An Evaluation of Height as an Early Selection Criterion for Volume and Predictor of Site Index Gain in the Western Gulf

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Abstract: -- Data from repeated periodic measures of height, diameter and volume from eleven loblolly pine progeny tests maintained as part of the Western Gulf Forest Tree Improvement Program (WGFTIP) were analyzed to 1) determine the potential of using early height, diameter, or volume as selection criteria for rotation-age volume, and 2) to develop a method of expressing height performance as predicted change in site index. Using family means, few differences in family mean correlations existed between 5-year traits with volume at 15 or 20 years, but they were slightly higher for volume than the other two traits. Gain efficiency estimates for all three traits at age 5 were similar, suggesting that the traits were equally efficient in predicting rotation volume. However, at age ten, per-acre volume was the better predictor of per-acre volume at later ages. Predicted gains in breeding value for height, expressed as percent change in site index (SIBV), were estimated following published WGFTIP methodology for volume. Age-specific site index equations and coefficient of genetic prediction (CGP) estimates for height were developed using the 15-year data from the eleven progeny tests. Estimates of CGP for height at ages 5 and 10 with height at age 15 were 0.55 and 0.61, respectively. Correlation between parental breeding values for volume production and site index breeding values were high (r=0.80). Predicted genetic gain for site index provides additional information for decision-making. Uses and limitations of this gain information are demonstrated.

Keywords: early selection, height, site index gain, loblolly pine (*Pinus taeda* L.)

INTRODUCTION

Early selection is critical to the long-term efficiency of any tree improvement program. Early selection for volume at rotation may be based on any number of growth traits, including height, diameter, or volume. Early tree height has been recommended as the selection criterion for loblolly pine (*Pinus taeda* L.) volume at rotation age (McKeand 1988, Balocchi and others 1993.) Height has been shown to be a good predictor of rotation age volume and is less affected by competition than diameter (Foster 1986, Lambeth and others 1983), and has a higher heritability than diameter (Bridgwater and others 1983, Foster 1986). Furthermore, height is more correlated with tree-form traits in *P. radiata* (Burdon and others 1992) and wood density in *P. taeda* (Bridgwater and others 1983) than diameter.

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Li and others (1996), however, found that average family mean age-to-age genetic correlations showed that juvenile DBH and volume were significantly better predictors than height for 20-year volume.

The Western Gulf Forest Tree Improvement Cooperative (WGFTIP) has always used early per-acre volume as its primary selection criterion to support the breeding objective of improvement in per-acre volume at rotation. The practice of ranking and selecting parents based on volume performance is based on early program research which showed that the composite trait, volume per unit area, was as good a predictor of rotation-age volume as a selection index composed of height, diameter or survival. Use of the composite trait also allows performance differences to be examined that may result from differences in survival and/or growth rates. Family height performance expressed as a function of site index, however, would be more useful for input into growth and yield models.

This study was conducted to 1) determine the potential of using early measures of height, diameter or volume as selection criteria for rotation-age volume in loblolly pine in the western gulf region, and 2) to develop a method of assessing height performance as a predicted change in site index. The objectives of the early selection portion of this work are 1) to estimate heritabilities of early selection criteria (height, DBH and volume at ages five and ten), 2) to estimate heritabilities for the breeding goal (volume at age 15 and 20), 3) to estimate family mean correlations between selection criteria and the breeding goal and 4) to evaluate the implications of these parameters on the current selection criteria used for loblolly pine in the Western Gulf Forest Tree Improvement Program. The objectives of the height performance portion of the study were to 1) develop age-dependent site index equations using data for loblolly pine in the western gulf region and 2), to develop an expression for height gain information as a function of site index.

MATERIAL AND METHODS

1. Early selection

The data come from eleven progeny tests established and maintained by four WGFTIP members, International Paper Company (IPCo), Plum Creek Timber Company (PlCrk), Potlatch Corporation (PC) and Weyerhaeuser Company (Weyco). For all tests differences among families were statistically significant for height, diameter and volume at 5, 10, 15 and 20 years. Three of the tests have data through age 20, while the remaining eight have data through age 15. The tests have varying numbers of half-and full-sib families comprised of first-generation parents and were established at various spacings and may have been thinned prior to the age 20 measurements. Most tests are located in southern Arkansas (Table 1).

Test	Owner[1/]	Location (County,State)	# Parents/ Families	# Reps	# Trees per Plot	Spacing (feet)	5	10	15	20
065	PlCrk	Ashley, AR	12 / 47	10	10	8 x 8	√	√	√T[2/]	√
357	Weyco	Sevier, AR	12 / 34	12	5	8 x 10	√	√	√	
412	IPCo	Grant, LA	7 / 24	6	6	8 x 10	√	√	√	√
420	IPCo	Columbia, AR	9 / 44	6	6	10 x 10	√	√	√	√
422	IPCo	Columbia, AR	8 / 29	6	6	10 x 10	√	√	√	
458	IPCo	Ouachita, AR	8 / 29	6	6	10 x 10	√	√	√	
498	PC	Bradley, AR	8 / 20	12	6	8 x 8	√	√	√T	
501	PC	Bradley, AR	8 / 20	12	6	8 x 8	√	√	√T	
502	PC	Bradley, AR	8 / 20	12	6	8 x 8	√	√	√T	
518	PC	Cleveland,AR	8 / 19	12	6	8 x 8	√	√	√	
536	IPCo	Lafayette, AR	12 / 27	8	6	6 x 8	√	√	√	

[1/] see text for full owner name [2/]T=thinned

Table 1. Details of progeny tests used in this study.

Volumes at ages 5 and 10 were calculated using the standard formula for conic volumes with data for height in meters and diameter at breast height in centimeters. Volumes at ages 15 and 20 received a standard adjustment for taper change. Volumes at age 5 are expressed in cubic decimeters per planted tree. Volumes at older ages are expressed as cubic meters per-hectare-per-year. In thinned tests, volume removed during thinning is added back prior to calculating final volume production.

All tests were analyzed using SAS PROC GLM (SAS Institute 1990). Means separation was provided by Duncan's Multiple range test. The statistical model used for all analyses was:

$$\gamma_{ijk} = \mu + R_j + F_k + e_{jkl}$$

where: γ_{ijk} = overall mean of the ith tree in the jth replicate and the kth family;
R_j = fixed effect of the jth replicate;
F_k = random effect of the kth family, and
e_{jkl} = error.

Family mean variance components were estimated using the VARCOMP procedure in SAS. Total phenotypic variance (σ^2_T) was estimated as: $\sigma^2_T = \sigma^2_F + \sigma^2_E$

Family-mean heritabilities were estimated as: $h^2_f = \sigma^2_F / [\sigma^2_F + \sigma^2_E/k]$

where: k=mean for number of trees per plot.

Family-mean correlations were calculated as correlation coefficients. Gain efficiency was estimated assuming equal intensities of selection between mature and young ages, using family means as described in Falconer and Mackay (1996):

$$E_{gen} = h^{-1}_{fj} * r_F * h^{-1}_{fm}$$

where:

E_{gen} = gain efficiency per generation,

r_F = family-mean correlation between the juvenile and mature trait,

and h^{-1}_{fj}, h^{-1}_{fm} = square roots of family-mean heritabilities at early and mature ages, respectively.

2. Site index prediction

The eight progeny tests with measurement data through age 15 were used in this portion of the study. Coefficient of genetic prediction (CGP) estimates were obtained between juvenile and mature height using the following formula (Baradat 1976):

$$CGP_{JM} = Cov_A(J,M) / \sigma_{PJ} * \sigma_{PM,}$$

where: $Cov_A(J,M)$ = additive covariance between the juvenile and mature traits,

and σ_{PJ}, σ_{PM} = phenotypic standard deviation at juvenile and mature ages.

Gain for height was determined using the methodology of Lowe and van Buijtenen (1991), whereby substitution, gain in site index (base age 25) can be expressed as:

$$Gain_{SI25J} = i_j * CGP * \sigma_{SI25.}$$

If gain is expressed as a deviation from 100 (i.e., mean value = 100), then predicted breeding value for site index can be expressed as:

$$PBV_{SI25J} = ((SI25 + i_j * CGP * \sigma_{SI25})/SI25) * 100.$$

where: SI25 = average site index (base age 25),

i_j = family deviation from the mean height in standard deviations or the standardized selection differential,

CGP = coefficient for genetic prediction for height between measurement age and age 15,

and σ_{SI25} = standard deviation about SI25 for family performance

Site index (base age 25) was estimated using equations specific to the western gulf coastal plain (Popham and others 1979) and the more general southwide equations (Golden and others 1981). The performance of the two equations was evaluated using data from several 25-year-old WGFTIP tests. The site index equations by Golden and others (1981) over-estimated the observed site index while those by Popham and others (1979) under-estimated the observed site index. It was decided that the site index equations by Popham and others (1979) would be used in this study because they made conservative estimates of site index at 25 years. Predicted site index for every measurement age was calculated for each test.

RESULTS AND DISCUSSION

1. Early selection

a. Heritability estimates.

Family-mean heritability estimates for height, diameter and volume ranged from 0.28 to 0.88 (Table 2). Age 5 heritability estimates were highest for height, followed by those for volume and diameter, which were identical. Age 10 heritability estimates were highest for diameter, followed by volume and then by height, which was the lowest. Family-mean heritability estimates for age-15 volume ranged from 0.45 to 0.88. Estimates for age-20 volume ranged from 0.49 to 0.81. Mean heritability estimates for all traits were highest at age 10.

Test	Ht05	DBH05	VOL05	Ht10	DBH10	VOL10	VOL15	VOL20
065	0.73	0.71	0.64	0.75	0.85	0.83	0.88	0.81
357	0.58	0.58	0.49	0.62	0.53	0.57	0.61	
412	0.66	0.54	0.58	0.60	0.66	0.57	0.73	0.78
420	0.54	0.57	0.57	0.70	0.76	0.70	0.70	0.49
422	0.51	0.38	0.39	0.63	0.58	0.60	0.61	
458	0.47	0.60	0.58	0.68	0.83	0.77	0.86	
498	0.63	0.61	0.65	0.70	0.87	0.83	0.78	
501	0.77	0.62	0.65	0.75	0.73	0.70	0.70	
502	0.79	0.75	0.78	0.76	0.82	0.84	0.78	
518	0.78	0.76	0.71	0.28	0.62	0.67	0.51	
536	0.79	0.73	0.79	0.82	0.80	0.79	0.53	
Mean	0.66	0.62	0.62	0.66	0.73	0.71	0.70	0.69

Table 2. Family-mean heritability estimates for height (Ht), Diameter (DBH) and volume (VOL) at each of the measurement ages for each test.

b. Family mean correlations.

Volume at five years had the highest correlation with volume at 15 years in eight out of eleven tests and on average was higher than the average correlations for either height or

diameter (Table 3a). Correlations of 10-year traits with 15-year volumes were highest for volume followed by diameter and then height.

(a)

Test	Ht05	DBH05	VOL05	Ht10	DBH10	VOL10
065	0.72	0.70	0.69	0.73	0.84	0.94
357	0.57	0.53	0.61	0.52	0.70	0.84
412	0.67	0.66	0.69	0.65	0.71	0.92
420	0.38	0.44	0.49	0.50	0.77	0.91
422	0.70	0.72	0.68	0.63	0.78	0.91
458	0.47	0.52	0.55	0.56	0.81	0.87
498	0.37	0.36	0.50	0.38	0.51	0.75
501	0.50	0.51	0.52	0.53	0.64	0.74
502	0.65	0.65	0.68	0.64	0.77	0.85
518	0.51	0.53	0.54	0.52	0.65	0.78
536	0.45	0.45	0.45	0.58	0.58	0.66
Mean	0.54	0.55	0.58	0.57	0.70	0.83

(b)

Test	Ht05	DBH05	VOL05	Ht10	DBH10	VOL10
065	0.64	0.61	0.60	0.65	0.79	0.87
412	0.67	0.65	0.69	0.65	0.70	0.89
420	0.30	0.36	0.41	0.44	0.72	0.84
Mean	0.53	0.54	0.57	0.58	0.73	0.87

Table 3. Family-mean correlations of height (Ht), diameter (DBH) and volume (VOL) at ages 5 and 10 with age15 (a) and age 20 volume (b).

Family-mean correlations of volume at 20 years with age 5 traits were not consistent across the three 20-year-old tests (Table 3b). Five-year volumes were highly correlated with 20-year volumes in tests 065 and 412, but had low correlation in test 420. Correlations in test 420 were low at age five for all traits. At age 10 the trend of the family mean correlations for the three traits was consistent across tests, with the exception of height in test 420.

For volume at age 15, across tests, no trait had consistently high efficiency of selection at 5 years (Table 4a). Both height and volume had the highest efficiencies in five out of eleven tests, although volume, on average, had a higher efficiency of selection at age 5 for 15-year volume than the other two traits. Volume at ten years had the highest efficiency for volume at 15 years in all tests. Efficiencies for selecting on 10-year traits were highest for volume when selecting for 15- or 20-year volume.

Efficiencies for selecting at age 5 for 20-year volumes were fairly similar for the three traits (Table 4b). Early selection for height at 5 years was an efficient predictor of volume at 20 years in tests 065 and 412, but not in 420 (Table 4b). Early selection for volume at 10 years was confirmed to be a superior predictor of volume at 20 years.

(a)

Test	Ht05	DBH05	VOL05	Ht10	DBH10	VOL10
065	0.66	0.63	0.59	0.67	0.83	0.91
357	0.56	0.53	0.55	0.23	0.65	0.81
412	0.64	0.57	0.61	0.59	0.68	0.81
420	0.34	0.39	0.44	0.50	0.80	0.90
422	0.64	0.57	0.54	0.64	0.76	0.90
458	0.34	0.43	0.45	0.50	0.79	0.83
498	0.33	0.31	0.45	0.36	0.53	0.77
501	0.53	0.48	0.50	0.55	0.65	0.74
502	0.65	0.64	0.68	0.63	0.80	0.88
518	0.63	0.65	0.65	0.39	0.72	0.89
536	0.55	0.53	0.55	0.71	0.70	0.81
Mean	0.53	0.52	0.55	0.52	0.72	0.84

(b)

Test	Ht05	DBH05	VOL05	Ht10	DBH10	VOL10
065	0.61	0.58	0.54	0.63	0.81	0.88
412	0.61	0.54	0.59	0.67	0.83	0.91
420	0.31	0.39	0.40	0.52	0.89	1.01
Mean	0.51	0.50	0.51	0.57	0.78	0.88

Table 4. Selection efficiencies at ages 5 and 10 compared to selection for volume at ages 15 (a) and 20 (b).

2. Site index prediction.

Coefficient of genetic prediction estimates for height for this dataset ranged from 0.22 to 0.90 (Table 5). Mean values, though comparing across different rotation ages, were similar those reported for volume by Lowe and van Buijtenen (1991).

Site index predictions for each measurement age in each test calculated from the equations of Popham and others (1979) are given in Table 6. Fifteen-year heights were the oldest measurement available and, therefore, assumed to provide the most accurate predictor if SI25. Compared to this standard, five-year heights poorly predicted site index. Ten-year heights predicted site index fairly well. Site index estimated from the 15-year measurements were used to derive predictive equations (Table 7).

The age-dependent site index equations and CGP estimates for height were incorporated into all loblolly progeny tests analyses programs and site index breeding values developed for all parents and families in tests measured in 2002-2003. In addition the oldest data from nearly every active WGFTIP progeny test was analyzed and site index breeding values (SIBV) calculated. For illustration SIBVs for the WGFTIP unimproved checklots were used as input into a growth and yield model (Harrison and Borders 1996) as implemented on the Texas Forest Service Timberland Stand Management website

(http://tfsfrd.tamu.edu/tdss/models/tis.asp). Predicted harvest volumes were calculated for a cutover, site prepared loblolly pine site of base site index

Test	Ht05-Ht15	Ht10-Ht15	Ht15-Ht15
065	0.69	0.73	0.82
357	0.57	0.62	0.66
412	0.62	0.67	0.77
420	0.48	0.42	0.59
422	0.56	0.67	0.82
458	0.43	0.77	0.90
536	0.72	0.76	0.61
498	0.33	0.53	0.55
501	0.64	0.69	0.62
502	0.66	0.62	0.70
518	0.31	0.22	0.30
Mean	0.55	0.61	0.67

Table 5. Coefficient of genetic prediction (CGP) estimates for height by progeny test.

60 established with 600 trees per acre and managed unthinned for 20 years. Percent change in volumes predicted for the unimproved checklots were calculated and compared to their volume breeding values. Results are presented in Table 8.

					Predicted SI25		
Test	N	Ht05	Ht10	Ht15	Age 05	Age 10	Age 15
065	461	2.24	7.55	13.11	7.60	14.39	17.37
357	359	3.54	8.58	13.15	11.94	16.36	17.44
412	114	2.95	7.31	10.47	9.28	14.20	13.86
420	197	3.64	10.30	14.68	12.39	19.67	19.44
422	150	3.48	9.81	15.39	11.74	18.74	20.38
458	150	3.93	10.36	13.43	13.32	19.78	17.79
498	190	5.13	12.33	16.66	17.48	23.32	21.97
501	192	5.11	12.49	16.92	17.35	23.86	22.41
502	190	4.81	12.31	16.68	16.38	23.35	21.99
518	179	4.89	10.34	14.53	16.63	19.66	19.20
536	216	3.44	8.95	12.34	11.68	17.10	16.34

Table 6. Height means (in meters) and predicted site index (base 25) using age 5, 10 and 15 mean heights.

Age	Regression	R^2
5	SI25 = 10.50 + 2.15 * HT05	0.58
10	SI25 = 5.62 + 1.33 * HT10	0.83
15	SI25 = -0.15 + 1.31 * HT15	1.00

Table 7. Site index predictive equations and coefficients of determination (R^2) developed from age 15 WGFTIP progeny test data.

Unimproved Checklot	No. of Obs.	SIBV (%)	No. of Obs.	BV Vol (%)	Predicted Vol (%)
NE TX	22	96.8	39	91.5	93.0
E TX	65	97.6	127	93.4	94.9
SE TX	31	99.0	46	97.4	97.9
N LA	31	95.2	37	90.1	89.7
LIV PAR	24	99.0	28	98.1	97.9
AR/OK	95	97.2	144	93.9	93.9
S MS	32	97.3	34	92.0	94.1
N MS	12	96.9	12	95.3	93.2

Table 8. Breeding values for volume (BV Vol) and site index (SIBV) for unimproved checks in WGFTIP tests and predicted volume breeding values derived from growth and yield model based on changes in SIBV.

CONCLUSIONS

1.Early Selection

Using family mean data, gain efficiency estimates for height, diameter and volume at age 5 were similar when selecting either age 15 or age 20 volumes, suggesting that the traits were equally efficient in predicting rotation volume. At age ten, per-acre volume was the better predictor of per-acre volume at later ages. These results support the current WGFTIP practice of ranking parents based on per-acre volume.

2. Site Index Predictions

Changes in harvest volume predicted from SIBV matched very closely with actual volume breeding values for each lot. On average the harvest volume breeding values based on changes in SIBV tended to be slightly higher than the actual values. This is due to the fact that predictions based on changes in SIBV are based on height alone compared

Predicting genetic gain for site index using early heights is now operational. The additional information provided with site index breeding values can assist in selection and deployment. Take for example a case where two families have identical volume breeding values but different site index breeding values. The family with the higher SIBV is likely to have obtained this result with larger, but fewer individuals and should be favored for deployment on better sites. The family with an equal volume breeding value but a lower SIBV has better survival and should be favored on more difficult sites.

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