) were carried out between 1940 and 1962 to obtain information on factors affecting germination, early survival and growth of white spruce regeneration. Initially, hand tools were used to create small plots to study the effects of seedbed, microtopography and micro-aspect. Later, an Athens disc plough (Figure 7 and 8) and a bulldozer blade (Figure 9) were used to create mineral soil seedbeds over large areas, and studies were initiated to determine the effects of weather, seedbed, seasonal periodicity of seed- and litter-fall, crown cover, site and animals on the regeneration of white spruce. In addition, one greenhouse study was undertaken to provide information on the effects of litter on the germination of spruce seed.

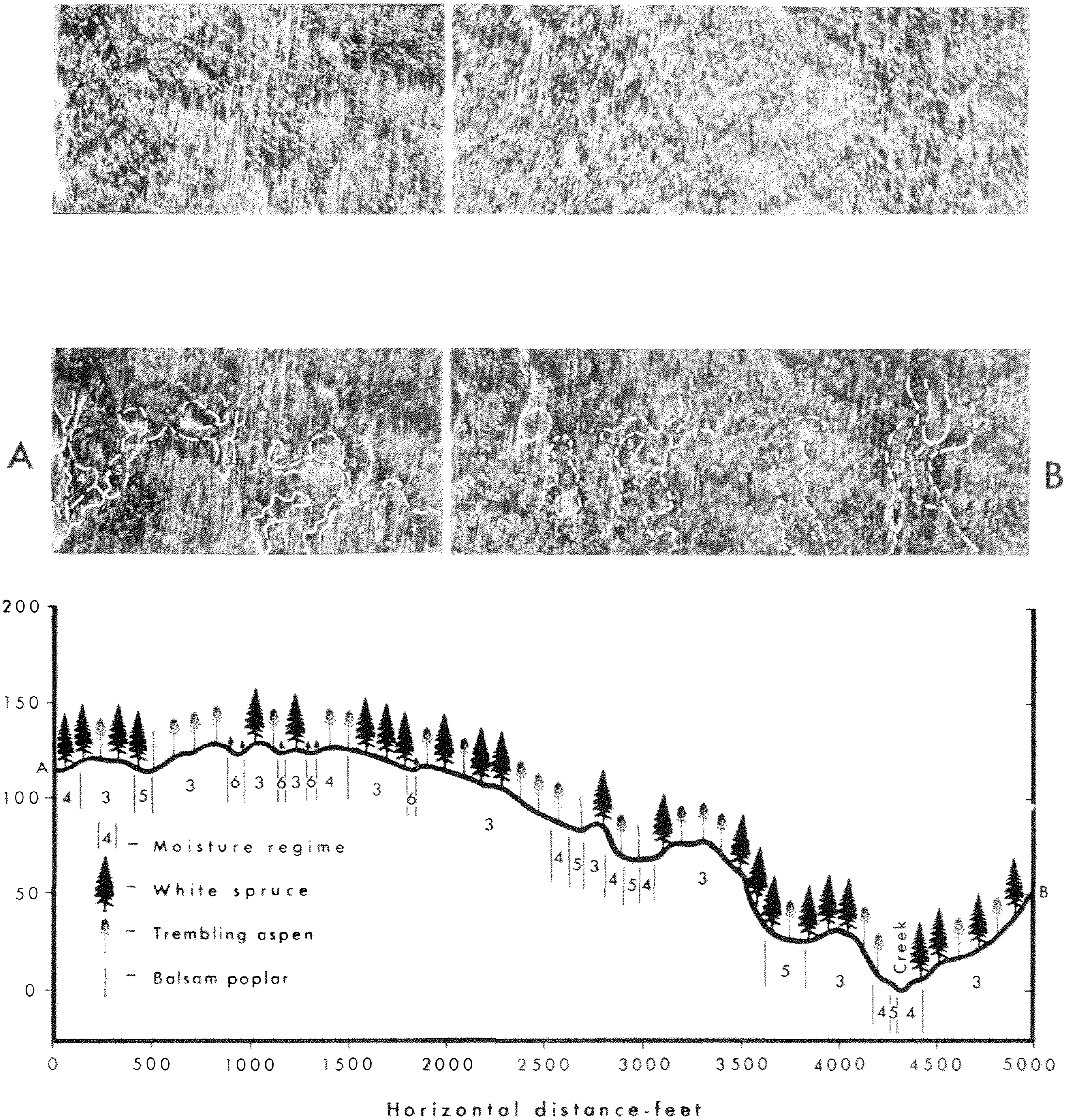

Figure 6. Actual forest and terrain profile on calcareous till.

Figure 7. Tractor-drawn Athens disc plough.

RESULTS

Data showing the effects of individual factors on white spruce regeneration were usually available from a number of studies. Representative results have been selected to illustrate commonly supported findings. Statistical tests of significance have not been employed to evaluate the data as most of the studies do not lend themselves to this type of analysis. In addition, it was not possible to evaluate the effects of all or any factors simultaneously.

Factors affecting germination

(1) Weather

On mineral soil seedbeds more than 90 per cent of germination occurred during June and July, and of this more than 75 per cent occurred during June (Table 1). Very little germination occurred during May. In 1951 germination was delayed until July and August as a result of below

Figure 8. Disced seedbeds.

Figure 9. Scalped seedbeds.

normal air temperatures during the spring (Rowe 1953). Germination may be delayed until autumn or even until the following season in dry years (Study 3)[11].

Variations in micro-climate also affect germination. Because of extreme soil surface temperatures, germination may be delayed on burned seedbeds. In one study (Study 2) 90 per cent of the germinants on undisturbed and mineral soil seedbeds had appeared by mid-August as compared to only 18 per cent on burned seedbeds.

(2) Seedbed

Germination was higher on manually prepared seedbeds than on undisturbed seedbeds (Table 2). Under partial canopy germination was higher on burned than on mineral soil seedbeds, but in openings was higher on mineral soil than on burned seedbeds. In openings, mixed mineral-soil-humus seedbeds gave intermediate results.

On manually prepared mineral soil seedbeds germination was found to be higher on a level surface than on a ridge one foot high and one foot wide (Table 3). On ridges germination was highest on north-facing slopes, intermediate on east- and south-facing slopes and lowest on west-facing slopes. On mechanically prepared mineral soil seedbeds germination was higher on scalped than on disced seedbeds. In one study a total of 716 germinants were recorded over a 6-year period; 640 of these were on scalped mineral soil, 73 on disced mineral soil, and 3 on undisturbed litter (Study 6).

(3) Litter

On the Riding Mountain Forest Experimental Area, seed dispersal generally is at a maximum during the first two weeks of September and is followed by aspen and spruce litterfall during the latter part of the month and in early October (Study 8). In 1961, litterfall in a predominantly white spruce stand amounted to 1/32-inch of spruce litter and 50 per cent of the ground covered with one-leaf thickness of aspen (Waldron 1963).

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[11]Rowe, J.S. 1958. Viable white spruce seed in the humus layer. Canada, Dept. Northern Affairs and National Resources, Forestry Branch, For. Res. Div., Unpublished MS.

TABLE 1. SEASONAL DISTRIBUTION OF WHITE SPRUCE GERMINANTS ON MINERAL SOIL SEEDBEDS*

Month	Seasonal distribution of germinants - per cent				
	1951	1952	1953	1956	Unweighted average
June	8	100	75	86	67
July	71	0	25	13	27
August	18	0	0	2	5
September	3	-	0	0	1
Basis: number of germinants	38	5	24	1,231	1,298

*Data from Studies 5 and 7. "Studies" are listed in Appendix II.

TABLE 2. EFFECT OF SEEDBED MEDIUM ON THE GERMINATION OF WHITE SPRUCE SEED*

Seedbed medium	Number of white spruce germinants-M/ac.				Basis: number of germinants
	Partial canopy		Natural openings		
	1941**	1943†	1943†	1951**	
Undisturbed litter	5	0	15	14	148
Mixed mineral soil-humus	-	-	-	69	549
Mineral soil	191	87	180	109	1,812
Burned	777	459	149	33	2,275
Basis: number of germinants	1,725	546	712	1,801	4,784

*Data from Studies 1 and 2.
**Artificially seeded: equal number of seed sown on each seedbed.
†Natural seedfall.

TABLE 3. EFFECT OF MICROTOPOGRAPHY AND MICRO-ASPECT ON THE GERMINATION OF WHITE SPRUCE SEED ON MINERAL SOIL SEEDBEDS*

Micro-topography	Micro-aspect	Number of germinants in 1957** M/ac.	Ratio sound seed sown / number of germinants	Basis: number of germinants
Level		138	5	1,236
Ridge†		12	100	135
	North	21	55	135
	East	12	100	
	South	9	130	
	West	5	240	

*Data from Study 4.
**Artificially seeded: equal numbers of seed sown on each seedbed.
†Ridges were one foot high and one foot wide.

Results from the greenhouse experiment (Study 9) showed that a covering of litter applied before or after seeding on mineral soil reduced moisture losses at the soil surface and under specific conditions increased germination (Table 4). A thin layer of aspen leaves applied either before or after seeding resulted in a higher number of germinants than where no litter was applied. The thin layer of leaves applied after seeding resulted in the largest number of germinants. The application of needles after seeding was not beneficial and was detrimental when applied before seeding (Cayford and Waldron 1962).

(4) Crown Cover

Regeneration on disced seedbeds was more abundant under a heavy crown cover than under a light crown cover (Table 5). This result was attributed to shading rather than to a greater number of white spruce seed trees in the overstorey, firstly because white spruce seed is dispersed

TABLE 4. EFFECT OF LITTER ON SOIL MOISTURE LOSSES AND GERMINATION OF WHITE SPRUCE SEED*

Treatment	Depth of litter	Water added to maintain the soil at field capacity†	Per cent of water added based on the "no litter" treatment	Germination of white spruce seed (per cent)	
				Litter applied after seeding	Litter applied before seeding
Bare mineral soil (No litter added)	-	630	100	7.2	
Spruce needles on mineral soil	1/8" - 1/4"	430	68	9.0	0.5
" " "	3/8" - 1/2"	340	54	4.0	0.7
Aspen leaves on mineral soil	3-leaf thickness	310	49	31.0	13.0
" " "	6-leaf thickness	200	32	10.7	10.2

*Data from Study 9.
†Water added three times each week.

TABLE 5. EFFECT OF CROWN COVER ON THE NUMBER OF WHITE SPRUCE GERMINANTS ON DISCED AND UNDISTURBED SEEDBEDS*

Crown cover classes (%)	Number of germinants - M/ac.		Basis: number of germinants
	Undisturbed seedbed	Disced seedbed	
0-20	33.0	50.8	1,922
21-40	44.7	57.6	774
41-60	43.6	58.6	752
61-80	39.0	85.2	1,131
81-100	39.6	81.1	3,878
Basis: number of germinants	2,934	5,523	8,457

*Data from Study 6.

TABLE 6. EFFECT OF SITE ON THE NUMBER OF WHITE SPRUCE GERMINANTS ON DISCED AND UNDISTURBED SEEDBEDS*

Site	Number of germinants - M/ac.		Basis: number of germinants
	Undisturbed seedbed	Disced seedbed	
Fresh	45.6	76.6	4,003
Moderately moist	31.6	69.9	2,827
Moist	30.5	67.7	1,335
Very moist	13.6	22.1	103
Wet	6.0	10.2	37
Basis: number of germinants	2,668	5,637	8,305

*Data from Study 5.

over long distances (up to 330 feet according to Rowe 1955) and secondly because there were just as many germinants on quadrats distant from (300 feet), as on quadrats close to (0 feet), a seed source.

Crown cover had no effect on the number of germinants on undisturbed seedbeds.

(5) Site

Fresh, moderately moist and moist sites are generally more favourable for germination than very moist or wet sites. Examinations carried out on scalped mineral soil seedbeds between 1951 and 1957 showed that 70 to 80 per cent of the regeneration quadrats on fresh to moist sites became stocked with germinants at least once, while only 20 per cent of the quadrats on the very moist site became stocked (Study 5). Similarly, germination on disced mineral soil seedbeds and on undisturbed seedbeds has been found to be higher on fresh to moist sites than on the very moist and wet sites (Table 6).

It has also been observed that the effect of site will vary depending on the amount of precipitation during the period of germination. In 1956, when June-July rainfall was 12.6 inches -- 6.3 inches above normal -- very few germinants were observed on the very moist and wet sites, whereas in 1961 when June-July rainfall was 1.9 inches -- 4.4 inches below normal -- there were more germinants on the moist, very moist and wet sites than on the fresh and moderately moist. Germinants on the fresh site were very infrequent and where they did occur spruce needles or aspen leaves were present and provided some protection against rapid loss of moisture from the soil surface (Study 5).

(6) Summary

White spruce seed normally germinates during the month of June but low air temperatures or inadequate moisture may delay germination until July and even as late as August. Germination is greater on disturbed (mineral soil or burned) seedbeds than on the undisturbed forest floor. A level mineral soil seedbed is best for germination and to date this type of seedbed is best prepared using a bulldozer and straight blade. Litter may be either beneficial or detrimental depending on its depth. A thin layer of white spruce needles or aspen leaves will increase germination, particularly in dry years on exposed sites. Heavy accumulations of litter occurring either before or after natural seedfall will reduce germination. The number of germinants on mineral soil seedbeds increases with increasing crown cover. In most years germination is higher on the fresh to moist sites than on the very moist and wet sites.

Factors affecting early seedling survival and mortality

The great majority of germinants ultimately succumb to one of the numerous factors that can cause mortality. On the Riding Mountain it has been found that more than 60 per cent of the germinants died during their first four years (Table 7). Seedlings are killed both in the summer and winter; in 1956, under exposed conditions, 40 per cent of the germinants had died by the end of September (Study 7). Subsequent mortality was found to be higher in winter than in the summer. For example, mortality on disced and undisturbed seedbeds between 1949 and 1952 was more than 65 per cent in winter but less than 20 per cent in summer (Table 8). Similar results were recorded on scalped seedbeds between the autumns of 1951 and 1954; overwinter mortality was 34 per cent compared to 24 per cent during the summer months (Study 5).

(1) Date of Seed Germination

Seedling mortality during the first summer has been found to be higher for June and July germinants than for August germinants (Table 9). However, the high rate of overwinter mortality of the August germinants reduced seedling survival the following spring well below that of the June and July germinants. Survival of the four-year-old June germinants was slightly higher than that of the July germinants and four times that of the August germinants.

(2) Weather

(i) Frost

Substantial losses of one-year-old seedlings have occurred following frost heaving during the winter of 1952, 11 per cent (Study 2), and in the spring of 1958, 23 per cent (Study 4). While seedling mortality

TABLE 7. CUMULATIVE AVERAGE ANNUAL MORTALITY OF WHITE SPRUCE SEEDLINGS ON DISCED, SCALPED AND UNDISTURBED SEEDBEDS*

Period of mortality	Age of seedlings (years)	Cumulative mortality** (per cent)			Basis: number of germinants (M)
		Un-disturbed	Disced	Scalped	
Autumn years 1 - 2	1-2	77 (6)†	57 (5)	29 (10)	19.9
" " 2 - 3	2-3	84 (4)	68 (3)	52 (8)	18.8
" " 3 - 4	3-4	86 (3)	76 (1)	63 (6)	1.7
" " 4 - 5	4-5	88 (1)	80 (0)††	67 (4)	.6
" " 5 - 6	5-6	90 (1)	81 (0)††	69 (2)	.4
Basis: number of germinants (M)		12.3	21.0	8.1	41.4

*Data from Studies 5 and 6.
**Values read from balanced curve.
†Basis - number of years in sample.
††Extrapolated values.

TABLE 8. SEASONAL DISTRIBUTION OF WHITE SPRUCE SEEDLING MORTALITY ON DISCED AND UNDISTURBED SEEDBEDS*

Year	Age of seedling (years)	Seedling mortality - per cent			
		Disced		Undisturbed	
		Over-winter	Summer	Over-winter	Summer
1949-1950	1	54		72	
1950	1+		13		9
1950-1951	2	8		7	
1951	2+		3		3
1951-1952	3	3		2	
1952	3+		>1		0
Total		65	16	81	12
Basis: number of germinants		890		557	

*Data from Study 5. Undisturbed mixedwood stands.

TABLE 9. EFFECT OF MONTH IN WHICH SEED GERMINATED ON THE EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS*

Month in which seed germinated during 1956	Seedling survival - per cent			Basis: number of germinants in 1956
	1956 autumn	1957 spring	1959 autumn	
June	58	33	21	1,055
July	67	28	13	156
August	80	15	5	20
September	-	-	-	0
All	60	32	20	1,237

*Data from Study 7.

resulting from frost action occurs mainly on mineral soil seedbeds, dead seedlings have been observed on humus and burned seedbeds.

(ii) Drought[12]

The occurrence of high temperatures accompanied by low precipitation resulted in the death of large numbers of germinants and seedlings growing on mineral soil seedbeds (Figures 10 and 11). Although drought conditions were more severe in 1951 than in 1956, fewer seedlings were killed - 11 versus 40 per cent. This difference is attributed to the difference in residual crown cover; basal areas were 97 and 41 square feet in the 1951 and 1956 studies respectively.

The severity of heat- and drought-caused mortality differed on the various seedbeds investigated. In 1941, a summer characterized by a 10-day period with no rainfall and maximum air temperatures exceeding 81°F, it was found that survival of germinants in the autumn averaged

[12] In this subsection no differentiation is made between seedlings killed by drought or by excessive soil surface temperatures (stem girdle). See Day (1963) for an excellent discussion on these two causes of spruce seedling mortality.

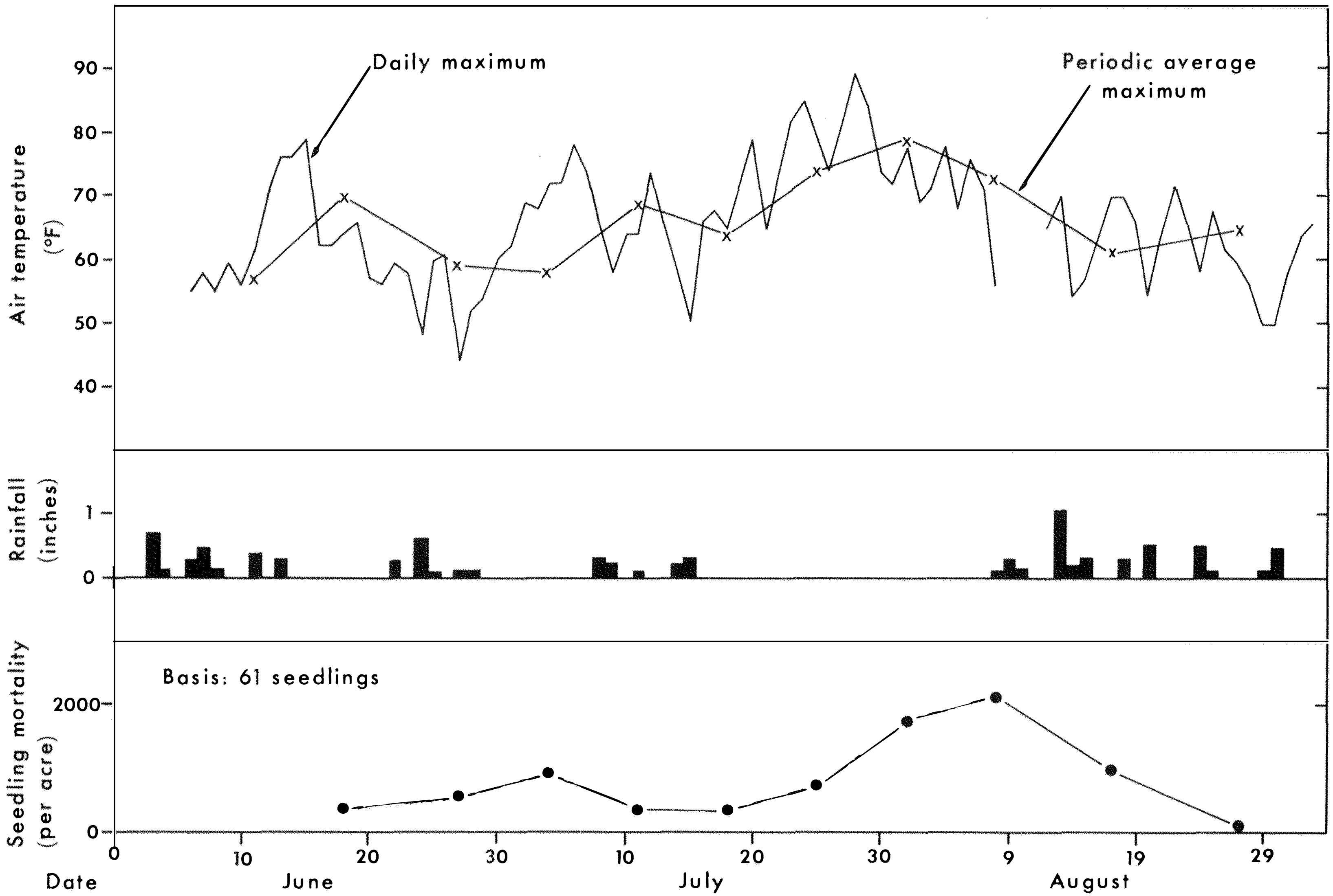

Figure 10. Effect of air temperature and rainfall on the mortality of two-year-old white spruce seedlings on disced seedbeds under partial canopy cover in 1951. Data from Study 5.

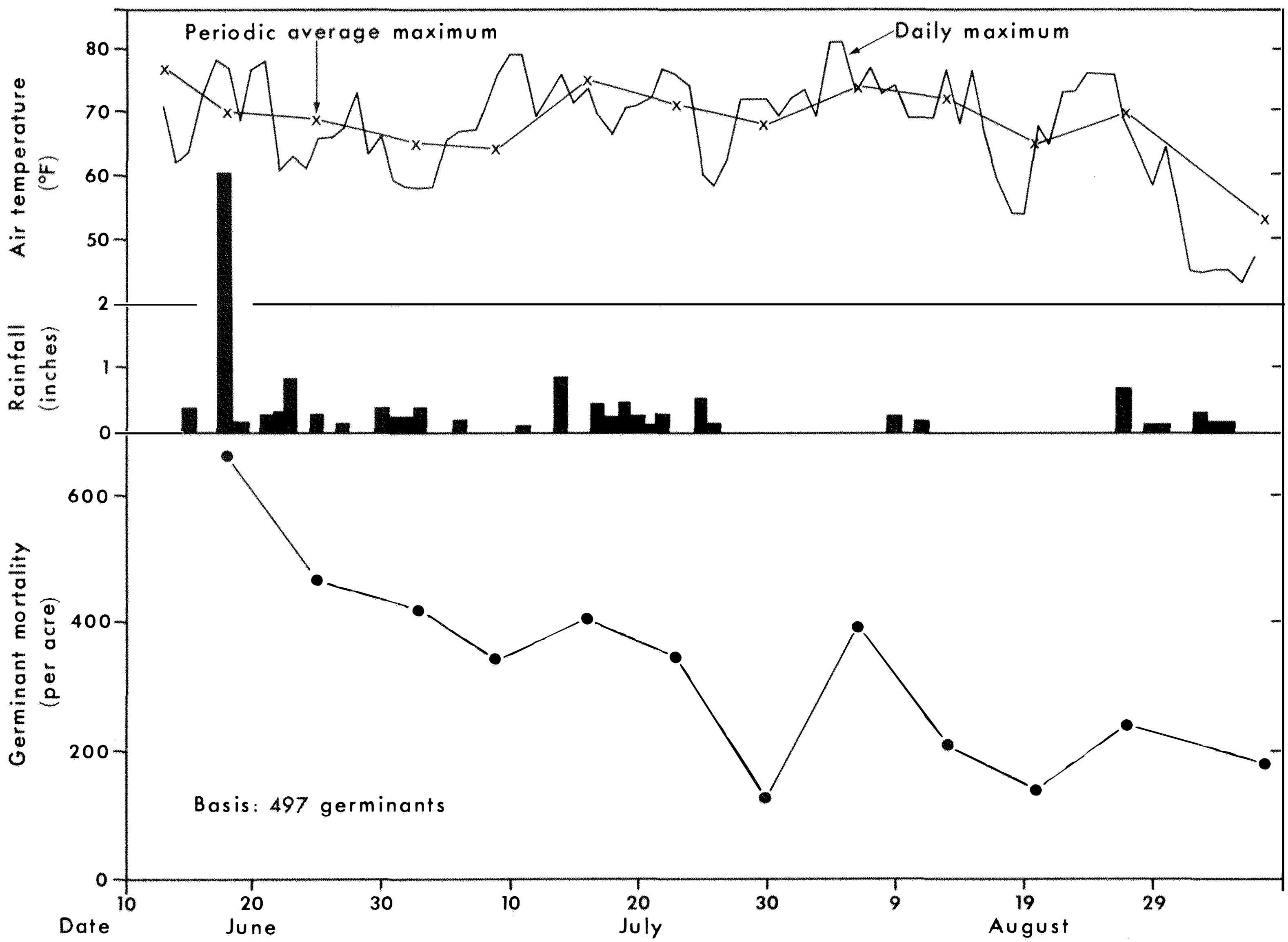

Figure 11. Effect of air temperature and rainfall on the mortality of newly germinated white spruce seedlings on scalped seedbeds under a light canopy in 1956. Data from Study 7.

56, 40, and 27 per cent for mineral soil, undisturbed, and burned seedbed, respectively. High temperatures at the black surface on the burned seedbed probably caused heavy seedling loss. Mortality on the undisturbed seedbed was probably caused by a lack of moisture.

(3) Mechanical Factors and Vegetative Competition

Crushing under aspen leaves, trampling by elk, and competition from vegetation were all important factors causing mortality. Their relative roles were determined from a detailed examination made in the autumn of 1951 in a stand of 2- to 3-year-old regeneration growing on disced and undisturbed seedbeds (Table 10).

Crushing under aspen leaves was responsible for 45 per cent of the mortality on disced seedbeds and for 36 per cent on undisturbed seedbeds. In all probability the furrows acted as catch-basins for aspen leaves. Mortality by elk trampling was considerably higher on disced than undisturbed seedbeds; this was a result of discing in ten-chain-long strips and thereby creating travel routes for the elk[13].

Seedling mortality attributable to vegetative competition was much less on disced than on undisturbed seedbeds (Table 10). However, on prepared seedbeds the importance of vegetative competition as a factor in seedling mortality increases with time since seedbed preparation.

There are indications that reinvasion of prepared seedbeds differ, and that disced seedbeds are more rapidly invaded than scalped seedbeds. After five years, disced seedbeds prepared in a partially-cut stand (15 per cent crown cover) supported a dense cover of tall grass (*Calamagrostis canadensis* (Michx.) Beauv.) and tall herbs, while after ten years on scalped seedbeds only short herbaceous plants were in abundance (Study 6). This difference in vegetation cover is significant as it has been shown that *Calamagrostis* is a greater hinderance to the survival of white spruce seedlings than are herbs[14]. Similar observations made in

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[13]Similar observations on heavy seedling losses brought about by aspen leaves and elk have been made by the author on scalped strips prepared in both cut and uncut mixedwood stands.

[14]Waldron, R.M. 1963. Planting white spruce in cut-over and undisturbed white spruce-aspen stands in Manitoba. Dept. of Forestry of Canada, Forest Research Branch, Manitoba-Saskatchewan District Report. 63-MS-9.

TABLE 10. EFFECT OF MECHANICAL FACTORS AND VEGETATIVE COMPETITION ON THE MORTALITY OF WHITE SPRUCE SEEDLINGS ON DISCED AND UNDISTURBED SEEDBEDS*

Seedbed	Age of seedling (years)	Causes of mortality - per cent				Basis: number of dead seedlings
		Crushing under aspen leaves	Trampled by elk**	Vegetative competition	Non-mechanical factors	
Disced	2-3	45	31	6	18	1,151
Undisturbed	2-3	36	6	18	40	392

*Data from Study 5. Undisturbed mixedwood stands.
***Cervus canadensis manitobensis* Millais.

TABLE 11. EFFECT OF SEEDBED MEDIUM ON THE EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS*

Seedbed medium	Survival of white spruce seedlings - per cent				Basis: number of germinants
	Partial canopy		Natural openings		
	3**	6**	5**	6**	
Undisturbed litter	0	-†	1	6	148
Mixed mineral soil - humus	-	-	10	-	549
Mineral soil	7	4	31	24	1,812
Burned	5	16	39	23	2,275
Basis: number of germinants	1,725	546	1,801	712	4,784

*Data from Studies 1 and 2.
**Age of seedlings (years).
†No germinants.

undisturbed stands indicated that the reinvading vegetation on both seedbeds was less abundant than in more open stands (Study 5).

(4) Seedbed

Seedling survival under a partial canopy and in openings was higher on both manually prepared and burned seedbeds than on undisturbed seedbeds (Table 11). Survival of the mixed mineral soil-humus seedbed was intermediate; the relatively low survival was attributed to rapid reinvasion by vegetation and resultant competition to seedlings.

On manually prepared mineral soil seedbeds survival after two years was higher on a level surface than on a ridged surface (Table 12). On ridges survival was highest on east aspects, lowest on west aspects, and intermediate on north and south aspects. On mechanically prepared mineral soil seedbeds seedling survival averages somewhat higher on scalped than on disced seedbeds (Table 7). However, differences in survival became progressively less; after one year there was a 28 per cent difference and after five years only a 12 per cent difference. In one particular study carried out in stand with a 15 per cent crown cover there was no difference in seedling survival on the two seedbeds (Table 13).

(5) Crown Cover

Early seedling survival on scalped mineral soil seedbeds was higher in a stand with a 15 per cent crown cover than a stand with 55 per cent crown cover (Table 14). It is considered that the reduction in the number of aspen leaves, as well as the increased light, accounted for this difference.

(6) Site

Survival of seedlings on both undisturbed and disced seedbeds between the autumns of 1949 and 1952 was approximately the same on fresh, moderately moist, moist, and wet sites and somewhat higher on very moist sites (Table 15). The higher survival on the latter sites, particularly on the undisturbed seedbeds, is in agreement with other studies in the same area which have shown that most advance reproduction is present on these sites as others are too dry or too wet (Rowe 1955). The high rate

TABLE 12. EFFECT OF MICROTOPOGRAPHY AND MICRO-ASPECT ON THE EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS ON MINERAL SOIL SEEDBEDS*

Micro-topography	Micro-aspect	Seedling survival - per cent 1957 Spring	1957 Autumn	1958 Autumn	1959 Autumn	Basis: number of germinants
Level		100	59	30	28	1,236
Ridge†		100	65	24	20	135
	North	100	62	19	14	
	East	100	75	42	33	135
	South	100	78	22	11	
	West	100	40	0	0	

*Data from Study 4.
†Ridges were one foot high and one foot wide.

TABLE 13. EFFECT OF MECHANICALLY PREPARED SEEDBEDS ON THE EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS*

Year of germ-ination	Scalping: No. of germ-inants per acre	Scalping: Survival in 1957 (%)	Discing: No. of germ-inants per acre	Discing: Survival in 1957 (%)	Undisturbed: No. of germ-inants per acre	Undisturbed: Survival in 1957 (%)	Basis: number of germinants
1952	150	40	0	0	0	-	5
1953	1,900	33	440	20	0	-	69
1954	380	38	180	50	0	-	15
1955	7,440	64	1,490	64	30	0	280
1956	8,800	91	1,690	100	60	51	318
All	18,670	73	4,800	72	90	34	
Basis: number of germ-inants	630		54		3		687

*Data from Study 6.

TABLE 14. EFFECT OF CROWN COVER ON THE EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS ON SCALPED MINERAL SOIL SEEDBEDS*

Year of germination	Age of seed-ling (years)	Crown cover 15% Number of germinants per acre	15% Survival in 1957 (%)	55% Number of germinants per acre	55% Survival in 1957 (%)	Basis: number of germinants
1952	6	150	40	410	24	56
1953	5	1,900	33	1,340	18	168
1954	4	380	38	90	9	11
1955	3	7,440	64	16,030	42	2,004
1956	2	8,800	91	3,640	70	455
All		18,670	73	21,510	45	
Basis: number of germinants		630		2,689		3,319

*Data from Studies 5 and 6.

TABLE 15. EFFECT OF SITE ON EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS ON DISCED AND UNDISTURBED SEEDBEDS*

Site	Survival of white spruce seedlings - per cent 1949-1952: Undisturbed seedbeds	Disced seedbeds	Basis: number of germinants
Fresh	2	8	4,205
Moderately moist	4	8	2,924
Moist	8	9	1,386
Very moist	17	13	119
Wet	6	2	52
Basis: number of germinants	3,049	5,637	8,686

*Data from Study 5. Undisturbed mixedwood stand.

TABLE 16. EFFECT OF SITE ON EARLY SURVIVAL OF WHITE SPRUCE SEEDLINGS ON SCALPED SEEDBEDS*

Site	Survival of various aged white spruce seedlings in 1957 (per cent)							Basis: number of germinants
	1	2	3	4	5	6	Unweighted average	
Fresh	64	45	10	17	29	31	33	2,114
Moderately moist	74	33	0	21	9	21	26	593
Moist	84	45	-	0	0	13	24	324
Very moist	-	0	-	-	0	-	0	2
Basis: number of germinants	463	2,021	11	169	51	318		3,033

*Data from Study 5. Undisturbed mixedwood stand.

of mortality on the fresh to moist sites was caused by crushing under aspen leaves, trampling by elk and vegetative competition, while on wet sites flooding was possibly of most importance.

Seedling survival on scalped strips prepared in an undisturbed stand was somewhat variable for the more recent germinants but definitely higher on the fresh site for the older seedlings; survival on the moderately moist site was higher than on the moist site (Table 16). No seedlings survived more than one year on the very moist site.

(7) Summary

The majority of seedlings which die on mineral soil seedbeds are killed during winter, with crushing by aspen leaves and trampling by elk being the most important causes. Spring and summer mortality occurs periodically, particularly during the year of germination, and may be brought about by frost heaving, drought conditions, and vegetative competition. The annual mortality of young seedlings is very high with more than 60 per cent of the seedlings dying before they are four years old. Seedlings which germinate in June and July have a better chance of survival

TABLE 17. EFFECT OF SEEDBED MEDIUM ON EARLY HEIGHT GROWTH OF WHITE SPRUCE SEEDLINGS*

Seedbed medium	Average total height of ten dominant seedlings on each seedbed (inches)	
	Age - 6 years	Age - 14 years
Mineral soil	11.4	43.8
Burned	9.8	47.3
Mixed mineral soil-humus	7.0	-

*Data from Studies 1 and 2.

than do those which germinate in late summer. Survival of seedlings is higher on disturbed than on undisturbed seedbeds and higher where the organic matter is completely removed either by scalping or burning. Microtopography plays an important role, with seedling survival being higher on a level surface than on a ridged surface. On ridges survival is highest on east aspects, intermediate on north and south, and lowest on west aspects. Survival on scalped seedbeds is higher than on disced seedbeds. Seedling survival is higher in stands with a low per cent crown cover. On both disced and scalped seedbeds survival of seedlings one to three years old is the same on fresh to moist sites. However, for older seedlings on scalped strips survival has been found to be highest on fresh, intermediate on moderately moist and lowest on moist sites. On undisturbed seedbeds survival is highest on the very moist sites.

Factors affecting early seedling growth

(1) Seedbed

Dominant six-year-old seedlings growing on manually prepared mineral soil and burned seedbeds were approximately the same height, but were slightly taller than those on mixed mineral soil-humus seedbeds (Table 17). On the mineral soil seedbeds, average top and root growth were both slightly greater on the level than on ridges; comparable figures were 1.7 and 2.0 inches on the level, and 1.5 and 1.8 inches on the ridge (Study 4). Height growth on mechanically prepared disced and scalped seed-

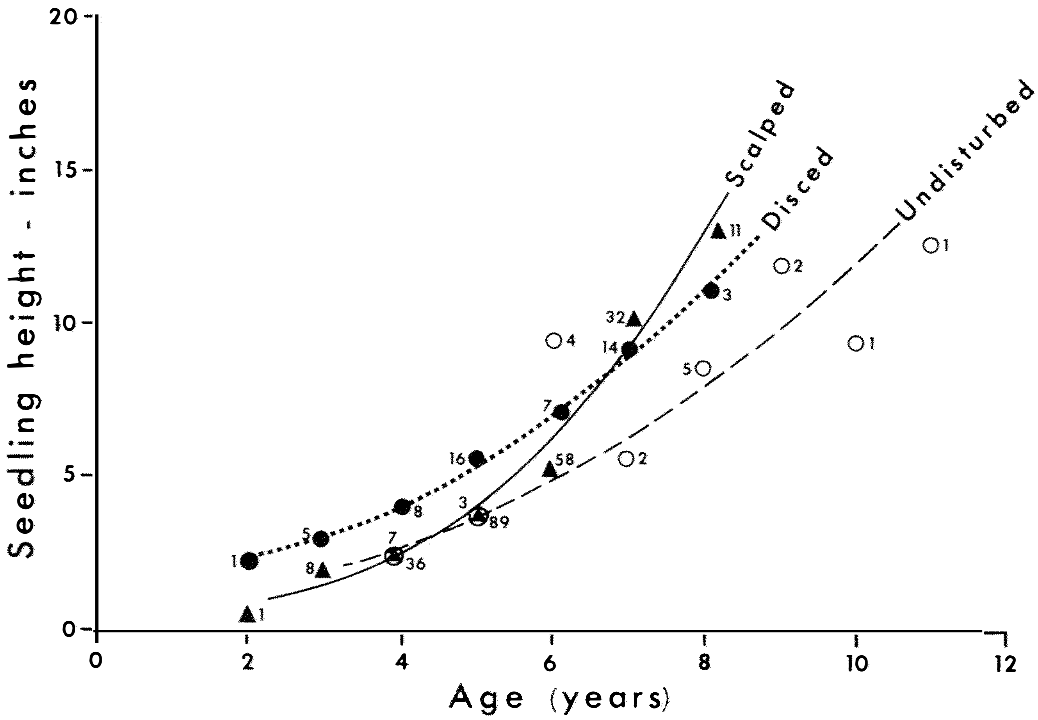

Figure 12. Effect of mechanically prepared and undisturbed seedbeds on the early height growth of white spruce seedlings. Data from Studies 5 and 6.

beds did not differ appreciably from that on undisturbed seedbeds for the first six years; after that, height growth on scalped seedbeds accelerated (Figure 12). Differences in growth between the seedbeds were largely a result of differences in vegetative competition.

(2) Crown Cover

Seedlings on all seedbeds investigated grew more rapidly under a light crown canopy or in stand openings than under a heavy crown canopy. On scalped seedbeds the average total height of seven-year-old seedlings was four inches more under a light crown cover (basal area of 40 square feet per acre) than under a heavy crown cover (basal area of 120 square feet per acre) (Figure 13). Dominant 14-year-old seedlings growing on mineral soil seedbeds averaged 43.8 inches in height in stand openings and 7.4 inches in height under partial shade; on burned seedbeds comparable figures were 47.3 and 14.4 inches, respectively (Study 1).

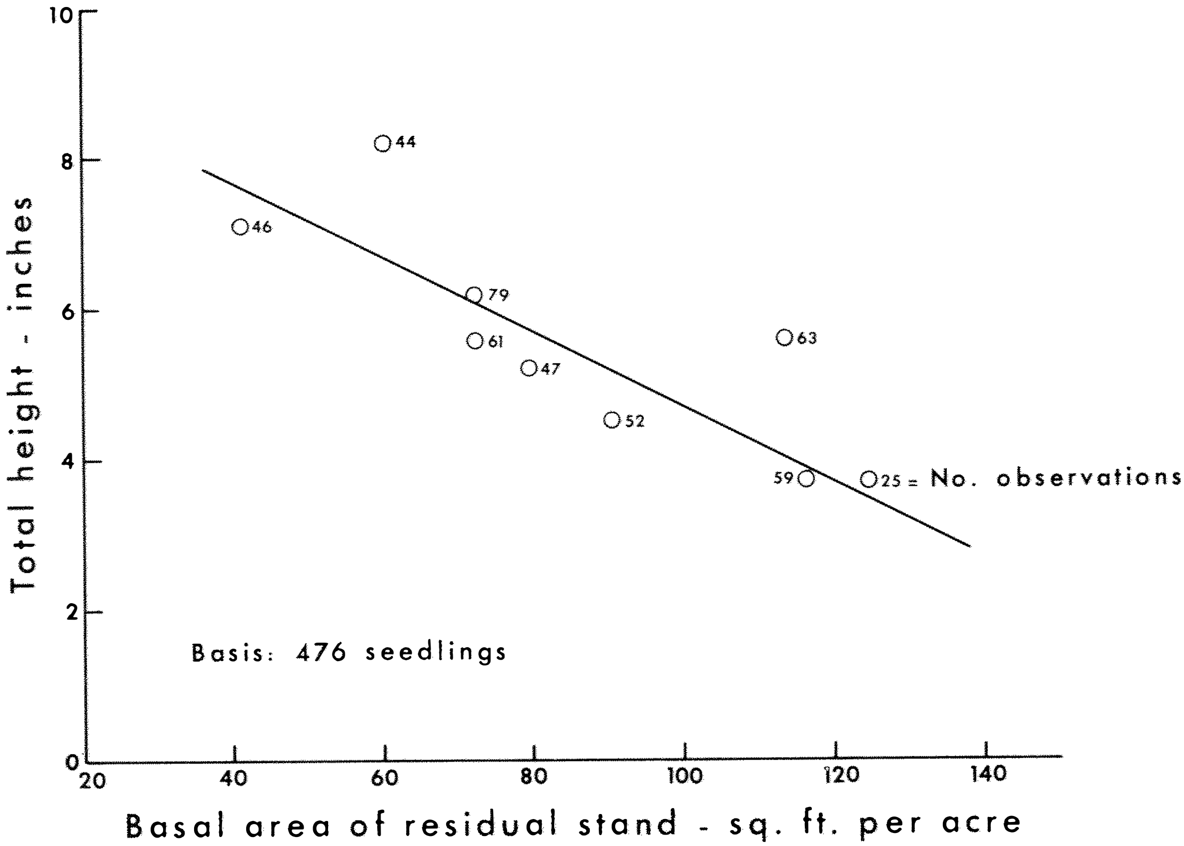

Figure 13. Effect of stand density on the total height of seven-year-old white spruce seedlings on scalped seedbeds. Data from Study 7.

(3) Summary

Early height growth of seedlings is higher on level mineral soil and burned seedbeds than on seedbeds containing a high organic content, or on the undisturbed forest floor. Height growth on scalped seedbeds is better than on disced seedbeds. Seedlings grow better in the open than in the shade, and in the shade better on burned than on mineral soil seedbeds.

SILVICULTURAL APPLICATION

From the results obtained in these studies, together with findings of other investigators, it is suggested that the following silvicultural treatments be carried out in the mature, white spruce-trembling aspen stands on the Riding Mountain Forest Experimental Area in order to secure the maximum amount of natural white spruce regeneration. These treatments are based on the silvical characteristics and ecological relationships of white spruce and trembling aspen - not on economic considerations - and are only applicable to normally stocked and over-stocked mixedwood stands growing on fresh to moist clay loam tills and containing a minimum of 25 square feet basal area per acre of white spruce. Briefly the treatments recommended may be grouped under four major headings as follows: (1) preparation of the overstorey, (2) preparation of seedbeds, (3) removal of the residual stand, and (4) subsequent treatments to release the seedlings from vegetative competition.

(1) Preparation of the Overstorey

Stands to be regenerated should be reduced to a residual basal area of approximately 40 to 60 square feet per acre. If possible, the residual stand should be composed entirely of white spruce but in no instance should there be less than 25 square feet basal area; sufficient trembling aspen should be left to make up the balance.

It is essential that as many trembling aspen as possible be eliminated in order to reduce subsequent seedling mortality by crushing under aspen leaves (Koroleff 1954; Place 1955; MacLean 1960). Aspen suckering may be kept to a minimum by poisoning the parent trees at least two years prior to any opening of the stand either by cutting or by ground preparation[15] (Waldron 1961a).

The suggested residual stand should not be dense enough to adversely affect the germination and early survival of seedlings on mineral soil seedbeds (Ackerman 1957; Lees 1963), but rather should be beneficial by conserving moisture at the soil surface for germination and providing protection for the seedlings from soil drought and lethal soil surface temperatures (Place 1955; Day 1963; Glew 1963). Excellent stocking on mineral soil seedbeds prepared in partially cut stands containing a total

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[15] Waldron, R.M. 1963. Observations on aspen suckering in Manitoba and Saskatchewan. Dept. of Forestry of Canada, Forest Research Branch, Manitoba-Saskatchewan District Report. 63-MS-22.

residual basal area of between 40 and 60 square feet per acre (25 of which was white spruce) has been reported by Crossley (1955b) and Waldron (1961b).

Leaving denser stands than those recommended will prevent satisfactory development of the seedlings (Quaite 1956; Lees 1963). Shirley (1945) reported that at least 20 per cent light is necessary for satisfactory establishment and growth; approximately 45 per cent for maximum height growth, and full sunlight for maximum dry weight production. Results presented in this paper showed that height growth was greater under a residual basal area of 40 square feet per acre than under 80+ square feet. Development of seedlings and saplings on seedbeds prepared by winter logging and burning of slash in mature mixedwood stands in Saskatchewan was found to be best under a residual basal area of 75 square feet (including poplar and spruce) per acre (Waldron 1959a).

(2) Preparation of Seedbeds

Mineral soil seedbeds should be prepared using a bulldozer and straight blade (Crossley 1955a; Waldron 1961b) in mid-summer following the death of the poisoned aspen. Where possible, scalping should be carried out in large patches in order to prevent treated areas from developing into game trails and, more important, to prevent rapid reinvasion of the seedbeds from adjacent undisturbed vegetation (Blyth 1955; Crossley 1955b; MacLean 1960). The importance of eliminating vegetation by deep scalping cannot be too strongly stressed, particularly since the removal of the aspen from the stand will have resulted in increased vegetative competition. Leaf litter from underbrush species on undisturbed ground and from the occasional white birch and living aspen will be available to act as a mulch and aid the germination of the white spruce seed and yet not be present in sufficient quantities to cause heavy losses by crushing.

With the reduction in aspen leaf fall there is a strong possibility that frost heaving could become a major factor in early seedling survival. Crossley (1952) found that frost heaving as a cause of mortality became of minor importance three years after the preparation of the seedbeds because of reinvasion by herbaceous vegetation. Observation indicated that this vegetation was not sufficiently dense to cause serious reduction in the receptivity of the seedbed.

The preparation of mineral soil seedbeds should be restricted to the fresh to moist sites only; the very moist and wet sites which occupy less than five per cent of the land area should be left to regenerate naturally (Rowe 1955).

(3) Removal of the Residual Stand

The residual stand will ordinarily be removed following the successful establishment of 2- to 3-year-old seedlings. Logging should be carried out in the winter and the slash piled and burned. If desirable, these burned spots may be artificially seeded a few years later if the seedbeds are suitable for seed germination, and when shade from reinvading herbs will prevent excessive soil surface temperatures (Place 1955).

The residual stand should be cut within a five-year period following seedbed preparation. A longer period is not recommended as the receptivity of the seedbed rapidly deteriorates after this length of time (Crossley 1955a, 1955b; Rowe 1955; Smithers 1959). At the Riding Mountain Forest Experimental Area this does not pose a real problem since records have shown that medium or heavy cone crops occur once every two years and light crops or better almost annually (Waldron 1965). If poor cone crops do occur in the years immediately following seedbed preparation, then artificial seeding should be carried out.

(4) Subsequent Treatments

Subsequent herbicide treatment of the reinvading vegetation will in most cases be necessary in order to keep seedling mortality and growth at acceptable levels. These treatments should be carried out using recommended techniques (Sutton 1958; Waldron 1959b; Arend and Roe 1961) when it becomes obvious that the seedlings are suffering from competition[16].

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[16]For a rating on the effects of various vegetation types on the survival of planted white spruce see: Waldron, R.M. 1963. Planting white spruce in cut-over and undisturbed white spruce-aspen stands in Manitoba. Dept. of Forestry of Canada, Forest Research Branch, Manitoba-Saskatchewan District Report. 63-MS-9.

Recommendations similar to those outlined above for obtaining white spruce regeneration have been suggested for white spruce-trembling aspen stands on sandy loam soils in Alberta (Smithers 1959; Lees 1963), for the aspen-birch-spruce-fir type on sandy, sandy loam, and loam soils in northern Ontario (MacLean 1960), and for white spruce-alpine fir (Abies lasiocarpa (Hook.) Nutt.) types on sandy loam to clay soils in British Columbia (Glew 1963).

Clear cutting and mechanical preparation of mineral soil seedbeds in alternate strips in white spruce-trembling aspen stands is currently being studied in Manitoba and Saskatchewan. Although this system of regenerating white spruce is based more on economic considerations than on the silvical characteristics and ecological relationships of the species concerned results to date have been promising. While the recent trend towards increased mechanization of logging in eastern Canada has not occurred to any noticeable extent in central Canada there is a strong possibility that clear cutting in alternate strips may have wide application. The problem of regenerating the leave strips has not, as yet, been solved and it is possible that the cost of artificially stocking these strips may exceed the savings resulting from the cheaper logging method.

The use of fire as an alternative to mechanical preparation of seedbeds suitable for the regeneration of white spruce in mixedwood stands would appear to be a promising possibility. However, before operational-scale trials can be undertaken detailed studies are needed to determine whether or not suitable seedbeds can be created by burning.

SUMMARY

Experiments have been underway at the Riding Mountain Forest Experimental Area in Manitoba since 1940 to study the silvics and ecology of white spruce with particular emphasis on the development of natural regeneration on artificially prepared seedbeds. Results showed that in addition to seedbed other factors including weather, litter, crown cover, site, lesser vegetation and animals had significant effects on germination, early survival and growth of white spruce.

Results clearly indicated that shelterwood cutting of mature white spruce-trembling aspen stands on fresh to moist clay loam soils, together with the preparation of mineral soil seedbeds using a bulldozer and straight blade, will provide conditions ideally suited for the establishment of white spruce regeneration. Specific silvicultural treatments recommended for regenerating mixedwood stands were as follows:

1. Preparation of the overstorey - Stands should be reduced to a total residual basal area of 40-60 square feet per acre including a minimum of 25 square feet of white spruce. Aspen stems to be eliminated should be harvested or poisoned.

2. Preparation of seedbeds - Mineral soil seedbeds should be prepared using a bulldozer and straight blade in mid-summer following the death of the poisoned aspen.

3. Removal of the residual stand - The residual stand should be removed following the successful establishment of adequate numbers of 2- to 3-year-old white spruce seedlings. Logging should be carried out during the winter to prevent heavy seedling losses.

4. Subsequent treatments - Release of the white spruce seedlings from vegetative competition will, in most cases, be necessary and should be carried out using treatments recommended in the literature.

SOMMAIRE

Une étude expérimentale se poursuit depuis 1940 sur l'écologie forestière de l'Épinette blanche dans la région d'expérimentation forestière du mont Riding, au Manitoba, en particulier sur les diverses étapes de la régénération naturelle dans des couches de semis d'aménagement artificiel. Selon les résultats obtenus, en plus de la couche de semis elle-même, d'autres facteurs, notamment les conditions atmosphériques, la litière, la voûte foliacée, l'emplacement, les plantes secondaires et la faune, influeraient sensiblement sur la germination, le développement initial et la croissance de l'Épinette blanche.

Les essais ont nettement établi que des coupes progressives de peuplements mûrs d'Épinette blanche - Peuplier faux-tremble croissant sur

des limons argileux allant de frais à humides, de même que l'aménagement, à l'aide d'un bulldozer à lame droite, de couches de semis dans des sols minéraux, engendrent des conditions idéales pour la régénération de l'Épinette blanche. Voici la liste des traitements sylvicoles particulièrement recommandés pour la régénération de ces peuplements:

1. Préparation de l'étage dominant: réduire la surface terrière globale du peuplement à quelque 40 à 60 pieds carrés à l'acre, y compris 25 pieds carrés à l'acre d'Épinette blanche au minimum. Les peupliers faux-trembles à détruire doivent être coupés ou empoisonnés.

2. Aménagement des couches de semis: aménager les couches de semis en sol minéral au moyen d'un bulldozer à lame droite vers la mi-été, après la mort des peupliers faux-trembles.

3. Abattage du peuplement résiduel: enlever le peuplement résiduel une fois qu'un nombre suffisant de plants d'Épinette blanche de deux ou trois ans sont bien établis. Effectuer les travaux d'abattage au cours de l'hiver pour ne pas occasionner de lourdes pertes de plants semis.

4. Traitement ultérieurs. Dans la plupart des cas, effectuer des coupes de dégagement autour des plants d'Épinette blanche en suivant une technique éprouvée.

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APPENDIX I

TABLE 1. STAND DESCRIPTION OF A TYPICAL UNDISTURBED MIXEDWOOD STAND RIDING MOUNTAIN FOREST EXPERIMENTAL AREA*

Species	Number of trees** (per acre)	Basal area (sq. ft. per acre)
White spruce	106	50
Trembling aspen	63	37
Balsam poplar	12	5
Others†	6	2
Total	187	94

*Based on a 200-acre tract sample.
**One inch d.b.h. and up.
†Includes black spruce, white birch and jack pine.

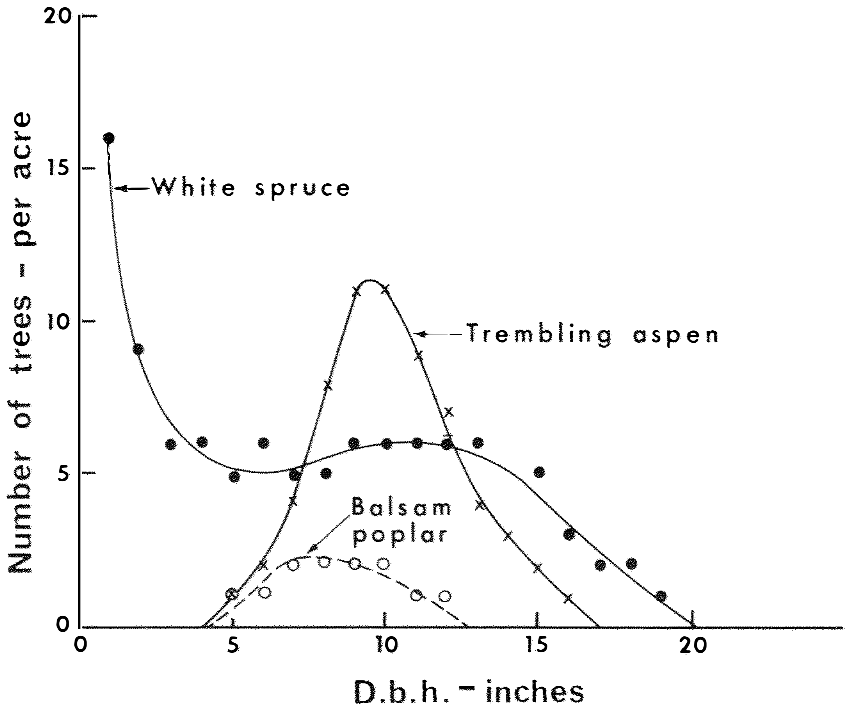

Figure 1. Diameter distribution of white spruce, trembling aspen and balsam poplar in a typical mixedwood stand at the Riding Mountain Forest Experimental Area.

APPENDIX II

BRIEF DESCRIPTIONS OF THE STUDIES CARRIED OUT AT THE RIDING MOUNTAIN FOREST EXPERIMENTAL AREA, 1940 - 1962.

Study	Description of Treatments*
1	Between 1940 and 1942 small, hand-made mineral soil, burned and undisturbed seedbeds were prepared in the open and under a spruce-aspen overstorey. White spruce seed was artificially applied on 29 quadrats of variable size with the largest being 1/700-acre. (Project MS-150)
2	In 1951 small, hand-made humus, mineral soil, burned and undisturbed seedbeds were prepared. White spruce seed was artificially applied on 32, 1/1000-acre quadrats set out in a cut-over white spruce-aspen stand. (Project MS-159)
3	In 1950 and 1951 the viability of white spruce seed in the humus layer under a mixedwood stand was studied on a number of small quadrats. (Project MS-161)
4	In 1957 small, hand-made mineral soil scalps and ridges (one foot high and one foot wide) were prepared. The ridged seedbeds were oriented in both east-west and north-south directions. White spruce seed was sown on 72, 1/8000-acre quadrats and on an equal number of ridges. (Project MS-191)

*For further details on any individual study the reader is referred to the following publication: Jarvis, J.M., Steneker, G.A., Waldron, R.M. and Lees, J.C. 1966. Review of silvicultural research, white spruce and trembling aspen cover types, Mixedwood Forest Section, Boreal Forest Region, Alberta-Saskatchewan-Manitoba. Dept. Forestry and Rural Development Publication No. 1156, in which the studies are described under their original project number (e.g. MS-150).

5 In 1947 and 1950 scarification using an Athens disc plough and a bulldozer blade was carried out in mature, undisturbed mixedwood stands containing 100 square feet basal area per acre. A total of 2900, 1/4000- and 1/8000-acre regeneration quadrats were laid out. (Project MS-124)

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6 In 1951 scarification using a bulldozer blade and an Athens disc plough was carried out in a partially cut-over mixedwood stand containing 56 square feet basal area per acre. A total of 315, 1/4000-acre regeneration quadrats were set out. (Project MS-156)

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7 Between 1953 and 1955 eighteen 10-acre blocks containing mature white spruce and trembling aspen were cut-over leaving residual stands with a range of basal areas between 40 and 120 square feet per acre. In the autumn of 1955 mineral soil seedbeds were prepared using a bulldozer and blade. A total of 3,600, 1/4000-acre regeneration quadrats were established. (Project MS-166)

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8 Between 1938 and 1962 annual estimates of white spruce cone crop abundance have been made in a mature white spruce-trembling aspen stand using five abundance categories - very heavy, heavy, medium, light and no crop. The seasonal distribution of seed- and litter-fall in a mature white spruce stand was studied in 1955, 1961 and 1962. (Project MS-158)

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9 In 1961 the effects of needle and leaf litter on the germination of white spruce seed was studied in the greenhouse using small tubs containing a clay-loam-textured soil. Variable depths of spruce needle and aspen leaf litter were applied both before and after seeding. (Project MS-223)

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