HERITABILITIES AND GAINS IN VOLUME, DIAMETER, AND HEIGHT FOR OPEN-POLLINATED PROGENY OF EASTERN WHITE PINE FROM THE CUMBERLAND MOUNTAINS

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Abstract.--Open-pollinated progeny of 22 white pine selections were analyzed for volume, stem diameter, and total height, and compared with Southern Appalachian commercial check seedlings. The half-sib progeny, age 8 years, averaged 14.5 dm in volume, 7.05 cm in diameter, and 4.67 meters in height while the checks averaged 5.7 dm^3 in volume, 3.73 cm in diameter, and 3.07 meters in height. Family heritabilities of .84, .84, and .68 and individual tree heritabilities of .28, .25, and .24 were calculated for volume, diameter and height respectively. Gains of 43% for volume, 16% for diameter, and 9% for height are reported.

Heavy mortality of eastern white pine (*Pinus strobus*) in the Cumberland Mountains adjacent to the Kingston Tennessee Steam Plant has been attributed to air pollution (Berry and Hepting 1964, Skelly et al. 1972). Most of the mortality occurred during the first years after start-up of the steam plant and has continued at a lower rate since that time.

In 1961, The University of Tennessee forestry personnel searched Morgan County in the proximity of the Kingston Steam Plant for white pine trees that exhibited a high level of resistance to SO_2. Trees selected were also evaluated for vigor, stem straightness, branching habits, and wood quality. The best 35 phenotypically superior trees were grafted into a clonal orchard in the Cumberland Mountains. This 1.6 hectare orchard has yielded large amounts of commercial seed in addition to the small amounts needed for progeny tests.

MATERIALS AND METHODS

Open-pollinated cones were collected and seed extracted in July 1972. Seedlings of 22 of these selected families were grown along with checks from a preferred Southern Appalachian seed source at the state-operated Tennessee nursery at Pinson, during 1973-1974. In February, 1975, they were outplanted at two locations. One location was on the Eastern Highland Rim near Tullahoma. The topography was relatively flat and the soil was a Dixon silt loam with a fragipan at about 46 cm. The second location was near Oak Ridge in the ridge and valley physiographic region. Here the plantation was on a Fullerton cherty silt loan on a south-facing slope. This location, which is about 4.8 kilometers from the Bull Run Steam Plant and about 32 kilometers miles from the Kingston steam plant, is periodically exposed to high levels of SO_2.

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Each test planting was established in a randomized complete block design with 10 replications. Each family was represented in a ten-tree row with 1.22 meters spacing within row and 2.44 meters between rows. Two border rows were established around each test with a mix of seedlings. Control of competitive vegetation was accomplished by mowing.

Measurements of height to the nearest dm, using a pole, and diameter at breast height (1.4 meters) to the nearest 0.5 cm, using calipers, were made during March 1983. Total above-ground volumes (cubic meters) were calculated as 0.0024619 + 0.000046121982 (D^4) Minns 1983) and converted to dm . Analysis of variance was accomplished on an IBM model 370 3031 computer at The University of Tennessee using the General Linear Model (GLM) and nested procedures of the Statistical Analysis System (SAS 79) (Barr et al. 1979). Partitioning of variation and estimation of heritabilities and gains were according to Wright (1976) and Falconer (1960). The expected gains are calculated as:

$$G = SD \times h^2$$

where G = Expected Gain
SD = selection differential
h^2 = heritability

The first analysis was conducted without the Southern Appalachian commercial seed source to estimate heritability. A second analysis was made to compare the performance of selected families with the commercial seed source.

RESULTS

Family effects for volume, diameter, and height growth were highly significant at both locations (table 1). Estimates of heritabilities for volume, diameter, and height were about 60% larger at Oak Ridge than at Highland Rim (table 2). The variance components for family effects were much larger in the Oak Ridge plantation.

In the combined analysis the family effects were highly significant for all three variables (table 3). Location was highly significant for volume and diameter, but not for height. There was a significant family by location interaction for height, but not for volume or diameter.

The within plot variance component accounted for approximately 70% of the total phenotypic variation (table 4). The next highest contribution was location at 12.3% for volume and 19.1% for diameter. Family contributions ranged from 4.9 to 5.9%. Single-tree heritability estimates were .28 for volume, .25 for diameter and .24 for height, and family heritability estimates were .84 for volume and diameter and .68 for height.

Table 1.-- Analyses of variance for volume, diameter and height for individual locations at Highland Rim and Oak Ridge for 8 year old Eastern white pine progeny.

Source of Variation	df	Volume MS	Diameter MS	Height MS
Highland Rim				
Replication	9	488.880**[a]	20.587**	13.120**
Family	21	303.533**	14.472**	3.123**
Rep x Family	188	104.043**	5.048**	1.115**
Within	1407	49.621	2.653	0.375
Oak Ridge				
Replication	9	111.188**	8.936**	1.573**
Family	21	182.534**	12.964**	3.674**
Rep x Family	188	35.421**	2.815**	0.604**
Within plot	1157	24.943	2.138	0.424

[a] Significant at the P = .01 level.

There was a large increase in treatment variation when the commercial seed data were added to the analysis. On an average, the treatment variation doubled in the combined analysis (table 5). There was no appreciable change, however, in the other sources of variation.

DISCUSSION

All the 1/2 sib-families showed greater volume growth than did the commercial check seedlings (significant at P = 01% level). The family means ranged from 10.9 dm^3/tree to 20.7 dm3/tree while checks averaged 6.1.dm^3/tree and the best 8 families was 16.7 dm /tree; this represents a difference of 169% and 208%, respectively, over the commercial seedlings available in 1974. All families had a larger volume at Highland Rim than at Oak Ridge.

All the families had a significantly greater diameter than did the commercial check. Family means ranged for 6.21 cm to 8.43 cm, while the commercial check averaged 3.73 cm (table 6). Overall mean diameter for improved families was 7.05 cm., while that for the best 8 families was 7.54 cm. This represents a superiority of from 89% and 102%, respectively, over seedlings available in 1974. Again, as with volume, all families had better diameter growth at Highland Rim.

Families grew significantly better in height than the checks. Family means ranged from 4.19 meters to 5.08 meters, while checks averaged 3.07 meters (table 6). The overall mean for improved families was 4.67 meters, and the best 8 families averaged 4.89 meters, a superiority of 52% and 59%,

Table 2.-- Variance components and heritability estimates for volume height and diameter of 8-year old eastern pine progeny at individual locations.

	S^2_w	S^2_{rxf}	S^2_f	S^2_r	h^2 a/
Volume					
Highland Rim	49.621 (70.9) b/	7.409 (11.8)	3.143 (5.0)	2.634 (4.2)	.209
Oak Ridge	24.943 (84.3)	1.688 (5.7)	2.604 (8.9)	0.363 (1.2)	.356
Diameter					
Highland Rim	2.653 (82.1)	0.326 (10.1)	0.148 (4.6)	0.106 (3.3)	.189
Oak Ridge	2.138 (86.3)	0.109 (4.4)	0.180 (7.3)	0.051 (2.1)	.297
Height					
Highland Rim	0.375 (63.6)	0.10 (17.1)	0.32 (5.4)	0.082 (13.9)	.252
Oak Ridge	0.424 (82.3)	0.029 (5.66)	0.054 (10.5)	0.008 (1.6)	.426

a/ h^2 = Single tree heritability

b/ Percentage contribution to the total variation.

Table 3.-- Analyses of variance for volume, diameter and height for combined locations of eastern white pine progeny at age 8.

Source of Variation	df	Volume MS	Diameter MS	Height MS
Location	1	11220.500**	1120.010**	1.620ns
Replication (Loc)	18	275.314** a/	14.068**	6.653**
Family	21	543.373**	29.196**	6.175**
Loc x Family	21	86.26ns b/	4.626ns	1.958**
Rep (Loc) x Family	376	69.723**	3.932**	0.589**
Within plot	2564	38.485	2.420	0.397

a/ Significant at the P = .01 level

b/ ns = not significant

Table 4.-- Variance components, heritability estimates and standard error of the estimates for volume, diameter and height combined locations of eastern white pine progeny at age 8.

Variance Component	Volume	Variables Diameter	Height
k_1^2	6.708018 (12.3)[a/]	0.6788 (19.1)	NC[b/]
$S_R^2(1)$	1.2608. (2.3)	0.0622 (1.8)	0.0355 (6.8)
S_f^2	3.2236 5.9	0.1733 (4.9)	0.02977 (5.7)
S.E. (S_f^2)[c/]	1.1895	0.0639	0.0140
S_{1xf}^2	0.2333 (0.4)	0.0098 (0.3)	0.0155 (3.0)
$S_{r(1)xf}^2$	4.4060 (8.1)	0.2133 (6.0)	0.0652 (12.5)
S_w^2	38.4850 (70.8)	2.4200 (68.1)	0.3770 (72.1)
h^2[d/]	.278	2.46	.243
S.E.h^2[e/]	+.107	+.094	+.119
h^2[f/]	.841	.842	.683

a/ Percentage contribution to the phenotypic variation
b/ NC = Negative component
c/ Standard error of S_f^2
d/ Single tree heritability
e/ Standard error of h^2 estimate
f/ Family heritability

respectively. There was no difference in height growth between the two locations. There was an interaction between families and locations (table 3). A covariate analysis yielded 9 families with significantly better height growth between locations; 3 of these grew better at the Highland Rim, and 6 grew better at Oak Ridge.

Table 5.-- Analyses of variance for volume, diameter and height for combined locations of eastern white pine progeny and commercial checks at age 8.

Source of Variation	df	Volume MS	Diameter MS	Height MS
Location	1	11089.080**	1151.20	0.930ns[b/]
Replication (Loc)	18	275.878**[a/]	14.999**	0.6888**
Treatment[c/]	22	954.807**	86.274**	19.838**
Loc x Treatment	22	92.320ns	4.509ns	1.953**
Rep (loc) x Treatment	393	67.294**	3.942**	0.868**
Within plot	2673	37.254	2.425	.407

[a/] Significant at the P = .01 level

[b/] ns = Not significant

[c/] Families and 1 Southern Appalachian seed source

Table 6.-- Volumes, diameters and heights of eastern white pine half-sib families and the Southern Appalachian commercial seed source.

	Highland Rim	Oak Ridge	Combined
Volume ($dm.^3$)			
Range of half-sib families	12.7 to 23.3[a/]	8.8 to 17.2	20.7 to 10.9
X of half-sib families	16.2	12.2	14.5
X of Southern Appalachian source	6.1	4.6	5.4
Diameter (cm.)			
Range of half-sib families	6.8 to 9.02	5.47 to 7.67	6.21 to 8.43
X of half-sib families	7.65	6.34	7.05
X of Southern Appalachian source	4.23	3.22	3.73
Height (meters)			
Range of half-sib families	4.27 to 5.10	4.10 to 5.04	4.19 to 5.08
X of half-sib families	4.67	4.67	4.67
X of Southern Appalachian source	2.95	3.19	3.07

[a/] Range

Eighteen individual progenies were selected for further evaluation in future breeding. It is realized that some of these trees might be related, but they are going to be evaluated with 45 to 50 selections from other heritability studies (Des Bordes and Thor 1979). The selection of the best individuals from within the best families will yield an additional gain.

The selection of the best 8 families will yield an expected gain of 1.85 dm3 (13%), .41 cm (6%), and .15 meters (3%) for volume, diameter and height, respectively (table 7). These gains would also be made with the establishment of a delayed clonal orchard. The expected gain from within-family selection is calculated using the selection differential of the selected trees and the mean of families selected and individual tree heritability. This results in a expected gain of 4.45 dm (30%), .72 cm (10%), and .27 m (6%) for volume, diameter; and height, respectively (table 7). Since both the expected ^{3}family and within family gains are additive, a total expected gain of 6.30 dm (43%), 1.13 cm (16%), and .43 m (9%) is expected for volume, diameter, and height.

Table 7. -- Expected gains of eastern white pine progeny, in volume, diameter, and height from selecting the best individuals within best families.

	Volume (dm^3)	Diameter (cm.)	Height (meters)
Mean of all 1/2 sib progeny	14.5	7.05	4.67
Means of selected families	16.7	7.54	4.89
Selection differential for selected families	2.2	.49	.22
Gains for family selection	1.85	.41	.15
Means of selected trees within the selected families	32.6	10.40	6.00
Selection differential for selected trees within families	15.9	2.86	1.11
Gains within family selection	4.55	.72	.27
Total gain	6.30 (43%)a/	1.13 (16%)	.42 (9%)

a/ Percent gain over mean of all 1/2 sib progeny.

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