VALUE OF TREE MEASUREMENTS MADE AT AGE 5 YEARS FOR PREDICTING THE HEIGHT AND DIAMETER GROWTH AT AGE 25YEARS IN LOBLOLLY PINE PLANTATIONS

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Abstract-Early growth measurements of pine plantations are often used to predict the productivity of the stand later in the rotation when assessing the effect of management on productivity. A loblolly pine (*Pinus taeda* L.) study established at 36 locations (2 to 3 plots/location) was used to test the relationship between height measurements at age 5 years and productivity at age 25. Mean heights of dominant and codominant trees at age 25 were used to represent site index at a location; basal area growth per tree from ages 20 to 25 was used as an index of individual tree growth.

The plot data showed a relatively weak relationship (r^2=0.40) between heights at age 5 and site index. Ranking age-5 heights and using only taller trees did little to improve the relationship. The fit of the regression equation changed gradually from an r^2 of 0.45, when only the tallest tree was used, to an r^2 of 0.43 when the tallest one-half of all trees was used, Using more trees did not degrade that relationship. As all trees must be measured to determine the tallest group, little is gained by attempting to designate dominant and codominants or crop trees for use in analyses and interpretations. Overall, predictions of stand productivity at age 25 using only individual tree parameters based on height at age 5 were of little value, accounting for only about 20 percent of the variation. Although plot location and rank of the tree within a plot each accounted for about 10 percent of the variability at age 25, a nearest-neighbor competition index and height at age 5 accounted for less than 0.1 percent each. However, rank by height at age 5 was an excellent predictor of individual tree survival, with 95-percent survival at age 25 for the tallest pines and almost no survival for the shortest pines. Based on the results of this study, we surmise that accurate modeling of stand development from early measurements probably requires more site information, such as amount and type of competing vegetation, soil properties, and a history of the land management.

INTRODUCTION

A major problem in evaluating new techniques for pine stand establishment and management manipulation is the long time required for the crop to reach harvest age. Even in short-rotation, intensively managed plantations, the rotation period closely matches that of scientists' careers. Thus, there is a need to reliably use early measurements to make projections about subsequent stand development. While there are several ways to make projections, the methods have not been validated.

Equations developed from site index curves can be used to predict relative growth at later ages from early measurements. This method has several disadvantages. First, local curves may not be available, and regionwide curves must be used (Shoulders 1976). Second, site index curves may be valid only for older stand ages and not be useful below age 10 (Farrah 1973). Third, when anamorphic site index curves are used, projecting heights from a young age to a site index is simply multiplying the mean heights by a constant. Thus, the manipulation adds no new information or changes the relative differences between treatment means. Finally, the use of anamorphic curves is based on the assumption that relative rates of growth are constant, and the falseness of this assumption is shown by studies in which treatments did change the rate of height and diameter growth (Cain 1978).

Identifying crop trees using heights at age 5 or other measurements from early ages is another method sometimes used to project stand development forward. The crop trees are trees in the stand at the early measurement period that are expected to develop into dominants and codominants at rotation age. The crop trees may be identified as a fixed percentage of the number of living trees or on a fixed-area basis such as using the tallest 247 trees per ha (Mann and Derr 1970). One disadvantage of this method is that the size of the neighboring trees is not taken into account. Secondly, like the anamorphic site index curves, the method assumes that all trees develop at the same rate. Wakeley (1971) found that trees of superior size at age 30 were usually of above-average size at early ages. However, a number of trees changed from being below average at younger ages to superior at age 30. There were sufficient trees in the late-surging population so that the correlations of heights at age 30 to heights at age 5 ranged from 0.31 to 0.47 for loblolly pines (*Pinus taeda* L).

In a preliminary examination of a loblolly pine data set, we also found that using plot means of heights at age 5 was a poor predictor of the actual site index (base age 25) on the same plots, accounting for only 40 percent of the variation. In this paper, we are using data from plantations located on a wide range of sites and measured over a period of 25 years to examine ways of using early measurements in predicting the size of the stand at later ages. First, we use ranked heights of all the trees on each plot to find the optimum number of large trees to identify as crop trees. Secondly, we use the heights, rank within the stand, competition index of nearest neighbors, and stand location to evaluate which tree and stand parameters at young ages are the most useful in predicting future tree size, stand structure, and survival.

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METHODS

Sites and Measurements

The data set used is a subset of a larger one from a study that compared the performance of different pine species on a wide range of sites in Louisiana and Mississippi (Shoulders 1976). Originally, 47 sites were planted in Louisiana in 1954-58 with each site consisting of three replicates each of loblolly, slash (*P. elliottii* Engelm.), and longleaf pine (*P. palustris* Mill.). Shortleaf pine (*P. echinata* Mill.) was also planted at some of the northern Louisiana locations. The sites were mostly on open, cutover forest land that had not been tilled but had been kept in grass by frequent fires after the original forest was cut in the 1920's. Each plot consisted of 11 rows of 11 trees planted at a 1.83-m spacing. Seedlings grown from unimproved seed lots in a State nursery were graded by Wakeley's (1954) rules, and only seedlings graded 1 or 2 were used. Only the loblolly data collected in Louisiana are used in this paper. By age 25, only 29 of the sites still had all three replicates with sufficient surviving loblolly pines to measure, 5 sites had two surviving replicates and 2 sites had only one replicate. This left a total of 99 plots for use in this paper. Heights of the center 49 planting positions were measured at ages 5 and 10. The d.b.h. of these same trees was measured at ages 10. 15, 20, and 25. At ages 15, 20, and 25, heights of at least 10 dominant or codominant trees were measured on each plot. Mean height of dominant and codominant trees at age 25 was used to represent site index of a plot. The d.b.h.'s were used to calculate basal area growth per tree from ages 20 to 25 for use as an index of individual tree growth.

Site Index Predictions

To find the optimum number of larger pines at an earlier age needed to predict site index at age 25, all measured trees in each plot were ranked by their height at the earlier age. Before ranking, a random value, less than 1 percent of the height, was added to the height of each pine. This transformation prevented ties in the ranked heights without affecting other statistics. The height of the largest pine in each plot at the earlier age was selected as the independent variable in a regression, having SI_{25} (site index at base age 25 years) as the dependent variable. Then the regression was rerun including the earlier-age heights of the two largest trees, three largest trees, and so on until the heights of all measured pines were included.

Basal Area Growth Predictions

To predict stand productivity at age 25, age-5 parameters were used in a general, mixed linear model. The model used was

$$BAG_{,.,} = f(HT_5, R_{HT5}\ CI_{,,,,}\ LOC) + E,$$

where

$BAG_{,.,}$ = annual basal area growth between initial and final age,

HT_5 = pine height at age 5,

R_{HT5} = rank of pine in plot based on heights at age 5,

$CI_{,,,}$ = competition index based on height of pine and its neighbors,

LOC = location, and

E = unaccounted -or variation.

The competition index is based on Hegyi's index (Hegyi 1974), except that total pine height was used instead of diameter to compare the tree to its neighbors. In the CI calculations, the four nearest pines in the rows (distance=1.83 m) and the four pines in the diagonal (distance=2.59 m) were used. Because the pines in the border rows were not measured, only the 25 center pines were used to calculate the competition and subsequently used in the regression with stand productivity. Stepwise fits of the model were used to find the relative importance of each independent variable. The model was then refitted with all independent variables included in the order suggested by the stepwise fits. The same order was used for all growth periods tested. To model survival, a cubic equation was fitted between the height-based rank within a plot and survival at age 25.

RESULTS AND DISCUSSION

Site Index Predictions

The mean height of all live pines on each plot at age 5 is a poor predictor of SI_{25}, accounting for only 40 percent of the variation. At age 10, the mean height accounted for more of the variation, increasing to 69 percent. Age-l 5 height was not as useful as age-10 height when used in the model to predict site index, accounting for only 65 percent of the variation. Beginning at age 15, heights were measured only on sample trees, and this may account for the weakened relationship. Age-20 height, based on sample trees chosen by the same criteria used to select trees at age 15, was much more useful, accounting for 88 percent of the variation. The regression between all trees measured at age 25 and those identified as dominants and codominants had an r^2 of 0.95. The variation in site index between locations by heights at younger ages is similar to results for loblolly pine in the Florida Parishes of Louisiana (Wakeley 1971). In earlier reports (Ferree and others 1958, Wakeley and Marreo 1958), the 5-year-growth increment after pines had reached breast height was more closely related to site index than were total heights at young ages. However, in the present study, the height increment from age 5 to age 10 was not a better predictor than total height at age 10, accounting for 70 percent of the variation.

Ranking age-5 heights and using only taller trees did little to improve the relationship (fig. 1). The fit of the regression equation changed gradually from an r^2 of 0.45, when only the tallest tree was used, to an r^2 of 0.43 when the tallest one-half of all trees were used. The relationship was similar for other ages, with the amount of variation accounted for increasing with the age of the pines but not changing with the number of taller pines used. Thus, the prediction of future growth cannot be improved by selecting tallest or crop trees at early ages. As all pines must be measured to

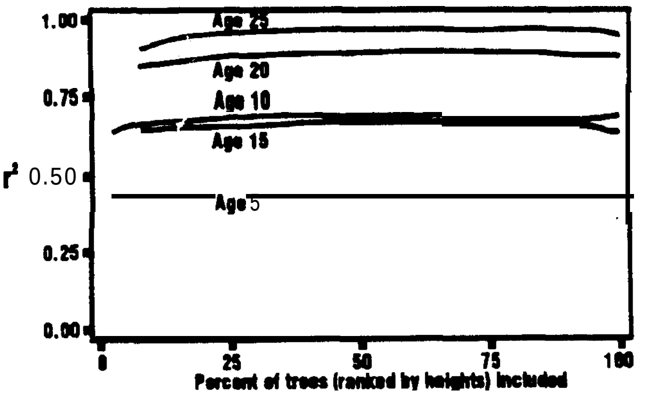

Figure l-Effect of percentage of largest pines included as independent variable on regression coefficient between age 5 heights and age 25 heights.

determine the tallest group, little is gained by attempting to designate dominants and codominants or crop trees for use in analyses and interpretations.

Detailed analysis of the changing ranks of pines with time can help explain why selecting larger pines at early ages does not improve the prediction of size at older ages. Ranks by ages are shown in figure 2 for two plots that show extremes in rank changes. Rankings of pines on plot 134-2 are relatively stable. For example, pine A is the tallest tree at age 5 and was still ranked number 5 by d.b.h. at age 25. Pine B was ranked number 45 by height at age 5 and had changed by age 25 to ranking 32, or last, because other small pines died. By contrast, ranks on plot 139-3 changed dramatically with age. Pine C was in rank 41 by height at age 5, but had climbed in stature to having the 4th largest d.b.h. by age 25. Pine D, which was the tallest at age 5, ended in 23rd place by age 25. As the number of intersections of lines in the ranking diagrams indicates, most of the changes in rank seem to take place in the 5th through 10th years of the plantation. While mortality was concentrated in the lower ranks, the pines often moved from higher to lower ranks before dying.

Using a somewhat different analysis also aids in understanding the relationship between rank by height at age 5 and relative position in the stand at index age. Consider the population consisting of the tallest tree on each plot at age 5. At age 25, the mean ranking by diameter of this population was 5.1 (fig. 3A), with a range of 1 to 26. As the ranking at age 5 moves from large to small pines, the mean ranking at age 25 increases in a linear fashion. However, while the mean indicates a good" relationship between rank at age 5 and rank at age 25, the large variation nullifies its utility as a predictor. Indeed. the population of pines ranked 36th at age 5 has nearly the same range of 4 to 39 as lower ranked trees (fig. 3A) even though the mean ranking by diameter has increased to 24. This wide range explains why selecting only a larger fraction of pines, based on age-5 heights, does not improve the predictability of SI_{25} (fig. 1). When ranks based on

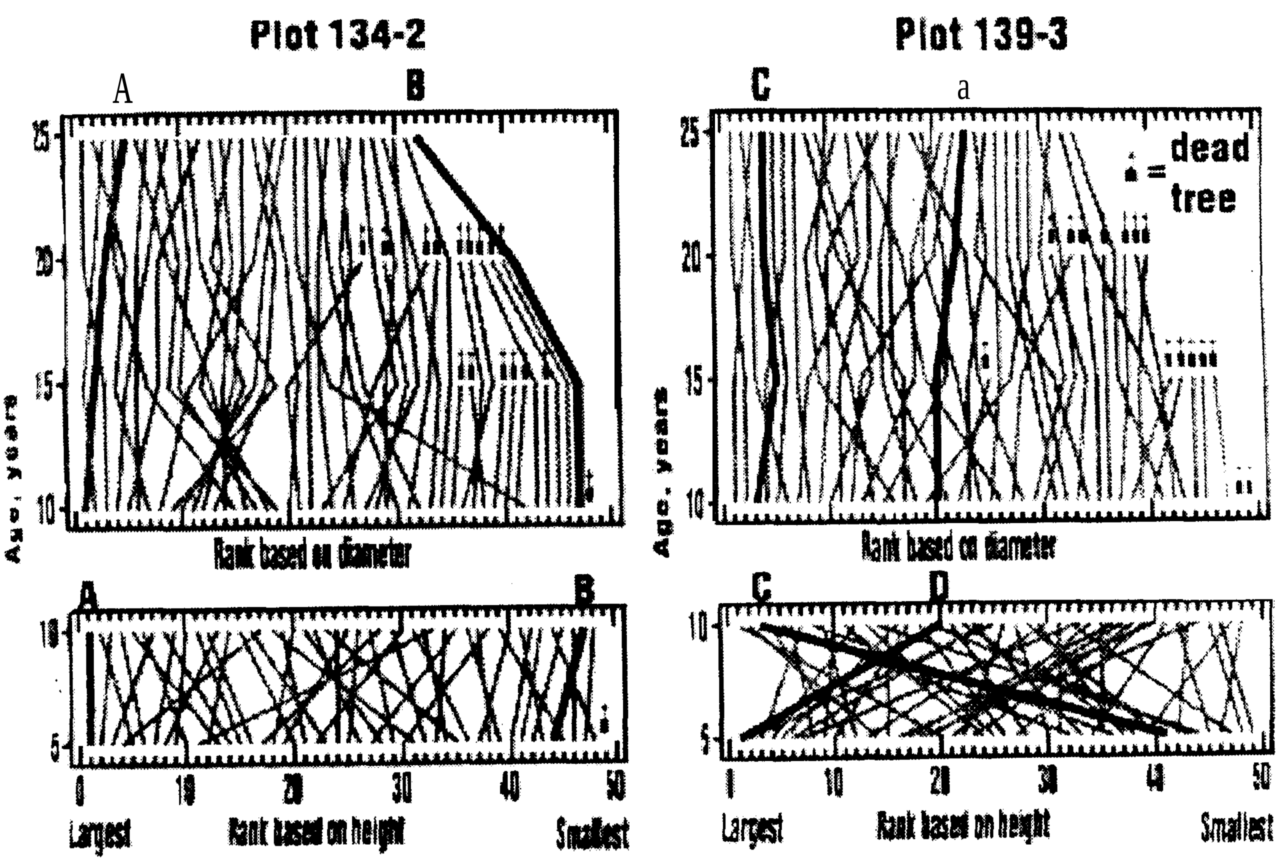

Figure 2-Pine ranks by heights and d.b.h. at different ages for two of the plots used in the analysis.

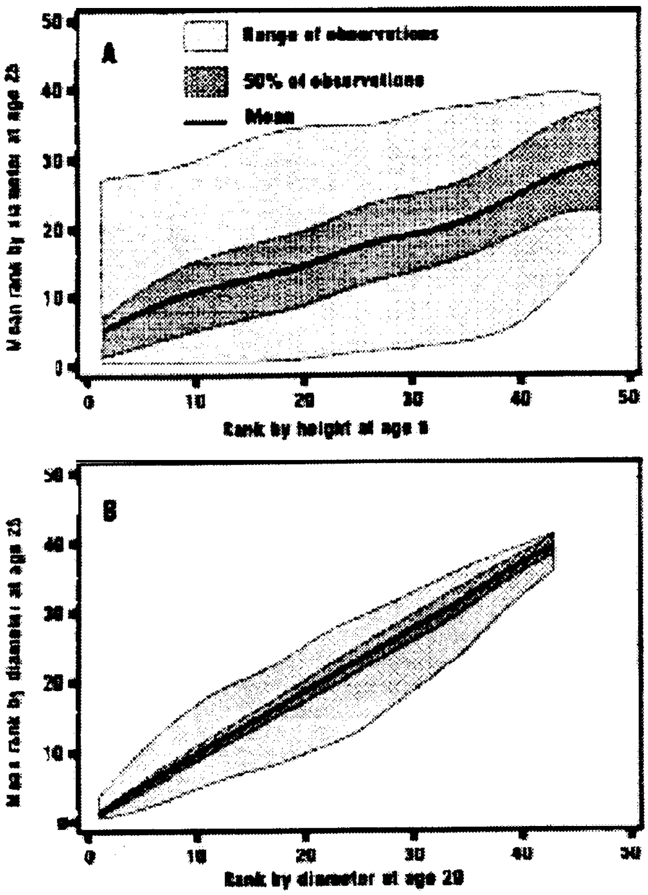

Figure 3--Relationship between rank by height at age 5 (A) and d.b.h. at age 20 (B) to mean rank by diameter at age 25.

diameter at age 20 are compared to ranks based on diameter at age 25, the mean ranking is remarkably similar to that at age 5 (fig. 3B). However, the range at all rankings at age 20 is much lower. This narrower range is expressed as a much higher r^2 in figure 1.

Basal Area Growth Predictions

Parameters for individual trees based on height at age 5 were of little value in predicting basal area growth of individual pines at later ages (table 1). The model accounted for about 35 percent of the variation in basal area growth between the ages of 10 and 15, but the model accounted for only about 20 percent for the age-20 to age-25 period. Height at age 5 accounted for less than 1 percent of the variation when included with the other variables in the model. Competition index, based on the height of a pine and its neighbors at age 5, was slightly more useful at the earlier ages, but by the age-20 to age-25 period, accounted for less than 1 percent of the variation. Ranking by height within plots was the only variable that was a better predictor at later ages than at earlier ones, accounting for 5.6 percent of the variation for the 1 O-l 5 age period and 9.9 percent of the variation for the 20-25 age period, Location was a good predictor for the 10-l 5 age period, but after age 15 it accounted for only 10 to 12 percent of the variation in basal area growth.

Table 1— Variation in basal area growth of loblolly pines of three ages accounted for by variables measured at stand age 5 years

Source	Sum of squares accounted for by variable at stand age		
	10-15	15-20	20-25
	.... Percent		
Height	0.54[a]	0.03	0.07
Competition index	1.66	2.21	0.45
Rank in plot by height	5.55	10.78	9.91
Location	27.64	11.68	10.16
Unaccounted (error)	64.61	75.3	79.41

[a] Percentage of total sum of squares (Type I).

Survival Prediction

Ranking by height at age 5 was an excellent predictor of individual tree survival (fig. 4). Of the pines that were the tallest on each plot at age 5, 95 percent were still surviving at age 25. In contrast, pines that were ranked near the bottom at age 5 had nearly all died by age 25.

CONCLUSIONS

Pine heights at age 5 accounted for about 40 percent of the variation in SI_{25} indicating that projections based only on age-5 heights should be used with caution. Predictions or decisions based on age-5 results should be considered tentative and need to be reevaluated as later measurements become available. None of the parameters based on height at age 5 was independently useful in modeling individual pine basal area growth. Little is gained by attempting to

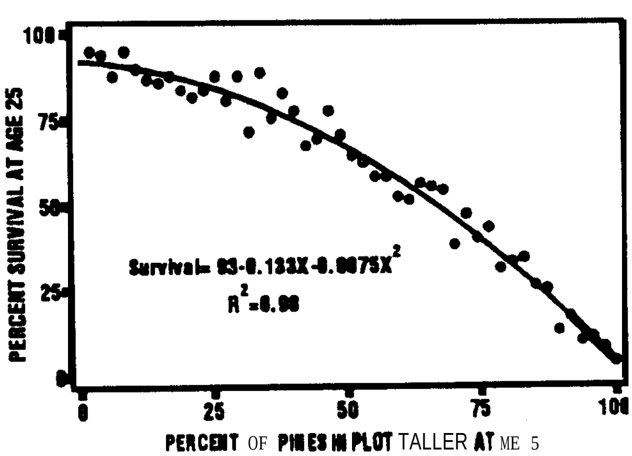

Figure 4—Relationship between rank of pines within each plot, based on height at age 5, and survival at age 25.

designate dominant and codominant or crop trees at age 5. A notable exception is that rank at age 5 was very useful in predicting survival of individual trees at age 25.

Predicting the site index or modeling stand development using early measurements probably requires more site information than is normally documented in research studies. Additional measurements need to be made to account for these factors, including competition, soil properties, past land management, and genetics. Competition at early ages may be an important factor in later stand size and structure. Pines on sites that have severe herbaceous competition may grow slowly in the first 5 to 10 years but grow more rapidly once the stand shades the competition (Haywood and Tiarks 1990). Soil properties may affect the rate of height growth by restricting root penetration or limiting water availability (Zahner 1962). The effects of soil properties may not be fully apparent until the stand has fully occupied the site. Past land management such as agricultural uses or prescribed fire may affect the amount and kind of woody competition and soil fertility. Some of the variation may be the result of differences in genotype, with some trees able to grow better after crown closure than before (Wakeley 1971).

We recommend that additional measurements be made beginning at age 5. These include diameters of the bole, both near the ground line and at breast height: the length of the crown; and a description of the amount and kind of competition. Studies should be located on sites that have uniform soils and have received common management in the past. More detailed studies should include crown diameter as well as a detailed measurement of the competition (Miller and others 1991). Unfortunately, the utility of these additional measurements will not be known until studies that have included these early measurements approach rotation age. Until then, studies testing new management practices should have a plot size large enough to allow measurement through rotation age.

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