Selection of black spruce progenies for the genetic improvement of height growth

E. K. MORGENSTERN

Canadian Forestry Service
Petawawa Forest Experiment Station
Chalk River, Ont.

Selection and breeding of rapidly growing trees is one way to improve growth in species that are established artificially. Unlike characters of the stem and crown, characters of growth are usually inherited to a lesser degree and rapidly growing genotypes are not easily identified. Studies of the genetic variation in black spruce (*Picea mariana* Mill. B.S.P.) at Petawawa Forest Experiment Station indicated that in a nursery experiment only 18% of the variation in total height was genetically controlled (Morgenstern 1973). This was no surprise in view of the low heritability of height growth reported from other species. While there is no doubt that selection for height growth is possible, it is clear that this requires very special procedures. The problem of developing and applying such procedures should interest management foresters and geneticists alike and is discussed here.

Rank of trees and their progenies in different environments

The concept of heritability implies that the total variation in a population of trees consists of two parts: that determined by the environment and that determined by genetic factors. Experiments with clones or progenies of individual trees are required to separate the influence of the two parts and calculate their percentage contribution.

In such experiments a given degree of control of a certain character by genetic factors (i.e. the heritability of this character) is manifested by the consistency of response in a number of environments. Characters that are strongly inherited will not change much in different environments while characters with weak inheritance will change more. When the progenies are ranked, say for the character height growth in two environments, the difference in rank may be used to compute Spearman's rank correlation coefficient (Steel and Torrie 1960). A very strong rank correlation would be expected for a character with high heritability and a weak correlation for another character with low heritability. Therefore the rank correlation can be used to express the meaning of a known heritability. Progeny rank is also important because it is used in selection.

In September 1963, four 30- to 50-year-old black spruce stands at Petawawa were located and five individual trees in each of them designated for seed collection and determination of height and age (Morgenstern 1969). No effort was made to select superior trees, but there was a tendency to prefer

dominant trees because of their more prolific cone production. Seedlings were then raised from these female parents and planted into 2 experiments: 1/ a nursery experiment with 10-tree plots and 4 replications each on a moist and a dry site, where measurements of total height were made following the completion of the fourth growing season; and 2/ using the same nursery trees, a field experiment on a fresh site with 5-tree plots and 5 replications which was measured after the completion of the ninth season. The data from the nursery experiment have been previously used to obtain the heritability estimate referred to above (Morgenstern 1973). For the purposes of this study, measurement results were then available from 5 "environments": 1/ the growth of each female parent in its native environment; 2-4/ the growth of progenies on the dry nursery site, moist nursery site, as well as all replications on both sites in the nursery together, here termed the "combined site"; and 5/ the growth of the progenies on the fresh field site.

Progeny growth was analysed by variance and the significance evaluated using a multiple-range test (Duncan 1955). Differences significant at the 5% level of probability were found in both the nursery and field experiment. However, the principal aim of this analysis was to obtain rank correlations between parental growth and progeny growth in the different environments and thereby seek guidance on how to select. Towards this end, the rank of the female parent trees based on mean annual increment in the 4 stands and of the progenies on the 4 sites is given in Table 1 and the rank correlation coefficients in Table 2.

Of the 10 possible rank correlation coefficients, only 3 were significant (Table 2). None of the progeny-parent correlations were significant: the simple assessment of mother tree growth made here (which did not take account of competition or microsite differences within a stand) was not a useful guide to growth of the progeny in the nursery (age 4) and field (age 9). On the other hand, progeny ranks on the moist site and dry site were correlated with ranks on the combined site — which is not surprising since the combined site means were merely obtained by pooling the data from the 4 replications each on the moist and dry site. However, of the rank comparisons between the nursery sites (age 4) and field (age 9), only the combined site was correlated with the field. Regarding the possibility of selection in these different environments when heritability is low, it is concluded that:

● selection in natural stands is ineffective if based on such simple comparisons of growth as applied here; a more effective method could be selection on the basis of the general regression of height over age in the same stand, whereby the selected tree should be one or two standard deviations above the mean at a given age, or by some other similar method (van Buijtenen 1969, Morgenstern *et al.* 1974); however, all of these methods will prove to be time consuming and costly;

● selection based upon experiments, where spacing and age are controlled, and populations are replicated over a range of environments, is more promising.

Selection of the best progenies

When selection is carried out, a significant rank correlation leads one to expect that some of the best progenies selected in different environments will be the same. However, if only a small percentage is selected, a very high rank correlation is needed before some of the same progenies will be selected in different environments. This is seen in Table 3. For example, if the tallest 5 progenies (25% of the population) are selected on the moist and combined nursery site, the order is number 8, 4, 6, 11, 14 on the moist site and 8, 11, 4, 10, 20 on the combined site. Therefore, only 3 out of 5 progenies, namely 8, 4 and 11, would be selected on both sites.

For selection at the same age, i.e. in the nursery, the results are summarized below:

Percent selected	Sites compared	Number of same progenies
25	Moist and combined	3
25	Dry and combined	4
50	Moist and combined	8

For selection at different ages, i.e. in the nursery at age 4 and field at age 9, the corresponding figures are:

Percent selected	Sites compared	Number of same progenies
25	Combined & Field	1
50	Combined & Field	8

Thus, if only the first 5 or fewer of the 20 progenies are selected, i.e. 25% or less of the population, only a fraction of the progenies selected in different environments is the same. If the first 10 are selected (50%), there is more overlap but a final selection of a percentage as large as this would be unusual since it would lead to a very small improvement. Secondly, as expected, the selection at different ages again decreases the likelihood of selecting identical progenies, for only one of the first 5 progenies selected on the combined site would also have been selected in the field. Therefore, early selection does not appear to offer an easy solution to the selection problem in this

TABLE 1. The rank order of 20 female parent trees in their natural stands^a based on mean annual increment and of their progenies on three nursery sites (age 4 years) and on a field site (age 9) based on total height

Parent no.	RANK ORDER				
	Nursery site				Field site
	Natural stand	Dry	Moist	Combined	
1	8	10	19	16	14
2	14	9	15	12	12
3	3	19	11	18	15
4	13	8	2	3	6
5	11	7	17	13	19
6	18	12	3	6	10
7	6	6	16	11	4
8	4	1	1	1	11
9	10	18	18	20	17
10	7	2	14	4	5
11	9	4	4	2	7
12	15	14	20	19	20
13	5	20	6	17	18
14	17	16	5	8	1
15	12	5	12	7	2
16	16	15	7	10	13
17	19	13	10	14	16
18	2	11	9	9	8
19	1	17	8	15	3
20	20	3	13	5	9
Range cm	21-41/yr	55-80	65-85	64-82	170-216
Mean cm	32/yr	67	75	71	193

^aFor the natural stand, ranking is based upon the percentage of growth of each parent in relation to stand mean growth.

TABLE 2. Rank correlation coefficients^a of parental and progeny height growth in five environments

Environment	1	2	3	4	5
1/Female parents in natural stands	—	+3.0	-.07	-.15	+1.0
2/Progeny, moist nursery site		—	+.02	+.61**	+.38
3/Progeny, dry nursery site			—	+.76**	+.37
4/Progeny, dry & moist combined				—	+.62**
5/Progeny, field site					—

^aSignificance level: **, 1%.

TABLE 3. The best five and best 10 progenies (progeny numbers in italics) in each environment and their height

Total height in cm ^a				
Dry	Moist	Dry & moist combined	Field	
8 80	8 85	8 82	14	216
10 76	4 82	11 77	15	211
20 74	6 82	4 76	19	204
11 73	11 81	10 74	7	202
15 72	14 80	20 74	10	200
7 70	13 78	6 73	4	199
5 70	16 78	15 73	11	197
4 69	19 77	14 72	18	196
2 68	18 77	18 71	20	195
1 68	17 76	16 71	6	195

^aRounded off to the nearest cm.

species. Its value may lie primarily in the possibility of reducing population size for subsequent planting into long-term field tests.

That the results of this study are not unusual has been shown by studies in other species. For example, a study by Snyder (1969) conducted with longleaf pine (*Pinus palustris* Mill.) in Mississippi indicated that comparison trees proved ineffective as an aid to phenotypic selection of parent trees in the forest in spite of little competition in the open-grown stands. Mean annual height growth of parents was the principal variable involved in realizing a gain for height of 12% through phenotypic selection in the forest. However, gain from selection in progeny tests was 35%, i.e. almost 3 times larger. Here again selection in replicated tests has been much more effective than selection in the wild.

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