EARLY FAMILY EVALUATION FOR GROWTH OF LOBLOLLY PINE

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ABSTRACT

Mean total family heights after two years in close-spaced early genetic evaluation trials are a useful tool for identifying slower-growing loblolly pine half-sib families in the southeastern United States. Culling the poorest 30% of families based on juvenile heights increased the expected average Performance Level (a standardized score) for total height of older siblings by 0.3 to 0.5 standard deviations. There were no "Type A" errors among 38 families from three provenances. Type A errors result when families are culled on the basis of poor juvenile performance, but have good mature performance. Two families were "Type B" errors. Type B errors result when families are not culled at the juvenile stage, but do not perform well in older trials. Type B errors are not as important as Type A errors because Type B errors will be revealed in subsequent long-term field tests. Culling half-sib families based on total height growth after two years in close-spaced tests will reduce the the numbers of families that must be included in long-term genetic tests. Early genetic evaluation of polymix parents also makes it possible to do positive assortative matings earlier in programs planning complementary mating schemes.

Keywords: early genetic evaluation, juvenile-mature correlation, genetic testing, complementary mating, positive assortative mating, *Pinus taeda.*

INTRODUCTION

Since breeding and testing trees in traditional, long-term tree improvement programs are very expensive, the ability to cull poor families before they enter breeding populations may be valuable. Early evaluation trials may also make it possible to do positive assortative matings earlier. For breeders to use early selection as a screening tool, a reliable and repeatable early selection method is required.

Stem elongation in first- and second-year loblolly pine (*Pinus taeda* L.) seedlings has reliably predicted 8–12 year field performance in eastern North Carolina (NC) and South Carolina (SC) provenances (WILLIAMS 1987; BRIDGWATER 1990; LI *et al.* 1989 & 1992). While other juvenile traits have been evaluated, stem elongation appears to be the most reliable and most easily assessed trait for early selection of loblolly pine in the southeastern United States. However, total stem dry weight at 4-6 months was a better predictor of the growth of older siblings for loblolly pine populations from west of the Mississippi River (LOWE & VAN BUIJTENEN 1989; BYRAM & LOWE 1995). Dry weights have not been good predictors of field performance of older siblings in studies of the NC provenance (WILLIAMS 1987; LI *et al.* 1992). Preliminary results from the same study presented herein suggested that the utility of juvenile stem elongation for predicting sibling growth after five years in the field differed among provenances (MCKEAND & BRIDGWATER 1993). Stem elongation after two years in the field was most strongly related to the fifth-year heights of half-sibs in the Atlantic Coastal Plain, Middle-Upper Gulf, and Marion County Florida regions. Stem elongation was only weakly related in populations from the Lower Gulf and Gulf Hammock, Florida regions. These preliminary results were not considered to be definitive since juvenile-mature family mean correlations continue to increase after age five (LAMBETH *et al.* 1983; MCKEAND 1988; BALOCCHI *et al.* 1994).

The objective of the study was to evaluate the use of stem elongation traits as a method of early selection for families from five provenances of loblolly pine.

MATERIALS AND METHODS

Older Trials

The older half-sibs from the Atlantic Coastal (ACP), Marion County (MC), Gulf Hammock (GH), and Lower Gulf (LG) provenances were planted in a series of six tests established in 1982 and 1983 by members of the University of Florida Cooperative Forest Genetics Research Program and the North Carolina State University – Industry Cooperative Tree Improvement Program ANONYMOUS 1988). The Middle-Upper Gulf

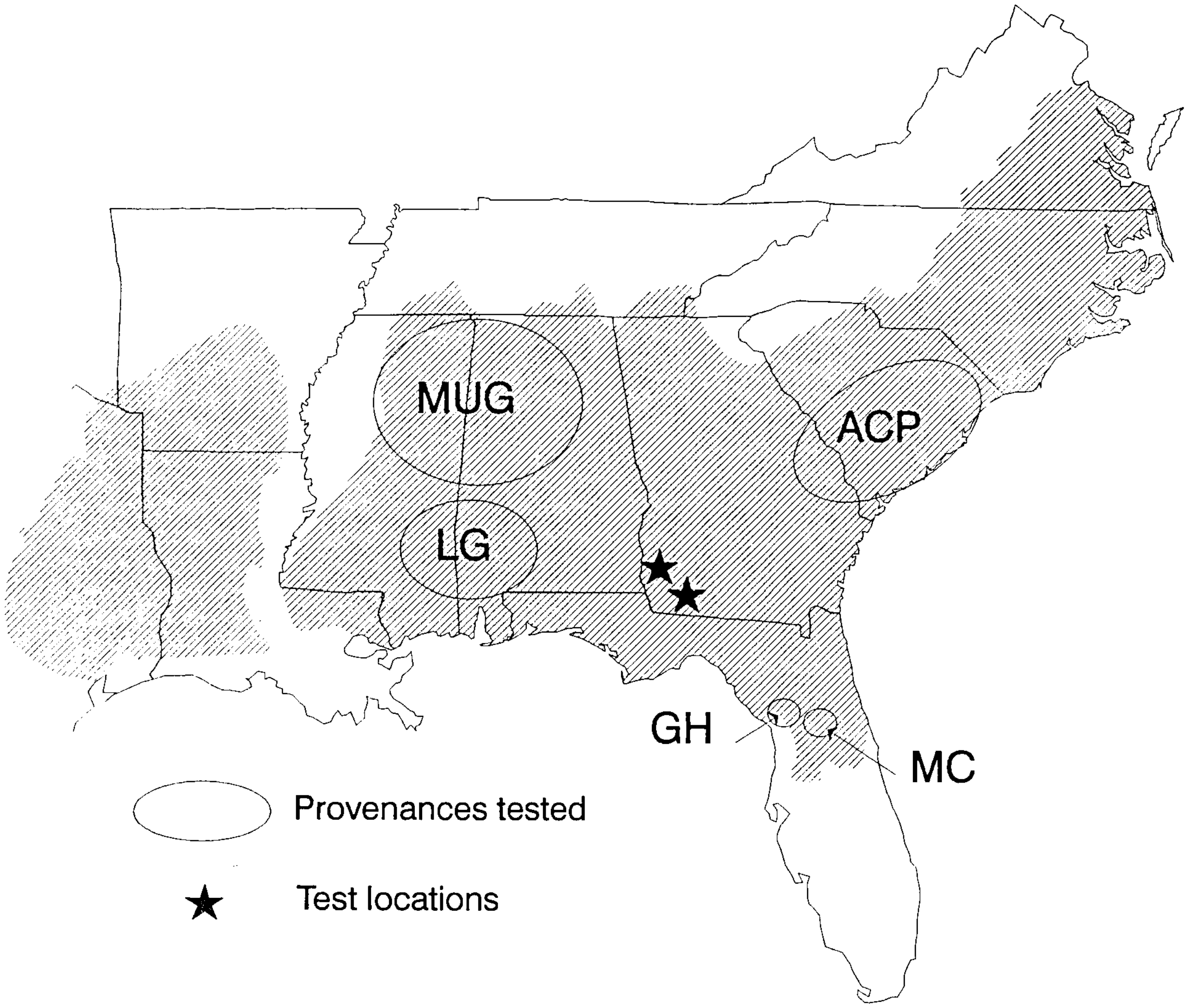


Figure 1. Geographic location of: the five provenances sampled, the two juvenile field study sites, and the nine older field study sites. Provenances are: MUG = Middle-Upper Gulf; LG = Lower Gulf; ACP = Atlantic Coastal Plain; GH = Gulf Hammock, FL; MC = Marion County, FL; The shaded region is the natural range of loblolly pine.

(MUG) families had been planted as series of three trials in central Alabama and Georgia in 1984 (ANONYMOUS 1990) (Figure 1). Tenth-year heights were measured for all tests except the MUG families for which final measurements were taken after year 6 (one trial) or year 7 (two trials).

Early genetic evaluation trials require precise measurements of both the juvenile and mature traits. If differences among older siblings are not clear, little confidence should be had in juvenile-mature correlations generated using these data. The converse is also true, but obtaining precisely estimated mature data is more problematical because many environmental factors can decrease the precision of estimates over several years in field trials.

Therefore, the data for each provenance were analyzed separately for each test location in the study. Only those trials which had significant differences ($P \leq 0.05$) in total heights among families were used to calculate standardized scores called Performance Levels (PLs) (after HATCHER *et al.* 1981). PLs were calculated for each test then averaged over tests to ameliorate the effects of imbalance and unequal variances among families in the older trials.

Younger Trials

Open-pollinated seeds of 13 to 16 families from each of the five provenances represented in the older trials were sown in a greenhouse in Raleigh, North Carolina, (35°47' N, 78°42' W) in early November, 1988. Seedlings were grown in RL Super Cells® (164 cc) until they were outplanted March 13-15, 1989, near Georgia-Pacific's (G-P) nursery at Cedar Springs, Georgia, (31°10' N, 85°3'

W) and at International Paper Company's (IPCo) Southlands Experiment Forest near Bainbridge, Georgia, (30°54' N, 84°36' W) (Figure 1). The G-P test site was on an Orangeburg loamy sand soil on a seed orchard site. The IPCo site was a Norfolk B soil. A randomized complete block design with 36 blocks of single-tree plots of 72 families was used at each location. The trees were planted at a spacing of 1.3m × 1m at G-P and 1m × 1m at IPCo to minimize block sizes. Different spacings were used to accommodate different test maintainance procedures used by G-P and IPCo. The different spacings should have had no differential effect on the results as it has been demonstrated that competition among loblolly pine seedlings does not significantly affect genetic expression until after age two at 1m ×' 1m spacing (FRANKLIN 1979 & 1989). No cultural treatments were imposed on the trees except that tip moths (*Rhyacionia* sp.) were controlled with periodic insecticide applications, and competing vegetation was controlled with periodic herbicide applications.

After the first growing season, height to the end of the free growth cycle and total stem height were measured. Free growth is that growth that occurs from hypocotyl emergence to the first terminal bud (SWEET & BOLLMANN 1976). A cycle is commonly referred to as a flush in reference to stem growth. After two growing seasons, total height was measured, and the lengths for first- (excluding free growth) and second-season elongations were calculated. The number of growth cycles or flushes was counted after both growing seasons.

Analyses of variance for all variables were performed using the GLM procedure in SAS (SAS INSTITUTE INC., 1985). A two-way analysis of variance was conducted for each provenance. Blocks and families were considered to be random effects. The form of the analysis of variance was as given in Table below.

The younger trials had very high survival (97%) and were of equal precision, thus least squares means (GLM procedure in SAS) were calculated for families in each provenance across the two planting sites and variance components were estimated using the VARCOMP procedure (Type I sums of squares) in SAS (SAS INSTITUTE INC. 1985). Genetic and environmental components of variance were estimated for each provenance separately. The variance among open-pollinated families within each provenance was assumed to estimate 1/4 the additive genetic variance (FALCONER 1989), and family-mean heritabilities for each provenance were calculated as:

$$h_F^2 = \frac{\sigma_F^2}{\sigma_F^2 + \frac{\sigma_{FxL}^2}{l} + \frac{\sigma_{B(L)xF}^2}{lb}}$$

where: σ^2_F = variance among families, σ^2_{FxL} = variance due to family by location interaction, σ^2 = variance among trees within families within location, l and b = the numbers of locations and blocks, respectively.

Family mean (product-moment) correlations between variables measured in the early selection trial and the older field trials were calculated for each provenance. Family mean correlations are usually conservative estimates of genetic correlations. If environments are not correlated, the estimates are the same.

Different stem elongation traits in the juvenile trials were compared for their potential in predicting the performance of half-sibs in the older trials using the product:

$$h_J \cdot r_{J,M}$$

where: h_J = the family-mean heritability for the juvenile trait, $r_{J,M}$ = the product-moment correlation between the family mean for the juvenile trait and the PL for height in the older trials.

This product is part of the equation to estimate correlated response to selection (FALCONER 1989) and is appropriate to discriminate among juvenile traits in our experiment (MCKEAND & BRIDGWATER 1993).

The values for the juvenile trait(s) with the highest

Source	d.f.	EMS
Location	$l-1$	
Block	$l(b-1)$	
Family	$f-1$	$\sigma^2_{B(L)xF} + b.\sigma^2_{LxF} + l.b.\sigma^2_f$
Location × Family	$(l-1)(f-1)$	$\sigma^2_{B(L)xF} + b.\sigma^2_{LxF}$
Block (Location) × Family	$l(b-1)(f-1)$	$\sigma^2_{B(L)xF}$
Total	$(lbf-1)$	

average product, $(h_J.r_{JM})$ over provenances were regressed on PLs for family mean heights.

RESULTS

Total heights for the Gulf Hammock and the Lower Gulf families were not statistically different at any test location. Thus, these provenances were not included in the juvenile-mature analysis. The eleven families from the ACP provenance were significantly different at $P < 0.02$ at four locations; and the fourteen families from the MC provenance were significantly different at $P < 0.04$ at three locations and at $P < 0.08$ at a fourth location. The thirteen families in the MUG provenance were statistically different at $P < 0.0003$ at all three test locations in that trial.

Standardized scores (PLs) were calculated for total heights using only the data from tests which had significant differences among families for the ACP, MC, and MUG provenances. Breeding values were also estimated using best linear unbiased prediction (BLUP) to see if differential weighting of the mature trials would be an improvement over PLs. Breeding values and PLs ranked all 38 families the same and gave the same family mean correlations to the second decimal place. Pls were used in the following discussion to facilitate gain predictions from family culling.

The potential for predicting the performance of half-sibs in the older trials varied among the juvenile traits (Table 1). The product, $h_J.r_{JM}$, was consistently greatest for all three provenances for the total cyclic growth over two years (Year 0–2) and total height after two years (Year 2). Since it is easier to measure total height, this trait was selected to compare with height PLs of mature siblings. This also agrees with the findings of LI *et al.* (1992). It is interesting to note that the product, $h_J.r_{JM}$, was greater for cyclic growth in the first year and for the number of growth cycles in year 1 for the ACP provenance. Cyclic growth in year 1 (WILLIAMS 1987) and the numbers of cycles in year 1 (LI *et al.* 1992) have been reported to have higher correlations with the performance of older siblings for the ACP provenance than total height growth.

Examination of the juvenile heights at age two and the PLs for height at age 10 reveals that the MC and ACP provenances ranked as expected (Table 2). Since the older data for the MUG provenance came from a separate trial it is not informative to compare it to the other two provenances. However, our interest was to evaluate the efficacy of early genetic evaluation among half-sib families within different provenances.

The regressions of least squares means of family heights at age two on PLs for family height of older siblings was significant for all three provenances. R^2 values for MC, ACP, and MUG provenances were 0.40, 0.62, and 0.44, respectively (Figures 2–4). All three regressions were statistically significant ($P \leq 0.02$). There were no significant Type A errors in any of the three provenances (LOWE & VAN BUIJTENEN 1989). Type A errors occur when older siblings performed well but would be rejected on the basis of the siblings in juvenile tests. Type B errors occurred only in the MUG provenance when two families with good juvenile performance had PLs below 30 (Figure 4).

Table 1. Family means heritabilities , and correlations and the product of the correlations and the square root of the heritabilities

Traits	Family Means Heritabilities (1)			Family Means Correlations (2)			Product (1) x (2)		
	MC	ACP	MUG	MC	ACP	MUG	MC	ACP	MUG
Height (mm)									
Year 1	0.64	0.91	0.94	0.52	0.77	0.58	0.42	0.74	0.56
Year 2	0.75	0.88	0.89	0.63	0.79	0.66	0.55	0.74	0.63
Elongation (mm)									
Free growth	0.82	0.66	0.85	0.01	–0.22	0.46	0.01	–0.18	0.42
Yaer 0–1	0.87	0.88	0.92	0.45	0.81	0.59	0.42	0.76	0.56
Year 1–2	0.74	0.81	0.81	0.50	0.73	0.67	0.43	0.65	0.60
Year 0–2	0.74	0.88	0.87	0.66	0.79	0.68	0.57	0.74	0.63
No of Growth cycles									
Year 1	0.96	0.95	0.95	0.34	0.83	0.62	0.33	0.81	0.61
Year 2	0.74	0.87	0.88	0.05	0.45	0.61	0.04	0.42	0.57

Table 2. Juvenile heights at age 2 (mm) and standardized height scores of older siblings for three provenances of loblolly pine.

Family	MC		ACP		MUG	
	HT2	HTPL	HT2	HTPL	HT2	HTPL
1	249.2	70.7	233.7	75.8	199.7	67.4
2	256.3	61.7	207.4	65.2	199.5	61.7
3	239.9	57.4	208.3	61.6	199.7	58.8
4	244.5	57.3	210.0	60.3	181.5	54.4
5	241.5	55.5	223.7	57.0	170.0	52.1
6	241.0	54.4	214.3	54.0	184.8	51.1
7	231.6	52.4	203.7	52.9	158.9	45.7
8	238.7	50.0	192.2	50.2	158.2	44.8
9	241.7	49.2	210.5	48.8	165.8	43.4
10	236.2	47.1	185.9	34.2	183.9	33.1
11	246.5	46.7	192.6	25.4	157.0	31.0
12	234.3	45.0	.	.	160.9	30.7
13	242.9	42.5	.	.	176.4	25.6
14	232.3	33.1	.	.	.	.
Means	241.2	51.6	207.5	53.2	176.6	46.1

Type B errors are not as important as Type A errors, because Type B errors will be revealed in subsequent field testing of families which had good juvenile performance.

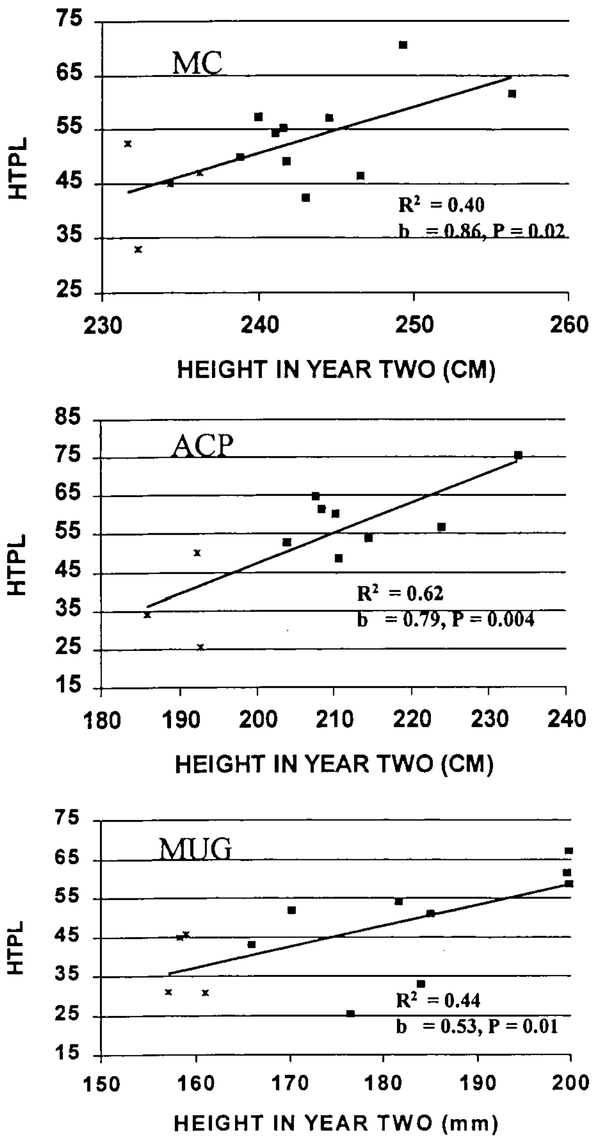
Incremental culling of families based on juvenile performance before establishing field trials has been shown to peak at about 30% (LOWE & VAN BUIJTENEN 1989). Doing so in these populations means that the four shortest families at age two would be culled before planting large field trials in the MC and MUG populations (Figures 2 and 4). The three shortest families would be culled from the ACP population (Figure 3). Culling the shortest 30% of families based on juvenile performance resulted in an increase in the average PL for all three populations (Table 3). PLs are relative scores, thus changes in average PLs are difficult to evaluate. PL values are averages of standardized scores over several blocks in several tests, thus they will always be between 0 and 100. A more meaningful estimate of the gains from culling can be had by rescaling the PLs from 0 to 100 using the range in PLs for each respective provenance as an estimate of the variance among PLs (HATCHER *et al.* 1981). Thus, culling 30% of families based on juvenile height growth increased the average height of the older siblings by 0.31, 0.50, and 0.34 standard deviations for the MC, ACP, and MUG populations, respectively (Table 3).

Table 3. Results from culling the 30% of families with the poorest mean height growth after 2 years.

Provenance	MC	ACP	MUG
Mean Height PL of Older Sibs Before Culling	51.6	53.2	46.1
Mean Height PL of Older Sibs After Culling	54.5	59.5	49.7
Gain from Culling (σ)	0.31	0.50	0.34

SUMMARY AND DISCUSSION

The means of families selected based on two-year heights in closely-spaced trials were greater in older trials. The expected gain from early evaluation was greatest for an Atlantic Coastal Plain (ACP) population where early height growth was previously shown to be a useful tool for early genetic evaluation. Early genetic evaluation based on early height growth was also useful for two other populations, one from Marion County, Florida (MC) and another from the Middle and Upper Gulf Regions of Mississippi, Alabama, and Georgia (MUG).



Figures 2, 3, and 4 The relationship between height at age two and Performance Levels for total height of older siblings (HTPL) for three provenances of loblolly pine. MC is Marion County, Fl, ACP is the coastal plains of SC and GA, and MUG is the upper coastal plains of MS, AL, and GA. * indicates families that would have been culled on the basis of height at age two in the early evaluation trial.

Mean total height growth after two years in field trials was shown to be a useful tool for culling half-sibfamilies before establishing larger, more expensive genetic tests. However, the reduction in cost of long-term field tests requires delaying their establishment for 2–3 years while juvenile tests are conducted. The economic desirability of early evaluation for this use depends on economic factors that are unique to organizations.

Early evaluation trials will permit making crosses among the best parents earlier. The major loblolly pine breeding programs in the southern United States currently plan to test progenies from polymix matings on selected parents in the field for five or six years and make controlled matings only among the best parents (LOWE & VAN BUIJTENEN 1989). The poorer polymix parents could be culled on the basis of two-year height growth and controlled matings could then procede three to four years early.

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