
ABSTRACT.--Open-pollinated progeny of mass-selected and average balsam fir (Abies balsamea (L.) Mill.), growing in half-sib progeny test plantations in Vermont and Maine, were evaluated for genetic variation in growth rate and branching characteristics. Family variation in height, terminal shoot length, number of branches per whorl and number of internodal buds per unit of terminal shoot is substantial and considerable improvement in the growth and quality of balsam fir Christmas trees can be expected through family selection. Although the family x plantation component was significant for height, most of the fast-growing families in the Vermont plantation also grew fast in the Maine plantation. Family rankings for the number of internodal buds was remarkably consistent over the two plantations. Progeny height and terminal shoot length, whether considered at individual plantations or by combined family averages over both plantations, were unrelated to parental growth rate. In fact, correlations between parental and progeny growth rate were either negative or approached zero. Furthermore, the mean height of progeny from average trees was equal to or exceeded the mean height progeny from trees that were phenotypically-selected for rapid growth. As practiced in this study, mass selection for growth rate was ineffective.

INTRODUCTION

Balsam fir (Abies balsamea (L.) Mill.) is a major component of northern forest regions of North America. It is frequently harvested for pulpwood and is the most commonly used Christmas tree species in New England and eastern Canada. Genetics research in balsam fir has focused primarily on its taxonomic affiliation with related species and the nature and extent of intraspecific geographic variation. Rangewide provenance tests of balsam fir in the Lake States and New England have revealed considerable genetic variation in growth rate, leafing-out phenology (Lester et al., 1976a; Lowe et al., 1977), insect susceptibility (DeHayes, 1981), wood properties (Dery and DeHayes, 1981) and the concentrations of foliar monoterpenes (Lester, 1974). Few studies have quantified the extent or

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replications. The Dover-Foxcroft, ME (D-F,ME) plantation, established with seedlings from the Greenbush, ME nursery, includes 17 families from New England and 10 replications. The Veazie, ME (V,ME) plantation contains only eight families and 4 replications. Most families included in the Maine plantations were also represented in the Vermont plantation.

Height and terminal shoot length were measured in the Lake Willoughby, VT plantation at age 11 years from seed and in the two Maine plantations at age 9 years. In addition, the number of internodal buds per centimeter of terminal shoot was computed at LW,VT and V,ME. The number of branches in the upper-most whorl was also recorded in the LW,VT plantation. At time of measurement, all plantations appeared vigorous and survival in each exceeded 98%.

Plot means for each trait and plantation were subjected to analysis of variance to determine the significance of differences among half-sib families. Family, plantation and family x plantation variance components were also computed for multi-plantation data. Correlation and/or linear regression analyses, using family means as observations, were used to ascertain the relationship between parental and progeny growth rates and the consistency of family performance in different plantations.

RESULTS

Family Variation

Growth rate. Family variation in height and terminal shoot length was large and highly significant at Lake Willoughby, VT and Dover-Foxcroft, ME plantations, but relatively unimportant at the small planting in Veazie, ME. At LW,VT and D-F,ME plantations, there was a 30 to 40% difference in height between extreme families and about one-third of the total variance was attributed to differences among half-sib families (Table 1). Family mean height was strongly correlated with mean terminal shoot length ($r = 0.772$ and $r = 0.800$, $P < .01$) at LW,VT and D-F,ME suggesting that tall families are continuing to grow at a rapid rate. Terminal shoot length also varied significantly among families at the V,ME plantation, but was uncorrelated with family mean height and indicative of a change in relative growth rate with age. Although selected parents were derived from a broad geographic area, there was no apparent relationship between family growth rate and geographic location of parent tree.

When variation in height was examined through combined analysis over the LW,VT and D-F,ME plantations, the family component of variance remained significant but was surpassed in importance by family x plantation interaction (Table 2). This interaction, however, is slightly inflated because it also includes a component attributable to family x age. The interaction is further exemplified by the relatively low and non-significant correlation ($r = 0.389$) among family means from the two plantations.

Table 1. Family variation in height, number of internodal buds per unit of terminal shoot and number of branches per whorl in balsam fir half-sib progeny test plantations located in Lake Willoughby, Vermont (LW,VT), Dover-Foxcroft, Maine (D-F,ME), and Veazie, Maine (V,ME).

Trait	Plantation	No. of families	Age	Mean	Family	
					Range % of mean	Variance % of total
Height	LW,VT	41	11	226 cm	78-115	31**
	D-F,ME	17	9	157 cm	84-113	29**
	VE,ME	8	9	134 cm	86-107	ONS
No. branches/whorl	LW,VT	41	11	4.86	89-117	8**
No. buds/cm	LW,VT	41	11	.38	67-136	37**
	VE,ME	8	9	.60	80-129	39**

Note: **, significant at 1% level
NS, non-significant

Despite the significance of the interaction and the relatively low family mean correlation between plantations, most of the fast-growing families in the LW,VT plantation also grew fast in D-F,ME (Table 3). In fact, if only those families in common to both plantations are considered, selection of the four fastest-growing families at LW,VT resulted in trees 9.3% taller than average at both plantations. The significant interaction appears to have resulted largely from the inconsistent performance of families 189 and 148, which were relatively fast-growing at D-F,ME and slow-growing at LW,VT, and families 187 and 182, which showed the reverse pattern (Table 3).

Branching characteristics. Family variation in the number of branches in the uppermost whorl and the number of internodal buds per cm of terminal shoot was significant in all measured plantations. Trees at LW,VT, averaged 4.86 branches per whorl and family means ranged from 4.3 to 5.7 branches per whorl. Although family variation in this trait was highly significant, it accounted for a relatively low proportion of the total variance (Table 1). Family mean number of branches per whorl showed a weak, but significant positive correlation ($r = 0.334$, $p < .05$) with family mean height. Thus, it seems possible that family selection for rapid growth rate may be accompanied by a slight increase in number of branches.

Family variation in number of internodal buds per cm of terminal shoot was greater than any other trait measured at both the LW,VT and V,ME plantations. There was a difference of 50 to 70% between extreme families and nearly 40% of the total variance could be attributed to differences among half-sib families (Table 1). Furthermore, since there is no apparent relationship ($r = 0.027$) between family means for this trait and height, it appears possible to practice family selection for growth rate and number of internodal buds simultaneously.

Table 2. Multi-plantation analysis of variance and family mean correlation of height (Lake Willoughby and Dover-Foxcroft plantations) and number of internodal buds per unit of terminal shoot (Lake Willoughby and Veazie plantations) from a balsam fir half-sib progeny test.

<u>Trait</u>	<u>No. of Families</u>	<u>Family</u>	<u>Variance Component</u>		<u>Family Mean Correlation</u>
			<u>Family x Plantation</u>	<u>Family x Block/Plantation</u>	
			- - - - - % of total variance - - - - -		r - -
Height	15	10**	16**	74	0.389NS
Buds/cm	7	75**	4*	21	0.750*

Note: **, significant at 1% level
 *, significant at 5% level
 NS, non-significant

Table 3. Relative height of open-pollinated progeny from mass-selected balsam fir in a half-sib progeny test planted in Vermont (age 11) and Maine (age 9).

UVM#	Origin	Relative Height of Families Planted at:	
		Lake Willoughby, VT Age 11	Dover-Foxcroft, ME Age 9
146	VT	115	113
166	NS	114	
160	ME	112	
172	NS	109	
162	ME	108	
178	ME	107	107
150	NH	107	108
169	NS	106	
154	VT	104	109
151	NH	103	102
163	ME	102	107
187	ME	104	91
182	NH	104	95
181	ME	101	95
188	ME	100	91
148	NH	96	106
189	ME	95	108
185	NH	92	100
Actual iE (cm)		226	157

Although only seven families were in common to both the LW,VT and V,ME plantations, the consistency of family rankings in number of internodal buds over the two plantations was remarkable ($r = 0.75$, $P < .05$). When variation in number of internodal buds was assessed on a multi-plantation basis, 75% of the total variance was attributed to differences among half-sib families and only 4% to family x plantation interaction (Table 2). Clearly, number of internodal buds is a highly heritable trait and, therefore, improvement in this trait would be expected to proceed rapidly with family selection.

Effectiveness of Mass Selection

Although progeny tests of mass-selected parents are frequently evaluated for magnitude of family variation, it is relatively uncommon that the actual effectiveness of phenotypic selection is assessed. In this study, parental height and age were recorded for most selected trees and some non-selected controls were included so the effectiveness of mass selection can be assessed.

DISCUSSION AND CONCLUSIONS

Genetic variation in growth rate and branching characteristics in balsam fir is substantial and, despite statistically significant interactions between family and environment, considerable improvement in the growth and quality of balsam fir Christmas trees can be expected through family selection. In fact, it seems possible to shorten Christmas tree rotations by 1 to 2 years through family selection for growth rate, while simultaneously improving form by selecting for a large number of internodal buds and branches per whorl. Without the necessary information on age-age growth correlations, it is not yet possible to project the effectiveness or impact of family selection for growth rate through a pulpwood rotation. Also, since components of genetic variation attributable to stand and family-within-stand could not be separated in this study, it is not possible to contrast the relative merits of family vs. stand and family selection. However, if data on the distribution of genetic variation in balsam fir from the Lake States (Lester, et al., 1976b) are applicable to New England, it would appear that a considerable proportion of the family variation observed in this study may actually be attributed to stand of origin. Studies currently underway will quantify the distribution of genetic variation in balsam fir from New England.

The low parent-progeny growth rate correlations and lack of differences in growth rate between progeny of selected and average parents clearly indicate that mass selection for growth rate in balsam fir was ineffective. Similar results have been reported for white spruce (*Picea glauca* [Moench.] Voss) (Khalil, 1975; Ying and Morgenstern, 1979) and black spruce (*Picea mariana* [Mill.] B.S.P.) (Morgenstern, 1974), which are common associates of balsam fir in northern forest regions.

Although there is considerable genetic variation in growth rate among balsam fir trees, it is apparently not possible to identify genetically fast-growing trees in the wild even with adjustments for age (Snyder, 1969) and corrections for the stand environment via the comparison-tree selection method (Morgenstern et al., 1975). Whether the ineffectiveness is due to the selection procedures or criteria employed, the structure of balsam fir populations, or a substantial environmental influence on parental growth rate is not known. Ledig (1974) has noted that if comparison and candidate trees are related, the effectiveness of comparison-tree selection may be reduced. Although the familial relationship between comparison and candidate trees in this study is obviously not known, there was nearly a 300% difference in mean annual increment between extreme parental selections which was not reflected in growth rate of the progeny and, therefore, must be attributed to environmental influences. Although more sophisticated selection procedures may somewhat improve the efficiency of mass selection, it doesn't appear that the selection method per se was responsible for the ineffectiveness of selection noted in this study. Despite uncertainty with regard to selection methods, results of this study clearly indicate that casual ocular selection for growth rate among balsam fir trees in the wild, as is commonly practiced by many Christmas tree growers and nurserymen, will not result in the production of fast-growing progeny. In addition, a mass selection method' that might be expected to improve the efficiency of selection for growth rate in balsam fir is likely to be time-consuming and costly.

