Height-Age Relationships in a Loblolly Pine Varietal Screening Trial: Implications for Stand Yields

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Loblolly pine clonal forestry has progressed substantially in the Southern United States. Over 10 million somatic embryogenesis seedlings have been planted in the last six years (McKeand et al. 2007). Studies using early age data have shown that the best clones have the potential to produce up to 35% more volume than second generation open pollinated (OP) seed orchard material (Isik et al. 20005, Fox et al. 2007). Concerns on how good the estimates of gain based on early data reflect the gains at rotation age and of the high cost of clonal seedlings are still an issue that may slow down the adoption of this potentially profitable form of forestry. In this report, we modeled the 15-year height growth of 96 clones growing in a varietal screening trial and used the model to extrapolate the growth to age 25. We then used the predicted height at age 25 (site index) in a growth and yield model to predict yields and financial gains that may be obtained from clonal plantations.

METHODS

Data

Tree total height measurements for age 1 to age 10 and ages 13 and 15 were obtained from a rooted cuttings clonal varietal screening trial established by Westvaco in Berkeley County, SC, in 1994. The trial was established on an old-field site. There were 120 clones planted as one ramet in each of ten contiguous blocks. The planting spacing in each block was 2.74m by 2.74m. There were two border rows around the entire study. Competition from hardwoods was controlled during the study period. Thinning was done in five of the blocks at age 8. Clones that had 5 or more trees that did not have any form of broken top damages were identified at age 15. Ninety-six of the 120 clones met this criterion. Arithmetic mean height at each of the ages, based on the five or more undamaged trees per clone, was computed for each of the 96 clones. The mean height was then modeled as a function of age.

Height-Age Modeling

The height-age relationship was modeled by the Chapman-Richards height-age function using both fixed and random parameters

$$H_i = (\beta_1 + u_{1i}) \times \{1 - \exp(-[\beta_2 + u_{2i}] \times Age)\}^{(\beta_3 + u_{3i})} \quad (1)$$

where H_i is the mean height of the i^{th} clone at the given age; β_1, β_2, and β_3 are fixed-effect parameters; u_{1i} , u_{2i} , and u_{3i} are random-effect parameters for the i^{th} clone (u_1~ $N(0, \sigma^2_{u_1})$; u_2~ $N(0,\sigma^2_{u_2})$; u_3~ N(0, $\sigma^2_{u_3}$); and no correlations among the random-effect parameters). Model fitting was done using the *nlme* package in S-Plus software (S-PLUS 8 Release 1 (2007) Insightful Corp., Seattle, WA). Heteroscedasticity in the height-age relationship was modeled as a power

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function of age while correlations due to the longitudinal nature of the data were modeled by the first order autoregressive correlation structure (AR(1)). The Akaike Information Criterion (AIC) statistic was used to identify the random parameters that were significant in model (1).

Yield Prediction and Economic Analysis
Yields were predicted using PTAEDA4.0 (Burkhart et al. 2008), a stand growth simulator with an economic valuation package. The simulation was done for a well drained coastal plain site with management options of chop and burn site preparation, 1077 trees/ha planted, herbaceous weed control for the first two years of stand existence, thinning to 17.22m^2/ha basal area at age 15, and clear cut at age 25. Thinning cost was set as 10% of thinnings revenue, final harvesting cost as 6% of harvest revenue, and compound interest rate as 6% per annum. Revenues were set at $9/ton for pulpwood, $24/ton for chip and saw, and $44/ton for saw timber (1 ton = 1,000kg).

RESULTS AND DISCUSSION

Height-Age relationship
The best fitting model was

$$H_i = (28.3 + u_{1i}) \times \{1 - \exp(-0.144 \times Age)\}^{(1.86+u_{3i})} \qquad (2)$$

where H_i is the mean height of the i^{th} clone in meters at the given age; 28.3, 0.144, and 1.86 are the fixed-effects parameter estimates; and u_{1i} and u_{3i} are random-effect parameters for the i^{th} clone ($u_1 \sim N(0, 1.5)$ and $u_3 \sim N(0, 0.003)$). Model 2 had an AIC value of 213 compared to 485 for the fixed- effects only model, 309 for the model with u_1 as the only random-effect parameter, 243 for the model with u_1 and u_2 random-effect parameters, and 215 for the model with all the three random-effect parameters. The low variance of u_3, though statistically significant, suggested that differences in shape among the height growth curves may not be practically significant. Differences in the curves are mainly due to differences their asymptotic heights.

Site index (base age 25) predicted using model (2) ranged from 24m to 29m. Clone AA90 exhibited the lowest site index and clones AA60 and AA110 exhibited the highest. Predicted height-age curves for selected clones (the extreme ones included) indicate that the height growth curves are essentially anamorphic (Figure 1). This conclusion is similar to that by Buford and Burkhart (1987) on provenance and first generation open pollinated loblolly pine families that for the same location, genotype affects only the asymptote parameter.

Yield and Financial Gain
Estimated yield for the best clones (site index 29m) was 99 tons/ha of pulpwood, 64 tons/ha of chip and saw, and 183 tons/ha of saw timber. Given a clonal stand establishment cost of $803/ha, this yield translates to a net present value (NPV) of $1648/ha. Estimated yield for site index 23m, which could be taken as a “typical” site index for open pollinated (OP) material on a good Atlantic coastal plain site, was 104 tons/ha of pulpwood, 64 tons/ha of chip and saw, and 136 tons/ha of saw timber. This translates to a NPV of $1376/ha given an OP stand establishment cost of $432/ha. Thus, planting the best clones in the Atlantic coastal plain of southern United States could provide better financial returns than may be got from planting OP material. However, our predictions are based on site index estimates made using data from a single

location. Our data do not allow estimating the effect of varying location on the height-age relationship of different clones. These predictions apply to the coastal plain areas with conditions closely resembling those in the study location.

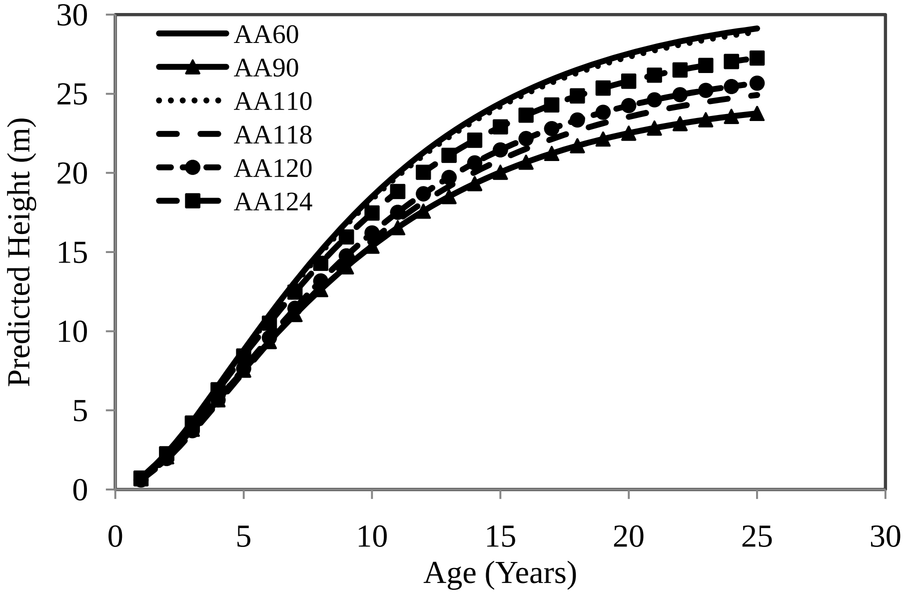

Figure 1: Mean height growth of select clones predicted by the equation $H_i = (28.3 + u_{1i}) \times \{1 - \exp(-0.144 \times Age)\}^{(1.86+u_{3i})}$. The differences in the curves are due differences in values of u_{1i} and u_{3i}, from clone to clone.

Acknowledgements: A Graduate Research Assistantship to support this research has been provided through the NSF Center for Advanced Forestry Systems. Additional funding for data collection came from ArborGen and from the Loblolly Pine Growth and Yield Research Cooperative at Virginia Tech.

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