A WHITE SPRUCE PROGENY TEST--SEEDLING SEED ORCHARD: 12TH YEAR PROGRESS REPORT[1]

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ABSTRACT-- Two hundred thirty-nine open-pollinated progenies of white spruce were established in a combination progeny test-seedling seed orchard near Grand Rapids, Minnesota. Characteristics evaluated included, total heights at 2-0 and 2-2 in the nursery and 9 and 12 years from seed (in the field); field survival 9 years from seed was included. Survival was just over 77 percent. Family mean heights were from 60 to 167 percent of the nursery test mean at 2-0 and decreased in variation to from 52 to 125 percent of the plantation mean at age 12. Narrow sense heritabilities (computed as four times the interclass correlation) were 0.27 at age 9 and 0.35 at age 12 and are comparable to earlier results with white spruce in Wisconsin. They exceed Canadian results probably because Canadian material represented a more narrow geographic base. Data suggest a possible relation between growth rates and climatic seed collection zones. Pending further study, nurserymen should not collect seed in the extreme climatic zones in northeastern Minnesota. Plans for conversion of the test to a seed orchard are described. Possible genetic gains of from 15 to 20 percent are predicted on the basis of present genetic parameters.

In 1962 a cooperative improvement project for white spruce (*Picea glauca* (Moench) Voss) was initiated by Blandin Paper Company of Grand Rapids, Minnesota, and the College of Forestry, University of Minnesota. Objectives included the establishment of a small commercial seed orchard to produce improved materials for use in a limited area of north-central

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Minnesota, the development of information concerning genetic variation in the species, and the identification of materials for use in future breeding work.

We decided to run a combination one-parent progeny test and seedling-seed orchard similar to that described by Wright and Bull (1963) for red pine in Michigan. Both the theoretical and applied aspects of such an approach are controversial. However, the choice was dictated by the objectives of the cooperators, the limited physical and human resources available, and our knowledge of white spruce genetics in the early 1960's. This report reviews the establishment of the project, presents a preliminary analysis of data collected through age ,12, and outlines plans for future developments.

MATERIALS AND METHODS

Seed Collection

All seeds were collected in 1962. The goal was 200 to 250 individual tree collections from the range of white spruce in Minnesota. To meet this goal, assistance was requested from foresters with the Minnesota Department of Natural Resources and other organizations.

Collectors were instructed to obtain 25 to 30 cones per selected tree, package single-tree collections separately, and mail the cones to a central point along with a legal description of the mother tree's location. Selection criteria for mother trees were not stringent: cooperators were to confine their selections to wild stands, avoid isolated specimens, and choose trees "above average in health and vigor when compared to trees of the same age in the immediate area."

The response by Minnesota foresters was outstanding and 281 usable single-tree collections were assembled. The collections represented the efforts of at least 35 individuals employed by several organizations.

Nursery Phase

Cleaned and dewinged seeds were sown in October of 1962 in the Blandin Nursery near Grand Rapids, Minnesota. The sowing was made in 3 blocks; each block contained 1 plot of each of the 281 seed lots. A plot was a 4-foot row across the nursery beds containing 110 to 150 seeds. Spacing of 6 inches between rows was maintained by using planting boards.

The sowing produced 249 open-pollinated progenies in each of which there were 20 or more healthy seedlings. The seedlings were transplanted in May of 1965 into a randomized complete block design with four replications.

Row plots of 12 trees each were used at a spacing of 4 by 6 inches. Low numbers of seedlings resulted in 33 of the families being transplanted to only 2 or 3 of the 4 plots.

In April of 1967 the 2-2 stock was labeled and lifted. At the conclusion of the nursery phase the original 281 seed lots had yielded 239 open-pollinated progenies with adequate numbers of plantable seedlings (fig. 1) .

Outplanting

Seedlings were hand planted in May of 1967 near Grand Rapids, Minnesota, on a gently rolling, old-field site with a sandy-loam soil. Before planting the site was plowed, disked, and divided into 30 contiguous 70 by 80 foot blocks. Spacing of 5 by 5 feet gave 240 positions per block and 1 seedling from each of the 239 families was randomly assigned to each position. The 240th position was filled with surplus seedlings from progenies with more than 30 seedlings as were voids caused by families having less than 30 seedlings. This resulted in the number of trees in a progeny varying from 15 to 38.

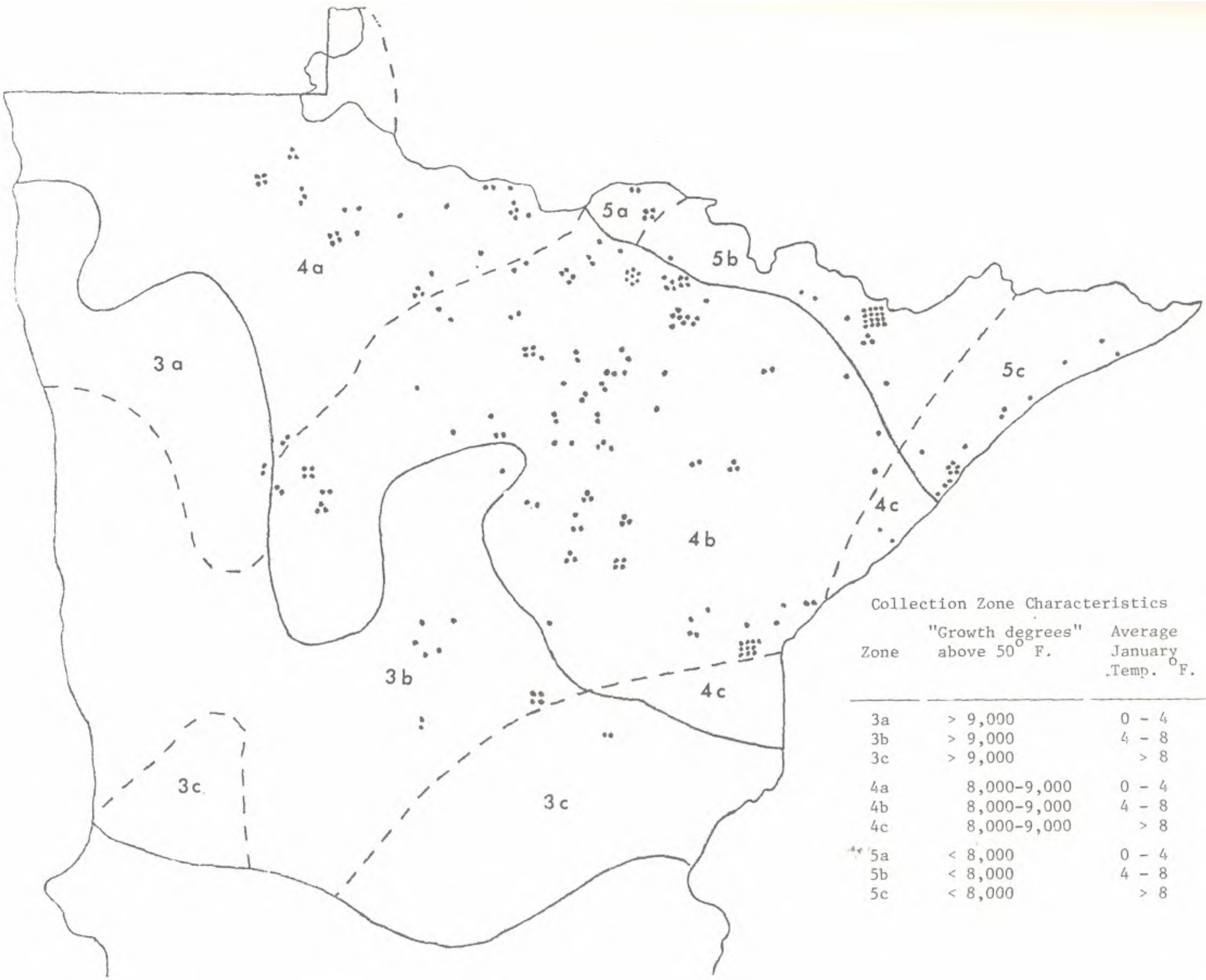
Post planting care include replacing 587 dead plants in 1968, treating an area around each plant with an herbicide in 1968, and spraying with an insecticide to control yellow-headed spruce sawfly each year.

MEASUREMENT AND ANALYSIS

Nursery measurements included the determination of plot mean heights for 2-0 seedlings in 1965 and the 2-2 transplants in 1967 to the nearest centimeter. Mean family heights were computed using these data and compared by analysis of variance, assuming a randomized complete-block design.

Field heights were measured after five and eight growing seasons in the field (in 1971 and 1974). Data from these measurements were examined on the basis of a completely random design because of the large number of missing plots.

Narrow-sense heritabilities for individual differences were calculated as four times the interclass correlation (Falconer 1960, Kung 1972). Further analysis of 12th year height data included computing the means and variances for families from six collection zones. The zones, modified from Rudolf (1956), were defined by average January temperature and the annual sums of normal average daily temperatures per year above 50°F (fig. 1).



Collection Zone Characteristics

Zone	"Growth degrees" above 50° F.	Average January Temp. °F.
3a	> 9,000	0 - 4
3b	> 9,000	4 - 8
3c	> 9,000	> 8
4a	8,000-9,000	0 - 4
4b	8,000-9,000	4 - 8
4c	8,000-9,000	> 8
5a	< 8,000	0 - 4
5b	< 8,000	4 - 8
5c	< 8,000	> 8

Figure 1.--Location of mother trees and seed collection zones for white spruce seedling seed orchard-progeny test.

Simple correlation coefficients among family means for height at the four measurement ages and survival in 1971 (age 9) were calculated.

Significance levels for all tests were set at 0.05.

RESULTS

Field Survival

All the field mortality occurred during the first 5 years after planting. By 1974, eight growing seasons after field planting, survival was just over 77 percent. On a family basis, survival ranged from 39 to 100 percent. The average family had 23.5 living plants and only 11 of the 239 families were represented by less than 15 trees. Mortality was strongly related to location in the planting with losses in the 30 blocks ranging from less than 1 percent to 55 percent.

Height Growth

Growth in the nursery and during the first 5 years in the field was slow (table 1). However, from 1972 to 1974 (10th-12th years) it averaged 28 cm per year. Much variation in individual tree height was shown by the field data. The standard deviations of individual tree heights were equal to 36 percent and 34 percent of the plantation mean in the 9th and 12th years, respectively.

Table 1.--Summary of nursery and field height measurements

Year	Years materials in: Seed-bed	Transplant bed	Field	Families (No.)	Test mean (cm)	Standard deviation (indiv.tree) (cm)	Range of family means: Actual (cm)	Test mean (percent)
1964	2	--	--	237[1/]	8.8	--	5.3-14.7	60-167
1966	2	2	--	237[1/]	17.2	--	8.3-24.8	48-144
1971	2	2	5	239	101	36	57-129	56-128
1974	2	2	8	239	184	62	96-230	52-125

1/ Two families omitted from nursery data because of missing plots.

Differences among open-pollinated families were significant for all height measurements (fig. 2). The range of family means was largest for the 2-0 measurements which ran from 60 to 167 percent of the plantation mean. Although the range of family means decreased over time (table 1), at age 12 it still ranged from 52 to 125 percent of the plantation mean.

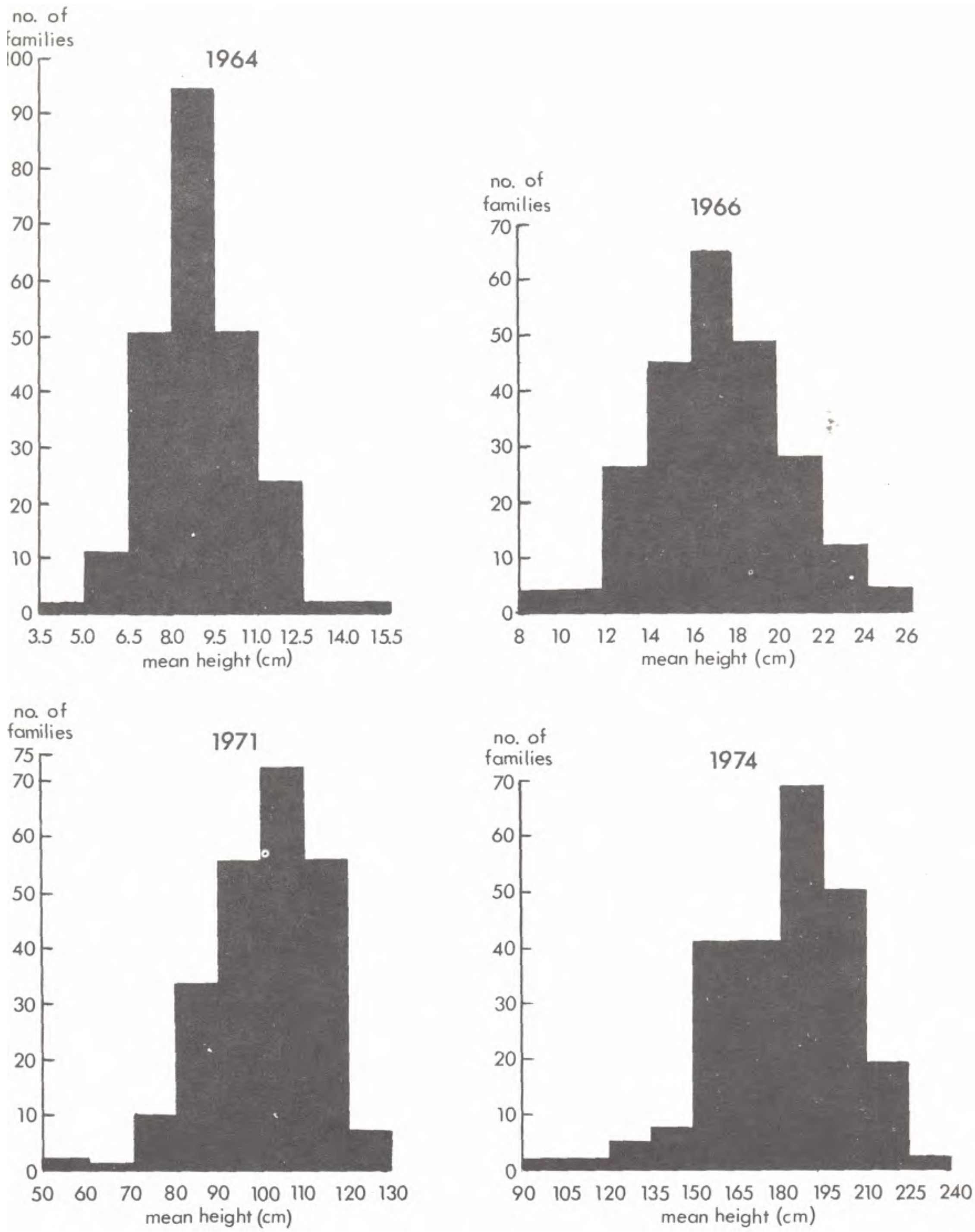


Figure 2.--Distributions of white spruce open-pollinated family means for height.

Narrow-sense heritabilities (individual tree basis) were 0.27 at age 9 and 0.35 at age 12.

The mean 12th-year heights for families from the six collection zones in which six or more individual trees were sampled are given in fig. 1, table 2 Bartlett's test indicated that the variances for the zones exhibited heterogeneity and the data were not subjected to further analysis (Steel and Torrie 1960).

Table 2.--Mean 12th-year heights for families in six collection zones

Seed collection zone1/	Families in sample	Mean height of families	Family variance	Standard error of mean
	(No.)	(cm)		
3b	12	193.2	8.58	4.57
4a	34	188.4	7.24	2.44
4b	138	183.8	15.36	1.83
5a	6	179.2	17.69	9.45
5b	24	177.4	12.06	3.96
5c	16	152.4	25.59	6.71

1/ Collection zone shown in figure 1.

The simple correlation coefficients of family mean heights for the four measurement dates and mean 9th year survival are given in table 3. All correlations between these variables were statistically significant.

Table 3.--Simple correlation coefficients (r)1/ for heights and 1971 survival

	2-0 height	2-2 height	9th year height	12th year height
1971 survival	.29	.48	.40	.48
2-0 height		.54	.44	.43
2-2 height			.58	.60
9th year height				.90

1/ r values are significant at the 5 percent level if they exceed 0.14

DISCUSSION

Heritabilities from similar tests with white spruce were converted to a common basis using the procedures outlined by Kung (1972). Jeffers' (1969) data for the height of 28 open-pollinated families at age 4 gave a value close to those obtained in this study (0.34 vs. 0.27 and 0.35). In contrast, heritabilities established from 8th or 11th year data from 4 Ontario tests with 8 to 18 open-pollinated progenies ranged from 0.03 to 0.09 (Holst and Teich 1969).

It should be noted that the Minnesota aid Wisconsin test materials came from a wide geographic area, but three of the four Ontario tests sampled a very limited area. The data summarized by table 2, although not evaluated statistically, suggest differences among materials from the several seed collection zones. A trend toward greater heights with increasing annual sums of normal average daily temperatures of 50°F or above and with lower average January temperatures may exist. Given these results, a reduction in variation would be anticipated when working with geographically restricted populations.

The possible relation of growth rates to collection zones suggested by the data also has implications for seed collection in Minnesota. Pending further study, nurserymen would be advised to avoid the northeastern region of the State; i.e., zones 5a, 5b, and particularly zone 5c (fig. 1).

Correlations between nursery and field height, although positive and statistically significant are only moderately high (table 3). Nursery-field correlations do not suggest that nursery data can form the primary base for selection. However, they are strong enough to indicate that culling in the nursery could improve cost/gain ratios in white spruce improvement programs.

Predictions of genetic gain based on the results of these data are encouraging. Given the heritabilities and magnitude of phenotypic variation observed for 9th and 12th year heights, conversion of the progeny test to a seed orchard by removing 90 percent of the trees would give an expected genetic gain in height growth of 15 to 20 percent.

Such predictions should be viewed with caution, however. The height data are for a maximum age of 12, which is far from rotation age. At least some culling of the materials must be done on the basis of early growth and, unless juvenile-mature correlations are high, predicted gains will be reduced. However, there is evidence of juvenile growth superiority of provenances persisting 29 years after field planting (Nienstaedt 1969), and the observed 9th-12th year correlation coefficient of 0.9 is encouraging.

It is also important to realize that testing was limited to a single site. Estimates of additive genetic variance and consequent predicted gains are biased upward by the failure to estimate the genotype-environment interaction component. The impact of this bias is unknown, however, it can be expected to be greatest on sites that differ most from the test site.

Despite these limitations, conversion of the progeny test site to a seed orchard appears worthwhile. Seeds produced by the orchard will be used in the area near the test location and this should reduce the impact of single site evaluation. In addition, much of the selection will be based on 20th-year or later measurements, so the probability of high selection age-rotation age correlation will be increased. The current plan for conversion to a seed orchard can be summarized as follows:

Activity	Year	Status at end of activity (Number)		
		Trees per acre	Total trees	Families
Measurement	1974	1,347	5,562	239
1st thinning	1975	870	3,600	228
Measurement, 2nd thinning	1982	435	1,800	50+
Measurement, final thinning	?	109	450	50+

The timing of the initial thinning is essentially an economic matter. Cutting and disposing of a large number of stems is cheaper when they are small. Although retaining all trees is theoretically advantageous, it is assumed that the low intensity of selection will have minimal impact on final gain.

The first thinning will be based on index values derived from the height of an individual tree, mean height of its family, and number of living trees in its family (Falconer 1960). Given the 12th-year estimate of heritability, the predicted response from this form of selection is superior to that expected from selecting only on the basis of a tree's phenotype (mass selection) and far superior to using the family as a selection unit. The thinning will eliminate only 11 of the 239 families and 125 of the remaining families will have 15 or more progeny.

The second thinning will occur at about 20 years from seed when trees begin flowering consistently. It will maintain the plantation's vigor and provide access for seed collection. This thinning will be of moderate intensity, leaving one tree per 100 square feet. The final thinning to about 8 percent of the stems now living is planned for the early 1990's. Because the objective is to improve the genetic quality of seeds being used as quickly as possible, the final thinning will be earlier if age-age correlations are high.

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