FAMILY AND SPACING AFFECT STEM PROFILE OF LOBLOLLY PINE AT AGE 19

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Abstract—Profile measurements were taken on a stratified sample of 19-year-old trees from 8 North Carolina families and a commercial Mississippi-Alabama check established at 3 spacings (5 x 5, 8 x 8, and 10 x 10 feet). Measurements were first fitted on a single profile equation using multiple-regression. Data were also segregated by family, spacing, and family-by-spacing and fitted on the equation. These new model types were tested using the reduction-sum-of-squares principle. Stem volumes were calculated using the different model types and compared. A significant decrease of error was obtained from the reduction-sum-of-squares method, indicating that accuracy of stem-volume estimation can be increased by accounting for family and spacing in the profile equation.

INTRODUCTION

Many species have natural form deviations due to age, butt-swell, silvicultural treatments, dominance, site, stand density, and heredity (Bügen and Münch 1929, Liu and Keister 1978). Deviations in form have been observed in pines by Baldwin and others (2000) and Allen (1993). These papers attributed form variation to different levels of competition. However, some variation is attributed to genetics. McLauchlin (1998) found significant differences in taper below d.b.h. between families of loblolly pine.

Many studies have favored selection on height for genetic improvement in growth and yield (Foster 1986, Gwaze and others 1997, McKeand 1988), while others have favored selection on diameter (Kusnander and others 1998, White and Hodge 1992). The Western Gulf Forest Tree Improvement Cooperative incorporates some measure of profile in their selection by basing selection on juvenile per-acre volume (Raley and others 2003). However, they use a common stem form for all families. The selection on height, diameter, or common form leaves no means to account for stem profile variation that may be present among families.

This study investigates variation in stem profile among families at age 19 and discusses the importance that these differences may have on selection gains. Because selection is practiced at early ages, juvenile traits are explored for correlations with profile differences. More accurate family selection and volume prediction may be possible by accounting for family-specific stem profiles.

METHODS

Containerized seedlings of eight open-pollinated families in North Carolina (NC) and one open-pollinated “genetic check” (bulk seed lot) from east-central Mississippi (MS) and west-central Alabama (AL) were provided by Weyerhaeuser Company. The 8 families were selected based on 12-year-old progeny tests to represent ideotypes of fast growth with small crowns (NC1 and NC8), fast growth with large crowns (NC4 and NC7), slow growth with small crowns (NC3 and NC6), and slow growth with large crowns (NC2 and NC5).

Seedlings were planted from April 22 to May 7, 1985, at two sites on the John Starr Memorial Forest (Mississippi State University school forest) in Winston County, MS. The experimental design consisted of a randomized complete block design with four replications at each site. The two sites were an old field and a cutover-and-site-prepared area. Treatments were arranged in split-split plots, where each rep was split into 3 spacings (5 x 5, 8 x 8, and 10 x 10 feet). Each spacing was split into a mixed family plot and a pure family plot. The pure family plot contained nine subplots, each having one family or the check. A single or double border row was planted around each subplot. The interior trees of each pure family subplot covered an equal area of 0.0367 acre. Survival, d.b.h., and total height were measured at ages 5, 9, 13, and 17 years. Crown length was measured at ages 9, 13, and 17.

Two trees from each 1-inch diameter class from each family in each spacing were selected for sampling. Selected trees had no major defects or fusiform galls (*Cronartium quercuum* f. sp. *Fusiforme*), and they could not be in the border rows. A partial profile of the stem was used for development of profile equations. Lee (2002) showed that full profiles and partial profiles were statistically the same at the 0.05 significance level. Measurements of diameter and height were taken with a caliper and tele-Relaskope at stump height (approximately 0.5 feet), 2 feet, d.b.h., midpoint between base of live crown and d.b.h., base of live crown, midpoint between base of live crown and top of the tree, and top of the tree.

Heights and diameters of the 361 sampled trees were fitted with regression on 2 third-degree polynomials conditioned through d.b.h. to characterize profiles. The data were first fitted on a general model that used all sampled trees. Then, data were segregated by family, spacing, family-by-spacing, ideotype, and ideotype-by-spacing and fit as separate models. The subset models were tested against the general model using the reduction sum of squares method described by Graybill (1961).

A computer program was written to apply the general model profile and subset model profiles onto age 17 height and d.b.h. measurements for all non-border trees > 4.5 inches d.b.h. Cubic foot volumes for every 4-foot segment of the stem, up

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to a 3-inch top, were calculated using Smalian's volume formula. These 4-foot-segment volumes were summed for the tree to closely estimate the tree's actual volume.

Profile equations for different family-by-spacing combinations were applied to a tree with the same d.b.h. and height to illustrate the effects of profile differences on diameters at various heights up the tree. Tree volumes calculated with the general model and the family-by-spacing model profiles were compared with juvenile traits (tree height, survival, crown length, and crown ratio). Correlations between family means for juvenile traits and family means for 17-year tree volume (calculated both by the general profile and by the family-by-spacing specific profiles) were tested using Kendall's distribution-free test for independence (Kendall and Gibbons 1990).

RESULTS AND DISCUSSION

Error (deviations of predicted from actual tree volume) was significantly reduced by inclusion of family-specific and spacing-specific profiles in the general model. This demonstrated that a single model does not adequately describe the range of profiles due to differences among the three spacings, eight families and check. The family-by-spacing model was compared to partial models adjusted for families only and spacings only. This full model significantly reduced error over those partial models.

The "reduction-sum-of-squares" method tests the adequacy of a broad (full) equation versus a more specific subset. Many profile models within a subset may not be different, and only a few extreme forms that are not fit by a general model may be the cause of significant error reduction. Pair-wise comparisons were conducted to test for profile differences between individual families in a spacing. Extreme families were selected based on the pair-wise tests, and their profiles are shown in figures 1 through 3.

There were family differences in profile within each spacing. Even in the tight 5 x 5 spacing, where uniformity was greatest, family NC6 had a profile where the stem diameter was larger at greater heights in the tree than the check or NC2 (fig. 1). This family, NC6, would therefore have more stem volume per tree than the check or NC2 for trees with the same d.b.h. and height. While there were also differences found in butt and crown taper, most merchantable volume is taken from the lower bole of the tree below the live crown. In all spacings, profiles differed between 10 to 30 feet up the bole. Therefore, differences in stem profile caused volume estimation to vary greatly among families. Stem volumes for trees (with the same d.b.h. and height) representing different families ranged from 4.48 to 5.50 cubic feet in the 5 x 5 spacing, 8.88 to 10.00 cubic feet in the 8 x 8 spacing, and 11.61 to 13.24 cubic feet in the 10 x 10 spacing.

Ideotype classifications were investigated as a method for grouping families to limit the number of different profiles needed. Both the ideotype model and the ideotype-by-spacing model significantly reduced error when compared to the general model. The ideotype-by-spacing model was compared to the family-by-spacing model. Out of 12 ideotype-by-spacing combinations, 5 profiles adequately described the 2 families contained by the classification. Adequate ideotype x spacing profiles were found for the 5 x 5 and 10 x 10 fast growth/large

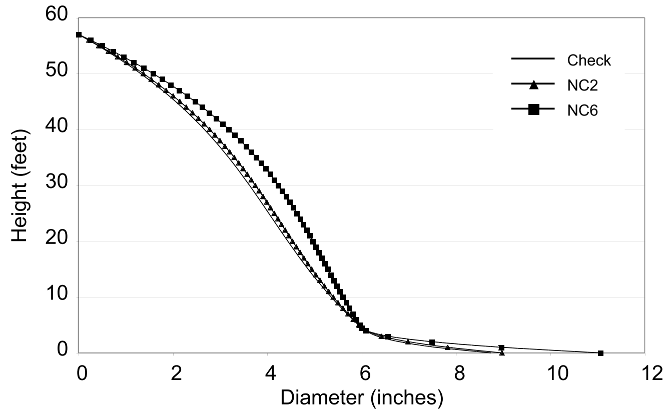

Figure 1—Profile based on a common tree height and d.b.h. of the two extreme families and check in the 5 x 5 spacing.

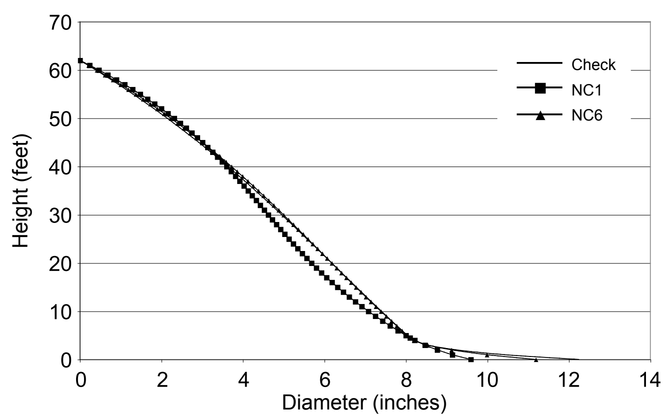

Figure 2—Profile based on a common tree height and d.b.h. of the extreme families and check in the 8 x 8 spacing.

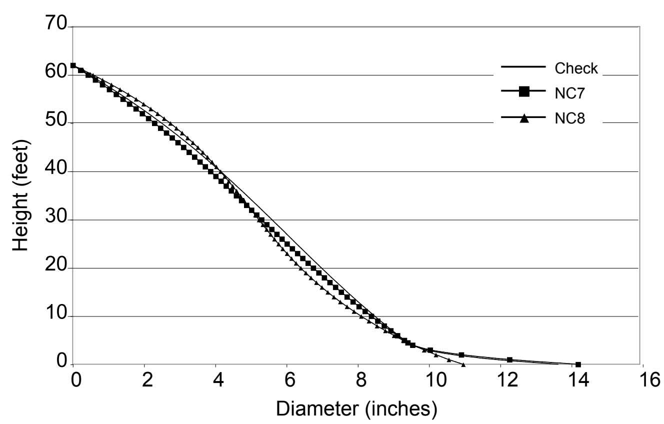

Figure 3—Profile based on a common tree height and d.b.h. of the two extreme families and check in the 10 x 10 spacing.

crown combinations, the 10 x 10 slow growth/small crown combination, and the 8 x 8 and 10 x 10 slow growth/large crown combinations. Other ideotype-by-spacing profiles did not sufficiently describe both families within the ideotype. These results indicate that the ideotype classifications used in the present study do not adequately account for all factors which affect stem profile. One trait not captured by these ideotypes is “competitive ability” (the ability to survive after crown closure), and number of trees per acre at age 17 years will affect profile.

Crown ratio, survival percentage, crown length, and tree height were juvenile traits shown to be significantly correlated with change in profile by Kendall’s Test for independence. Quantification of profile was done through application of the family-by-spacing model to a tree from each family with the same d.b.h. and height. Changes in volume could then be attributed to changes in profile. These volume estimates were tested against juvenile traits for correlations. All juvenile traits were weakly and negatively correlated with profiles that produce more volume. Traits with the strongest correlations were 9 year crown ratio in the 5 x 5 spacing, 13 year survival percentage in the 8 x 8 spacing, and 17 year tree height in the 10 x 10 spacing. “Kendall’s Correlation Values” for these were -0.25, -0.39, and -0.37 respectively.

Taper is the change in diameter between two points on the stem, while profile refers to the entire geometrical shape of the stem. Two extreme forms of stem profile are the “frustrum of a parabaloid” and the “frustrum of a neiloid” (figs. 4 and 5). Both of these could have the same taper but would differ in volume. The frustrum of a parabaloid produces greater volumes than the frustrum of a neiloid. Thus, taper differences (or absence of difference) among families may not be a good measure of stem volume differences, because one family may have a neiloid profile and another family may have a parabaloid profile.

Survival, crown length, crown ratio, and total tree height were positively correlated with the neiloid profile. As survival increases, competition for available resources increases. This causes growing emphasis to be on height and crown development rather than on diameter growth. The bole will be smaller with a form resembling the frustrum of a neiloid. On the other hand, when profiles were fitted on families with shorter heights or less survival such as those found in the slow growth ideotype, more taper was localized in the crown area. This caused the form of the bole to resemble the frustrum of a parabaloid. Thus, if height and d.b.h. are kept constant for all families in the correlations, profiles modeled on shorter families and profiles modeled on families with less survival produce greater stem volume per tree. This is an artifact of the forced condition that the trees from all families were the same height and d.b.h. In real life, what this indicates is that slow-growing, poor-survival families will not be as far below the fast-growth, high-survival families in stand volume at age 17 as expected.

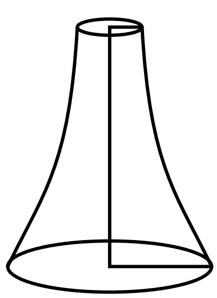

Figure 4—Frustrum of a Neiloid.

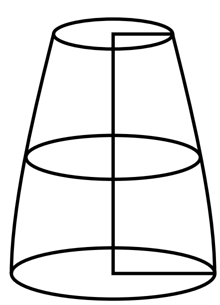

Figure 5—Frustrum of a Parabaloid.

Of the traits tested, height was of great interest because of its importance in early selection for tree improvement. However, if correlations between height and greater-volume-producing profiles are negative, height’s use as a selection tool may not produce as much gain as expected. Age 9 height was tested for its ability to predict mean tree volume at age 17 before and after specific profiles were applied (table 1).

If families were selected based on mean height at age 9, the 2 tallest families would have 1 percent taller dominant height at age 17 than the average of the 8 families and 2.9 percent greater dominant height than the age 17 heights of the 2 shortest families (identified at age 9). Also, selection based on age 9 height resulted in the 2 “top” families still outperforming the 2 “worst” families by +2.5 percent in mean tree volume at age 17, when the same general profile was used on all families. However, these two “top” families had a -2.6 percent smaller mean-tree volume than the average of the eight families when the general profile was used. After applying the family-by-spacing profiles, mean-tree volume of the top two families for age 9 height was even further below that of the other families, -6.7 percent of the average for all eight families and -4.5 percent of the mean for the two worst families. The 2 best families for height at age 9 had the 2 smallest mean-tree stem volumes at age 17. This is a result of family differences in survival at age 17 (competitive ability). The 2 top families for height at age 9 also had the greatest survival (and thus density) at age 17. Higher density resulted in smaller d.b.h.s and neiloid profiles, which gave smaller mean-tree volumes for these two families. Inclusion of the neiloid profiles accentuated the deficit in mean-tree volume. This is illustrated in the column of table 1 labeled “General minus Family”. The general profile was more parabaloid than the neiloid profiles of NC1 and NC4, so the general model overestimated the mean-tree volume of those two families. The implication is that survival of the selected families must be sufficiently greater than the survival of the other families to compensate for the smaller mean-tree volume and give a greater volume per acre. That improvement in survival must be even greater than what would be calculated if mean-tree volumes from the general model were used.

The effects of neiloid versus parabaloid profiles on accuracy of family estimates for mean-tree volume are illustrated in the right four columns of table 1. Using the general model, families NC1 and NC4 would both have their volumes over-predicted (neiloid profiles). On the other hand, NC2, NC3, NC5, and NC6, all in the slow-growth ideotype with parabaloid profiles, would have their volumes underestimated from -4.1 percent to -7.6 percent by a general profile. Differences between the two volume calculations demonstrate that estimates of gains in volume per acre from family selection may not be as great as predicted from a general profile model, because volumes from high-surviving families (neiloid profiles) are over-predicted and volumes from low-surviving families (parabaloid profile) are under-predicted.

Table 1—Effect of family differences in stem profiles on tree-volume estimates at age 17 in a loblolly pine test in northeast Mississippi

	Family means[a]				Mean tree volume(cubic feet) at age 17			
		Age 17						
Family	Age 9 height	Dom ht	dbh	Surv.	General profile[b]	Family-spacing profile[c]	General minus family	Error
	feet	*feet*	*inches*	*%*				*%*
NC1	35.5	63.1	7.8	85	8.13	8.11	+0.02	+0.3
NC2	34.8	62.3	7.9	69	8.48	9.02	-0.54	-6.0
NC3	34.2	61.7	8.0	64	4.26	8.94	-0.68	-7.6
NC4	35.8	62.7	7.9	78	8.25	8.08	+0.17	+2.1
NC5	33.5	61.8	7.7	74	8.16	8.50	-0.35	-4.1
NC6	34.0	60.4	7.6	66	7.82	8.42	-0.61	-7.2
NC7	35.1	63.4	7.9	74	8.62	8.79	-0.17	-1.9
NC8	35.4	63.3	8.0	66	9.22	9.42	-0.19	-2.0
Avg. All Fams.	34.8	62.3	7.9	72	8.40	8.64	-0.24	-2.7
Percent Gain [Best two families at age 9 (=NC1&4)] compared to:								
(1) Avg. all fams (%)	+2.5	+1.0	-0.6	+13.2	-2.6	-6.7		
(2) Worst two fams at age 9 (%) (=NC5&6)	+5.6	+2.9	+2.6	+16.43	+2.5	-4.5		

[a] Based on all trees measured at ages 9 and 17 (not just sample trees).
[b] Based on profile derived from all 321 trees sampled. This is a general profile for the site (across all families and spacings). Volume per tree is calculated by applying the family means at ages 17 to this general profile.
[c] Based on profiles derived for each family-by spacing combination. Volume per tree is calculated by applying the spacing-by-family means at ages 17 to the specific family-by-spacing profile.

CONCLUSIONS

Selection of families generally occurs at ages before stem profile can be considered for selection. However, stem profile differences were present at age 19. Both spacings and families had profile variation not adequately described by a general model. Profile equations were developed for each family within each spacing. This family-by-spacing model was better at describing the different profiles than models adjusted for spacings or families independently. Profile differences were shown to occur throughout the stem. Difference in family profile caused stem volume to vary in all spacings. These differences between families increased with wider spacing. Ideotype classification was tested and found to better describe profiles than the general equation. However, when the ideotype-by-spacing model was compared to the family-by-spacing model, only 42 percent of the ideotype-by-spacing combinations adequately described both families within the class.

Profiles resembling the frustrum of a parabaloid give greater stem volume per tree. These parabaloid profiles were negatively correlated with survival, height, crown length, and crown ratio. Selection for increased values of these traits results in profiles that resemble the frustrum of a neiloid and reduce individual-tree volume. While this latter profile may be desirable for better quality later in the tree's life, stem volume per tree will be less than may be expected from projections using a general, more parabaloid profile.

Selection of the top two families (of eight) based on their age 9 height did not translate into gains in tree volume over the average of the eight when general profile was used. Application of the fully- adjusted profile model for family and spacing even caused the "top" families' mean stem volume per tree to fall below the "worst" families. This calls into question the use of height as the only criteria for making selection. While height may warrant use due to its high heritability and age-age correlations, a selection criteria that incorporates more comprehensive stand dimensions would be more promising. Selection based on juvenile per-acre volume as implemented by the Western Gulf Forest Tree Improvement Cooperative is an example of this. However per-acre volume would still be prone to error if a common profile is assumed for all families. This error is demonstrated by volume projections, using a general model, that overestimate two families and under estimate the other families in the current study.

Profile differences among families and spacings should be considered for selection programs that desire to improve yield. Growth-and-Yield models should be refined for these differences to better handle today's deployment of improved families in single-family blocks. However, development of models for each family in each spacing can be arduous. Ideotype classifications may be used to supplant use of individual-family models. However, the ideotypes tried in this study were not adequate for classifying family differences in profiles, and some measure of "competitive ability" must be incorporated. Profile models, specific to spacing and family, will aid in more accurate selection and help minimize overestimation of stand volume in fast-growth, high-survival families and underestimation of stand volume in slow-growth, low-survival families.

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