Forest Science, Vol. 33, No. 2, pp. 577–582.

Early Genetic Evaluation of Open-Pollinated Douglas-Fir Families

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ABSTRACT. In a test of early genetic evaluation of the growth potential of 14 families of open-pollinated Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), measures of growth and phenology of seedlings grown in a coldframe were correlated with height of saplings in evaluation plantations at 9, 12, and 15 years. Fifteen-year height was most strongly correlated with measures of seedling budset ($r = -0.57$), height ($r = 0.54$), and branchiness ($r = -0.53$). Seedling growth and phenology values generally were poorly correlated with seed weight; however, seedling-sapling correlations were related to seedling-seed weight correlations. Seedling-sapling correlations improved with sapling age from 9 to 15 years. FOR. SCI. 33(2):577–582.

ADDITIONAL KEY WORDS. *Pseudotsuga menziesii*, juvenile-mature correlation, tree improvement, seed weight.

EARLY GENETIC EVALUATION OF SEEDLINGS would aid tree breeding by reducing generation time and allowing screening of large numbers of genotypes. Previous tests of early evaluation include nursery-bed selection (Bengston 1963, LaFarge 1975, Snyder 1976) and selection in several seedling test environments (Cannell et al. 1978, Waxler and van Buijtenen 1981, Lambeth et al. 1982). Testing along environmental gradients is advantageous when genotype by environment interactions affect field performance of selected genotypes—especially when the gradients can be approximated in test environments (Cannell et al. 1978). Some test environments magnify genetic differences (Campbell and Sorenson 1978), making them easier to detect and to correlate with field performance.

Cannell et al. (1978) found that 8-year volume of families of loblolly pine (*Pinus taeda* L.) correlated positively with their growth rates as seedlings. Production on droughty sites correlated better with values for seedlings in droughty test environments, and the shoot-root ratio was negatively correlated with field performance. In contrast, Waxler and van Buijtenen (1981) found that the shoot-root ratio correlated positively with long-term field performance of loblolly pine families. Lambeth et al. (1982) reported that total dry weight of Douglas-fir seedlings correlated positively with 6-year field height. Cannell et al. (1978), exploring phenological evaluation criteria, found no significant correlations between budset and field production.

This paper summarizes the results of a test of early genetic evaluation of 14 open-pollinated Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) families from a northwest Oregon breeding zone. Seedlings were assessed for genetic variation in growth, phenology, and responses to shade and drought stresses. Mean values for seedling growth and phenology of a given family were then correlated with mean height of 9-, 12-, and 15-year-old trees of an earlier seed crop grown in five plantations.

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Methods

In 1969, the Vernonia Tree Improvement Cooperative (Silen and Wheat 1979, Silen and Mandel 1983) established test plantations to evaluate Douglas-fir families from northwest Oregon. Wind-pollinated seeds collected in the wild in 1966 were planted in 12 plantations, and tree heights were measured at 9, 12, and 15 years. We obtained wind-pollinated seeds from 14 of the original parent trees in 1981. The 14 parents were selected (from those having seed available) to span the range of 15-year progeny heights. Progeny arising from the parent trees are referred to hereafter as "families."

Fifty filled seeds from each parent tree were individually weighed. On April 10, 1982 (age 0 days), after all seeds had been soaked in distilled water and stratified, they were sown into 165 cc plastic tubes (2 to 3 per tube) with a peat and fine-sand rooting medium. The tubes were kept in a controlled-environment chamber during a 29-day germination period, then thinned to one healthy seedling per tube. Tubes were then removed to an outdoor fiberglass-covered coldframe at the Forest Research Laboratory, Oregon State University, Corvallis.

The tubes were watered every 2 to 3 days until budset, unless experimental protocol dictated otherwise. A complete fertilizer was applied biweekly until budset, and a 0-10-10 fertilizer twice after budset. Mortality was 4% during the first growing season (mainly due to mechanical damage and damping off) and 30% over the winter. Budburst was induced in a heated glasshouse.

Three experiments were designed. Experiment I, for determining dates of budset among families, consisted of four replications of four seedlings per family in a randomized block design. Experiment II, for determining dates of budburst among families, was a completely random sample of 8 to 15 seedlings per family. Experiment III consisted of five replications of a split-plot design with four treatments (main plots) and 14 families (subplots) of three seedlings each. (Mortality reduced the latter to a harmonic mean of 2.9 per subplot.) Experiment III treatments, in a factorial combination of shade (yes-no) and drought (yes-no), were applied at 85 days. Ambient coldframe lighting under a fiberglass roof was 50% of full sun, which the shade treatment reduced to 15%. Drought was imposed by withholding water during two 6-day periods in the month preceding budset and during the period from completion of budset until seedlings were harvested. Families were considered to be random effects and treatments to be fixed for the analysis of variance.

Budset, the first observation of brown terminal budscales, was scored in Experiment I at 117 and 126 days, and budburst, the first observation of green needles in terminal buds, was scored in Experiment II at 285 and 292 days. A chi-square statistic was used to test percentage data in both experiments (blocks were ignored in Experiment I). In Experiment III, subplot means were analyzed for the following: height (epicotyl length to the base of emerging primary needles or terminal bud at 169 days), basal area (computed from the average of two subcotyledon stem measurements at 170 days), etiolation index (ratio of height to basal area), branching index (ratio of the number of branches plus buds to height at 169 days; three replications only), height growth rate (from 85 days to 169 days), basal area growth rate (from 115 days to 170 days), total dry weight (180–182 days), and shoot to root dry-weight ratio (180–182 days). For dry-weight determinations, seedling components were individually oven-dried and weighed.

After removing data for dead or damaged trees from evaluation-plantation records, we rejected seven plantations because there were too few trees for some families. For each of the five planatations retained, we obtained an average 7.6 trees (range 3–11) per family. Nine-year height measurements were available for three of the plantations and 12- and 15-year height measurements for all five. Because family-by-plantation interactions were not significant by Tukey's test of nonadditivity (e.g., Steel and Torrie 1980, p. 372), plantations were equally weighted for computation of overall family mean height at each of the three measurement ages.

Results and Discussion

Family means obtained in the experiments and from field plantations are shown in Table 1. (Statistical analyses are not shown but are summarized here; see also

TABLE 1. *Means and correlations of Douglas-fir families in field plantations and seedling experiments.*

Family	Mean seed weight[a] (mg)	Field-plantation data: Number of trees	Mean height (cm)[b] 9 yr	12 yr	15 yr	Experiment I, % budset at day— 117	126	Experiment II, % budburst at day— 285	292	Experiment III[c] Height (cm)	Basal area (mm^2)	Height growth (cm/cm)	Basal area growth (mm^2/mm^2)	Dry weight (g)	Shoot-root ratio (g/g)	Etiolation index (cm/mm^2)	Branch index (no./cm)
1	12.2	36	213	439	706	20	60	8	25	10.0	2.07	2.42	1.82	0.94	1.27	5.14	1.07
2	11.4	35	205	451	742	20	100	10	50	10.5	2.37	2.54	1.76	1.01	1.28	4.62	1.16
3	10.9	39	210	425	691	50	81	8	25	10.2	2.39	2.42	1.84	1.03	1.23	4.47	1.19
4	10.8	37	220	471	761	7	73	36	46	10.3	2.19	2.62	1.89	0.94	1.29	4.90	0.95
5	8.6	44	206	445	716	25	69	31	69	10.0	2.12	2.44	1.82	0.91	1.19	5.04	0.95
6	11.1	40	208	487	767	6	69	18	46	11.2	2.48	2.78	1.91	1.06	1.32	4.72	0.90
7	12.9	46	222	448	726	6	81	39	77	10.7	2.44	2.40	1.63	1.08	1.23	4.68	1.00
8	9.2	42	203	449	726	0	56	25	50	9.9	1.98	2.70	1.79	0.86	1.18	5.25	1.06
9	10.3	39	212	450	729	0	67	31	46	9.8	2.38	2.50	1.80	0.95	1.31	4.32	1.24
10	12.5	35	189	398	684	19	56	13	38	9.3	2.31	2.56	1.77	0.94	1.20	4.19	1.10
11	10.9	31	199	429	724	0	56	13	67	11.1	2.46	2.27	1.86	1.04	1.42	4.67	1.10
12	10.8	34	210	426	716	13	63	15	54	10.4	2.11	2.60	1.77	0.98	1.20	5.21	1.21
13	11.6	32	200	452	744	0	13	36	73	12.6	2.60	2.62	2.00	1.15	1.50	5.08	0.93
14	11.0	39	195	425	708	13	81	17	33	10.2	2.47	2.50	1.89	1.07	1.38	4.31	1.10
Correlation[d] with mean seed weight						0.01	−0.01	−0.17	−0.11	0.19	0.44	−0.16	−0.20	0.50	0.19	−0.33	0.02
Correlation[d] with mean field height: 9 years						0.01	0.32	0.40	0.11	0.03	−0.20	−0.06	−0.32	−0.06	−0.24	0.30	−0.10
12 years						−0.38	0.04	0.48	0.24	0.42	0.07	0.50	0.26	0.11	0.21	0.35	−0.58
15 years						−0.57	−0.06	0.49	0.38	0.54	0.20	0.52	0.32	0.22	0.39	0.30	−0.53

[a] Mean of random samples of 50 seeds per family.
[b] Mean of three plantations for 9-yr height, five plantations for 12-yr and 15-yr height. Plantations equally weighted.
[c] Values averaged over treatments.
[d] With 12 degrees of freedom, correlations of plus or minus 0.46 and 0.53 are significant at $P = 0.10$ and 0.05, respectively.

Riitters 1986). Family differences in budset (Experiment I) were significant ($P < 0.01$) at 117 and 126 days, when overall budset was 13% and 66%, respectively. Among the 70% of seedlings that survived the winter in Experiment II, cold damage may have differentially affected budburst; therefore, family differences in budburst may have been confounded with differences in cold tolerance. Differences in budburst were not significant at 285 or 292 days, when overall budburst was 22% and 48%, respectively. In Experiment III, treatment and family differences were significant ($P < 0.01$) for every variable, but there was virtually no evidence of family-by-treatment interactions. Shade and drought treatments (averaged over families) reduced total dry weight 24% to 45%, illustrating that the treatments imposed rather substantial growth stress. Mean total dry weight of families (averaged over treatments) varied from 0.86 g to 1.15 g, and height from 9.3 cm to 12.6 cm. Because family-by-treatment interactions were not important, family means were averaged over treatments for computation of correlations with the family means from field plantations.

With some exceptions, correlations of seedling variables with field height (Table 1) were low. Highest correlations with 15-year height (significant at $P < 0.05$) were obtained for budset at 117 days ($r = -0.57$), height ($r = 0.54$), and branching index ($r = -0.53$). Two other 15-year correlations were significant ($P < 0.10$): budburst at 285 days and height growth rate. It is interesting that earlier measures of budset and budburst had stronger correlations with field height than later measures (Table 1). Interpretation of this outcome depends, of course, upon within-family variation in budset or budburst date, and that information was not available for this study.

The correlation of field height with the branching index suggests that trees in families that direct more growth to branches than to the leader will be shorter. However, since the field plantations were just achieving crown closure after 15 years, this result was essentially for open-grown trees. Because relative growth rates after crown closure depend on both relative leaf area (partly a function of branchiness) and relative height (Trenbath 1974), correlations with the branching index may change as field competition intensifies. The influence of stand development and crown closure on genetic test results must be considered (Franklin 1979).

The important seedling variables and the magnitude of correlations obtained in this study are not entirely in agreement with the results of Cannell et al. (1978), Waxler and van Buijtenen (1981), or Lambeth et al. (1982); and several seedling variables not previously correlated with field height were found to be significantly correlated. However, direct comparison of study results is difficult owing to differences in species, experimental design, and field plantations.

Although one objective of Experiment III was to improve correlations with field height by recognizing possible family-by-treatment interaction, no such interaction was detected. However, it was also not detected in the field, and correlations based on overall family means in plantations and in Experiment III provided some interesting results. One of the most interesting was the trend toward better correlation of all seedling growth variables with field height as plantation age increased (Table 1). No correlations were significant at 9 years, but by 15 years, five correlations attained significance ($P < 0.10$). Correlations of basal area growth rate and shoot-root ratio with field height changed by more than 0.6 units from age 9 to 15 years. At 9 years, 7 of the 12 seedling variables had illogical signs of correlation; at 15 years, all signs were logical. It may be that correlations will improve further with increasing plantation age.

Other researchers have found that juvenile-mature correlations usually worsen rather than improve as age difference increases (Namkoong et al. 1972, Namkoong and Conkle 1976, Lambeth 1980). However, results in this study are for different seed crops rather than for the same trees, as in earlier studies. In addition, correlations in some of the previous studies were computed across different stages of stand development as well as across age, whereas correlations in this study are essentially for open-grown seedlings and trees. The trend obtained here might therefore be attributed to the diminishing effect of a differential response of plantation trees to early cultural treatments (Dalmacio 1982). The trees had been mowed twice in the nursery because of constraints imposed by the cooperative (R. R. Silen, personal communication)—and other interactions that would account for the results can be hypothesized.

A second interesting result in this study is the relationship of seedling-field height correlations at 15 years to seedling-seed weight correlations. Except for values for the second budset, higher absolute values for the seedling-seed weight correlation are associated with lower absolute values for the seedling-field height correlation (Figure 1). It is unclear why the second budset measurement did not follow this trend, or why any phenology measure should. Although most seedling-seed weight correlations are not significant in this study, it appears that correlations with seed weight may have been strong enough to mask seedling-field height correlations. Inasmuch as potentially useful early evaluation criteria may emerge as seed-weight effects diminish or are accounted for by future studies, the practice of accepting or rejecting evaluation criteria on the basis of simple tests of their correlation with seed weight should be questioned.

Possible explanations for the generally poor correlations between field heights and seedling traits in this study are that relatively large experimental error may have made field rankings unreliable, or that different seed lots used in field and seedling tests may have been sources of error. Some of these influences could be overcome by different experimental design.

At best, early genetic evaluation requires refinement, but further testing appears warranted. This study identified measures of seedling budset, height, and branchiness that correlated well with height of 15-year-old half-siblings, and the effects of seed weight and plantation age were important in explaining some unexpected relationships.

As these results are based on plantation records from which data for dead and obviously damaged trees had been removed, survival and growth rate on adverse sites cannot be predicted. Selection based on the criteria identified in this study could favor genotypes adapted to the wettest and mildest sites in the breeding zone. The choice of criteria for early evaluation should depend on the strategy for deployment of selected material.

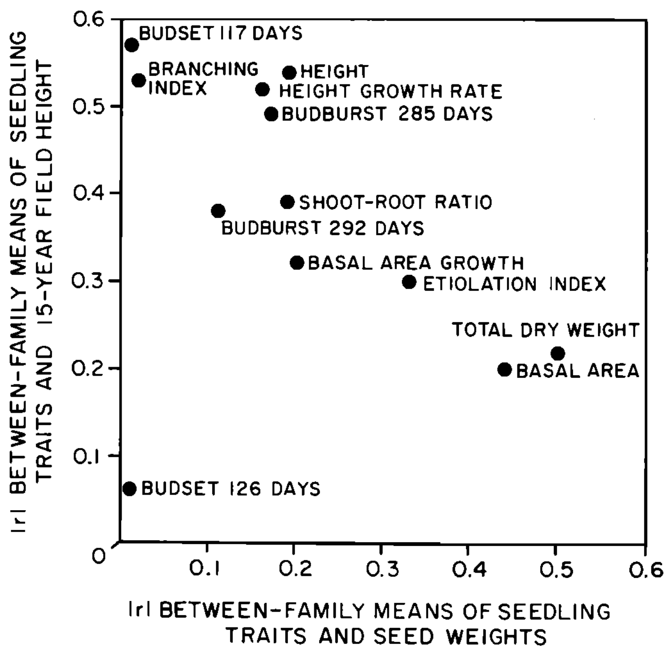

FIGURE 1. The relationship between seedling trait-field height correlations and seedling trait-seed weight correlations for 14 Douglas-fir families.

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