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Variations in Height-Over-Age Curves for Young Longleaf Pine Plantations

WILLIAM D. BOYER

ABSTRACT. Some environmental factors related to height growth of longleaf pine (*Pinus palustris* Mill.) plantations were identified by analyses of data from remeasured plots. A total of 660 plots, mostly from the Southwide Pine Seed Source Study, provided 2,737 height-over-age observations from age 3 through ages 15 or 20 to 22. A single variable equation derived from all observations, $\mathrm{Log}_{10}(\mathrm{Height}) = b_0 + b_1(\mathrm{Age})^{-1}$, was fitted to each plot. Slope coefficient (b,) from individual plots became the dependent variable for analyses to determine association of height growth patterns with recorded site and stand variables. Seventy percent of slope coefficient variation among 32 seed-source plantings was accounted for by classification of planting sites into (1) old fields, (2) mechanically prepared cutover sites, and (3) unprepared cutover sites. Among plots, coefficient values were significantly related to stand density, site quality, and seed source. Results indicate the need for a series of polymorphic plantation site-index curves, or growth models, that take into account important site-specific variables affecting early height growth. FOREST SCI. 29: 15–27.

ADDITIONAL KEY WORDS. *Pinus palustris*, site index, site quality, stand density, site preparation, height growth.

EXISTING SITE-INDEX CURVES for southern pines are not always reliable, particularly for young plantations. Often, the predicted site index for a plantation will change over the years, whatever curves are used. Errors increase with the time from index age (McGee and Clutter 1967). Any single set of curves appears to be applicable to a narrow but undefined range of conditions.

Some errors in site-index estimation stem from recognized sources. It has long been known that the height growth pattern of pines established on old fields differ from that of trees established on forest sites. Chapman (1938) reported that height-over-age curves for old fields differed from those in natural stands and warned of inaccuracies in yield tables constructed by combining data from natural and old-field longleaf pine (*Pinus palustris* Mill.) stands. Allen (1955) reported that 10-year-old longleaf planted on old fields averaged 2.1 m taller than those planted on cutover sites although soils were similar. This same phenomenon has been reported for other southern pines, when curves derived from old-field stands are compared with those from cutover forest sites (Bailey and others 1973).

That site quality sometimes influences the form of height-over-age curves (McGee and Clutter 1967, Beck 197 1, Bennett 1972, Beck and Trousdell 1973, Graney and Burkhart 1973, Trousdell and others 1974) suggests that site-related polymorphic site-index curves may often be better than the common proportional curves. Stand density sometimes affects the height-growth pattern of conifers (Alexander and others 1967, Bennett 1975, Curtis and Reukema 1970, Harms and Lloyd 198 1, McClurkin 1976), and such density effects are another source of error in site-index estimates.

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FIGURE 1. Longleaf pine plantation in its fifth growing season. Does the rapid early growth on this mechanically prepared site signify an improvement in site quality?

Site index is a major independent variable in volume yield projections, and errors in site-index estimates will lead to equally serious errors in projected yields. For example, a reduction of 5 ft (from 60 to 55 ft) in age-25 site index for slash pine results in a 25 percent reduction in volume yield at age 20 (Bennett and others 1959). Despite the probability of errors in site-index estimates and associated yield projections for young plantations (Fig. 1), such estimates are often used to evaluate effectiveness of cultural treatments. This can lead to serious miscalculations of economic benefits.

The many sources of error in existing site-index curves should be recognized and minimized in all new sets of curves. New polymorphic curves developed from height-over-age data derived from stem analyses or periodically remeasured trees should reduce the biases inherent in the traditional procedure for construction of proportional curves. For the study reported here, height-over-age data from 660 remeasured plots were used to investigate relationships between early height growth of longleaf pine plantations and several stand and site factors.

METHODS

DATA BASE

The Southwide Pine Seed Source Study (SPSSS), described by Wells and Wakeley (1970), provided most of the data, 637 of 660 remeasured plots, for this study. The other 23 plots were from two separate studies conducted in west Florida. Trees on all plots were scheduled for measurement at age 3 and 5 and at 5-year

TABLE 1. Distribution of plots among stand density (survivors at age 10) and site quality (height at age 15) classes.

Site condition and stand density (trees per hectare)	Height (meters)—							Total
	4	6	8	10	12	14	16	
Old field	....	....	....	*Number*	....	....	....	....
400		0	8	8	0	2	0	18
1,000	0	0	5	14	11	7	0	37
1,600	0	2	7	14	34	12	0	69
2,200	0	2	15	21	62	16	3	119
2,800	0	0	3	2	25	10	0	40
Prepared forest site								
400	1	4	11	1	0	0	0	17
1,000	11	8	7	3	3	0	0	32
1,600	11	18	8	3	2	0	0	42
2,200	1	7	5	9	2	0	0	24
2,800	0	1	0	0	0	0	0	1
Unprepared forest site								
400	2	7	4	3	2	0	0	18
1,000	4	6	25	17	12	4	0	68
1,600	5	3	22	37	22	5	0	94
5200	2	9	12	27	20	5	0	75
2,800	1	0	0	2	2	1	0	6
Total plots	38	67	132	161	197	62	3	660

intervals thereafter, although the remeasurement schedule was not always strictly met. Of the 660 plots supplying measurement data for this study, 468 had no measurement data beyond age 15. Seventy-one plots were measured through age 16 or 17, and 12 1 plots were measured through ages 20 to 22. All told, 14 plots had 6 height-over-age measurements, 91 plots had 5, 533 plots had 4, and 22 plots had only 3 measurements.

SPSSS series 1 and 2 (planted during winter 1952-53) and series 4, 5, and 6 (planted during winter 1956-57) are represented in this study, with 34 plantings covering all coastal states from Texas to North Carolina. At two planting locations, plantings were replicated. Replicates were combined, so the recognized plantings totaled 32.

The SPSSS plots were each 20.12 m (66 ft) square, with six plots per block and four blocks per planting. Within each plot seedlings were planted at 1.83 X 1.83 m (6 *X* 6 ft) for 12 1 trees (11 *X* 11) per gross plot. Measurements were taken from a central net plot of 49 trees (7 *X* 7). The 34 SPSSS plantings, with 24 plots each, originally had 816 plots. Of these, 637 (78 percent) were used in this study. The other plots were excluded because of excessive mortality (over 50 percent) between remeasurements after age 5 or because they had less than four survivors per net plot (245 trees/ha). None of the plots had been thinned. Most mortality had occurred by age 5.

At each examination, on each plot, the number of surviving trees was recorded and mean height of the tallest half of surviving trees was determined. Plot data indicated that this fraction included the largest number of probable crop trees while consistently excluding all the slow-growing individuals most likely to become intermediate and suppressed trees.

The 660 plots provided 2,737 height-over-age observations and were distributed among three planting-site conditions (old fields, mechanically prepared cutover forest sites, and unprepared cutover forest sites) and also a range of stand density and site quality classes (Table 1).

ANALYSES

Selection of a Height-Growth Model.-The objective of this study is to identify factors associated with plot-to-plot differences in height-growth patterns of planted longleaf pine. For this purpose, a regression model with a function of age as the independent variable will provide a coefficient that is characteristic of each plot. To determine what single function of age will be most applicable to 660 individual plots, I included all height-over-age data (2,737 observations) in a stepwise regression analysis of the form $\text{Log}_{10}(\text{Height}) = b_0 + b_1(\text{Age})^{-1/2} + b_2(\text{Age})^{-1} + b_3(\text{Age})^{-2} + b_4(\text{Age})^{-3} + b_5(\text{Age})^{-4}$. Next, to see if the best function of age for all data combined was also best for each site condition, I applied the same stepwise regression analysis to all observations within each of the three planting-site conditions.

The best single-variable height-over-age model derived for all observations was then fitted to the height-over-age data for each plot, and 660 equations obtained. Then I used regression analysis to explore for associations between height-growth patterns, as represented by slope coefficients, and recorded site and stand variables.

Of the 660 plots, 512 were not measured after age 16. So, curves fitted to data through age 15 or 16 may differ from curves derived from data that included measurements at later ages. Using 121 plots with measurements through age 20 to 22, I explored how well the form of height-over-age curves is established by age 15. First, for each plot, I fitted a height-over-age curve and determined slope coefficient for observations through age 15 only. Then, using all height-over-age observations, I fitted a curve and determined slope coefficient for each of the same plots. The relationship of coefficients derived from measurements through age 20-22 to those through age 15 only was explored by regression analysis.

Independent Variables. -*Planting-site conditions:* All planting sites were classified as: (1) old-field sites, (2) mechanically prepared cutover forest sites, or (3) unprepared cutover forest sites, on the basis of information in the planters report for the SPSSS, plus some field checks. A broad range of treatment intensities occurred within each class. For example, some old-field sites were plowed and disked before being planted, some were burned, and others were untreated. Old fields abandoned long enough to grow a stand of trees that was then removed (over 15 years old) were considered cutover sites.

Stand density: The number of surviving trees per plot at age 10 expressed as trees per hectare. Trees present at this time should have the greatest effect on growth through age 15, the final year of measurement for most plots.

Site quality: The measurement of site quality used for each plot was mean height of tallest half of surviving trees at age 15. For those few plots measured at age 16 or 17 instead of 15, the height at age 15 was estimated with an assumed equal annual height increment from age 10.

Seed source: There are six seed sources represented in each planting of each of the five series. All plantings of a series contain the same seed sources. Relationship of seed source to form of height-over-age curves was tested within each series.

Geographic location: In these analyses, geographic location includes each planting within each series. So sources of variation include not only plantation location and attendant differences in climate, soils, and topography, but also seed sources represented in the planting (Series) and year of planting (Series 1 and 2 vs. Series 4, 5, and 6).

RESULTS

Development of Height-Over-Age Curves

All Data (2,737 Observations). -The best one-variable regression for all observations was $Log_{10}HT = 1.3684 - 6.1764(Age)^{-1}$. Standard error ($sy \cdot x$) was 0.2740. The only other significant variable (0.05 level) was $(Age)^{-4}$; improvement was slight, decreasing standard error to 0.2729.

Grouping observations into the three planting-site conditions resulted in the following regressions:

(1) *Old fields* (1,172 observations).

The best one-variable regression was $Log_{10}HT = 1.4006 - 5.2442(Age)^{-1}$ with a standard error of 0.1362. No other independent age variable made a significant contribution to the regression.

(2) Prepared forest sites (488 observations).

The best one-variable regression was $Log_{10}HT = 1.2315 - 6.4476(Age)^{-1}$ with a standard error of 0.2319. The only additional variable making a significant improvement in the regression was $(Age)^{-4}$ which, when included, reduced standard error to 0.2304.

(3) Unprepared forest sites (1,077 observations).

The best one-variable regression was $Log_{10}HT = 2.4870 - 5.8434(Age)^{-1/2}$ with a standard error of 0.2363. The best two-variable regression included (Age))' first and $(Age)^{-2}$ second, with a standard error of 0.2362. Use of $(Age)^{-1}$ as the only independent variable is nearly equivalent to the "best" obtained with $(Age)^{-1/2}$. The equation is $Log_{10}HT = 1.3867 - 7.0027(Age)^{-1}$ with a standard error of 0.2466.

Single-variable regressions with $(Age)^{-1}$ as the independent variable resulted in intercepts of about 1.4 for both old fields and unprepared sites, and 1.2 for prepared sites. Slope coefficients differed markedly among the three planting-site classes (-5.2 for old fields, -6.4 for prepared sites, and -7.0 for unprepared sites).

Plot Data. -In all studies, the plot was the treatment unit. All recorded independent variables, and many unrecorded variables, may influence the form of height-over-age curves on individual plots. The best single-variable height-over-age model applicable to the data as a whole ($Log_{10}HT = b_0 + b_1(Age)^{-1}$ was fit to each plot, giving 660 regression equations. Differences in slope coefficient *(b,)* represent differences among plots in shape of height-growth curves. Individual-plot slope coefficients, with negative sign omitted, became the dependent variable for further analyses.

Application of one height-growth model to all plots was necessary so that comparable slope coefficients would result. The model used while best for all observations combined, was not necessarily the best for every plot, although suitable for most according to individual-plot regressions.

Analyses indicated that slope coefficients obtained from observations through age 15 were very close ($r^2 = 0.99$ 1) to those from observations through age 20-22. The change in coefficient value from age 15 to age 20-22 averaged only 0.07 percent for old fields, 0.29 percent for prepared, and 1.65 percent for unprepared forest sites. So, coefficients for all plots were pooled for further analyses without regard to plantation age at the last measurement.

Effect of Site Variables on Height-Over-Age Curves

Planting-Site Condition. -Grouping into the three planting-site conditions accounted for 70 percent of the variation among the 32 SPSSS plantings in average slope coefficient for height-over-age curves. The residual variation can be attrib-

TABLE 2. Duncan's Multipe Range Test[1] of within-series differences in growth-curve coefficients. Location of planting and planting-site condition are indicated.

Series	Coefficients									
1	Ga. (O)[2]	Miss. (U)	Ala. (U)							
	5.34	6.19	6.13							
2	N.C. (O)	S.C. (O)	Fla. (P)							
	5.16	5.48	7.04							
4	Ga. (O)	Tex. (O)	Ala. (O)	Ga. (O)	La. (U)	Miss. (U)	Ala. (U)	La. (U)	Ala. (U)	Ala. (U)
	4.77	4.84	5.18	5.72	6.23	7.08	7.14	7.25	7.47	7.70
5	S.C. (0)	S.C. (O)	Ala. (O)	S.C. (O)	N.C. (O)	Fla. (P)	Ala. (P)	N.C. (U)		
	4.34	4.88	5.09	5.20	5.76	6.27	6.31	7.93		
6	Ga. (0)	S.C. (O)	Ga. (O)	N.C. (U)	La. (U)	Miss. (U)	La. (U)	S.C. (U)		
	5.14	6.17	6.24	6.33	6.37	6.60	7.22	7.50		

Means underscored by a single line are not significantly different at 0.05 level of probability.

[2] Location of planting (State) and planting-site condition (0 = old field, P = prepared forest, U = unprepared forest).

uted to factors such as year of plantation establishment, varying seed sources, and geographic location with associated climatic and soil-site differences. Inclusion of average plantation stand density or site quality did not contribute significantly to the regression.

With equal weight given to the average slope coefficient for each planting, the values for each of the three planting-site conditions are

Planting site	*Plantings*	*Coefficient*	*Standard deviation*
Old field (0)	15	5.286	0.519
Prepared forest (P)	3	6.526	.444
Unprepared forest (U)	14	6.980	.575

With equal weight given to each of the 660 plots, the average value of coefficients for the three planting-site conditions are 0 = 5.275; P = 6.477; U = 6.983. These values are quite close to those derived from all height-over-age values within each planting-site condition.

Planting-Site Location.-An analysis with Duncan's Multiple Range Test was made of coefficients for plantings in each of the five SPSSS series, with each plot constituting an observation. Within each series, old fields have the smallest coefficients and unprepared forest sites the largest; prepared sites are in between (Table 2). Classification into planting-site condition alone accounted for 43 percent of all plot-to-plot variation.

Seed Source. -Seed source significantly affected slope coefficients in four of the five series. Seed source is therefore a known source of variation contained in the residual error term in all analyses of site variables. Normal commercial plantations would not have this source of variation.

Stand Density and Site Quality. -Both stand density at age 10, and site quality expressed as tree height at age 15 were significantly related to slope coefficients. Within each of the three planting-site conditions, the possible relationship of both stand density and site quality to shape of height-over-age curves was explored through regression analyses. Stand density and site quality were both related to slope coefficients on prepared and unprepared sites. Only stand density was associated with slope coefficients on old fields. The relatively few old-field plots with poorer than average site quality may be a factor.

Equations for each planting-site condition are listed below. The Y is growth curve slope coefficient, TPH is stand density in trees per hectare, and SQ is site quality indexed as tree height (meters) at age 15.

(1) *Old-field sites* (283 plots).

$$Y = 5.8310 - 0.000296(\mathrm{TPH})$$

$F_{1/281}$ = 17.30; Prob. greater F = 0.0002; Std. error $(Sy \cdot x)$ = 0.7425; $Sb_1(\mathrm{TPH})$ = 0.000071; r^2 = 0.0580.

(2) Prepared forest sites (116 plots).

$$Y = 7.7162 - 0.000428(\mathrm{TPH}) - 0.08920(\mathrm{SQ})$$

$F_{2/113}$ = 7.26; Prob. greater F = 0.0014; Std. error $(Sy \cdot x)$ = 0.9800; $Sb_1(\mathrm{TPH})$ = 0.000149; $Sb_2(\mathrm{SQ})$ = 0.04029; R^2 = 0.1138.

(3) Unprepared forest sites (261 plots).

$$Y = 8.2746 - 0.000395(\mathrm{TPH}) - 0.06952(\mathrm{SQ})$$

$F_{2/258}$ = 14.33; Prob. greater F = 0.0001; Std. error $(Sy \cdot x)$ = 0.9098; $Sb_1(\mathrm{TPH})$ = 0.000106; $Sb_2(\mathrm{SQ})$ = 0.02381; R^2 = 0.1000.

In all three planting-site conditions, slope coefficient values (negative signs omitted) declined with increasing stand density. For prepared and unprepared forest sites, but not old fields, increasing site quality similarly resulted in declining coefficient values. Lower coefficient values indicate a greater proportion of height growth taking place at an early age.

Based on results of this study, planting-site condition, stand density, and site quality should be included as variables in development of height-growth models and construction of site-index curves for longleaf pine plantations.

Growth-Curve Comparisons

The height-over-age curves for the three planting-site conditions differed greatly from one another. All three differed considerably from longleaf pine site-index curves using equations developed from Misc. Publ 50 (U.S. Department of Agriculture 1976, Farrar 1973) for the years from 15 to 25. With height-over-age curves for unprepared forest sites used as a basis for comparisons, deviations of height-growth curves for old-field and prepared-site plantations, and also of curves from MP-50, were plotted for age-25 site-index values fixed at 6, 15, and 24 m (Figs. 2, 3, and 4). Plantation stand density (age 10) was set at 2,000 trees/ha for these comparisons.

For all three site qualities (poor-medium-good) the curves for prepared sites fell between those for old-field and unprepared sites. As site quality improved, prepared-site curves approached those for old fields. All old-field curves reached maximum departure from unprepared-site curves at plantation age 9 years. Maximum departures of prepared-site from unprepared-site curves ranged from age 9 for the good site to age 10 for the poor site. The MP-50 curves fell below all the plantation curves, so their use for 15- to 20-year-old plantations will greatly overestimate site index.

On good sites, old-field plantings at age 9 averaged 1.7 m (20 percent) taller than plantings on unprepared sites. Even on poor sites the difference between the two planting-site conditions at age 9 was 0.7 m, which amounts to a 37 percent height increase of old-field over unprepared-forest plantings at that age.

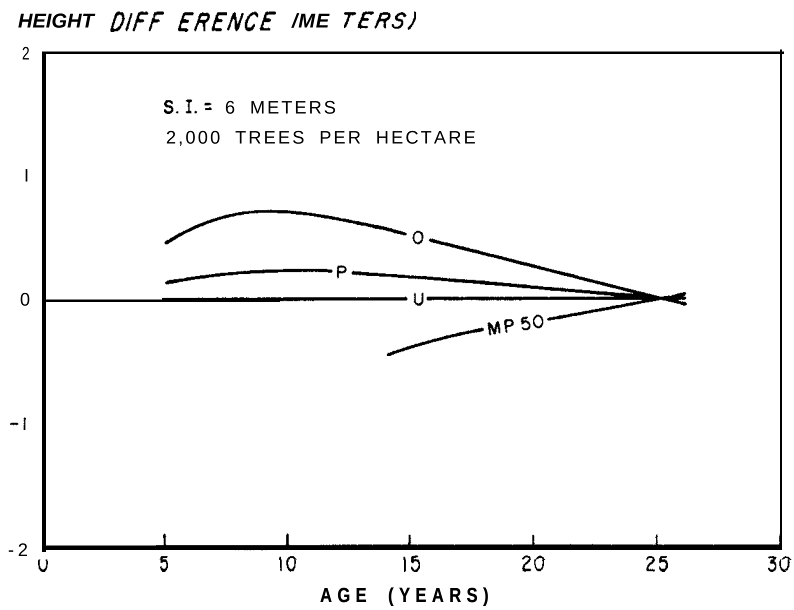

FIGURE 2. Deviations of plantation height-over-age curves for old fields (0), prepared sites (P), and MP-50, from the curve for unprepared sites (U) on a low site (SI,, = 6 m).

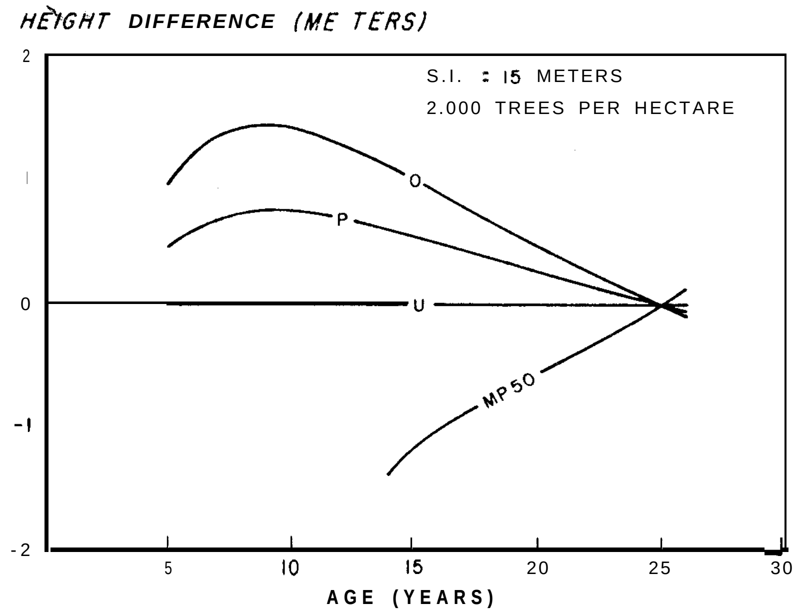

FIGURE 3. Deviations of plantation height-over-age curves for old fields (0), prepared sites (P), and MP-50, from the curve for unprepared sites (U) on a medium site (SI,, = 15 m).

Changes in annual height increment also illustrate differences among planting-site conditions in height-growth patterns. Comparison of annual height growth in old fields and unprepared forest sites, again for a plantation of 2,000 trees/ha, was made for each of the three site qualities (Fig. 5). Trees on old fields reached their peak in annual height increment at age 6-7. On unprepared sites the peak was not reached until age 8-9. On plots with the same site index, annual height

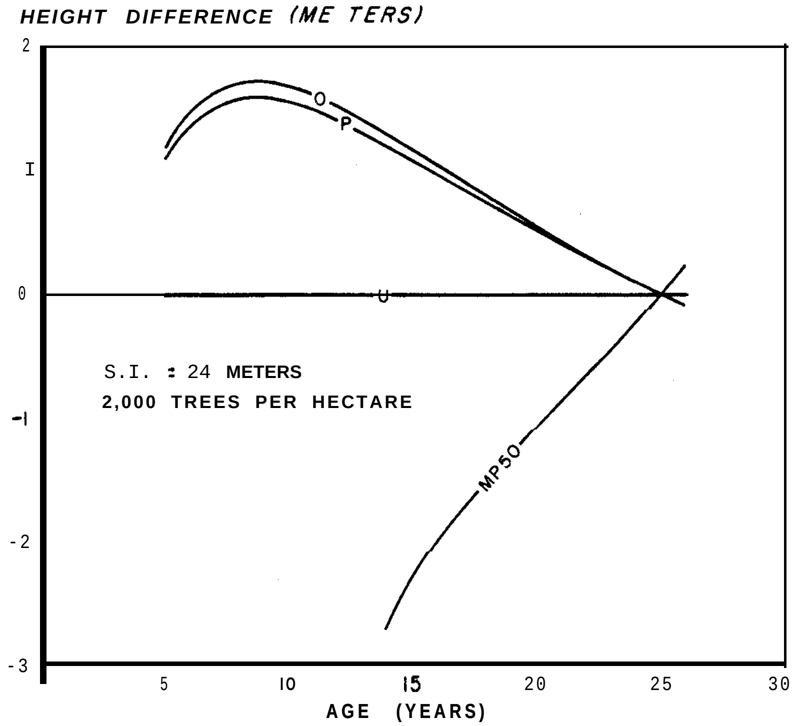

FIGURE 4. Deviations of plantation height-over-age curves for old fields (0), prepared sites (P), and MP-50, from the curve for unprepared sites (U) on a high site (SI_{25} = 24 m).

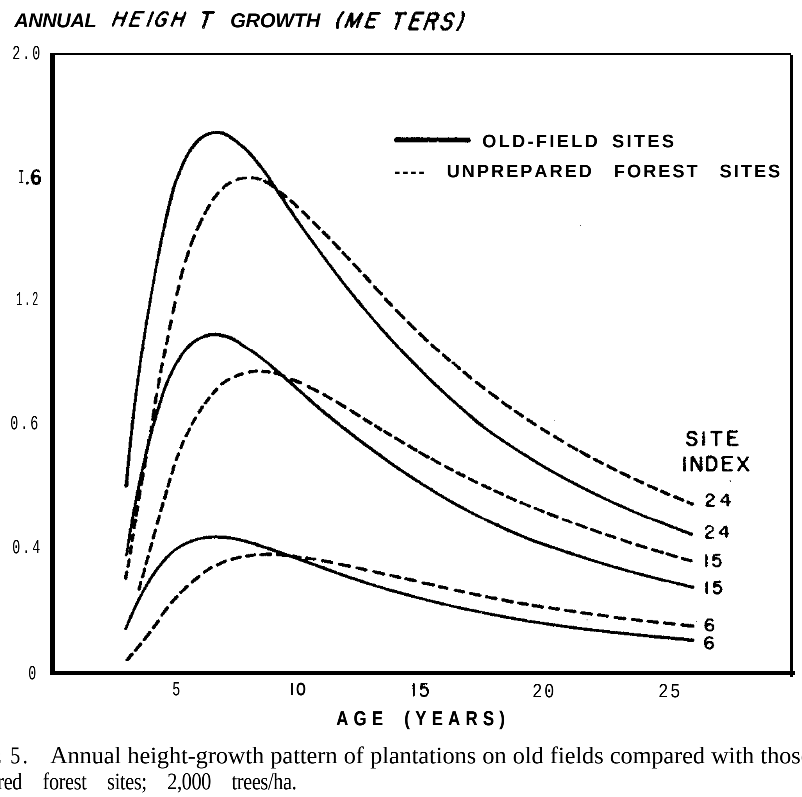

FIGURE 5. Annual height-growth pattern of plantations on old fields compared with those on unprepared forest sites; 2,000 trees/ha.

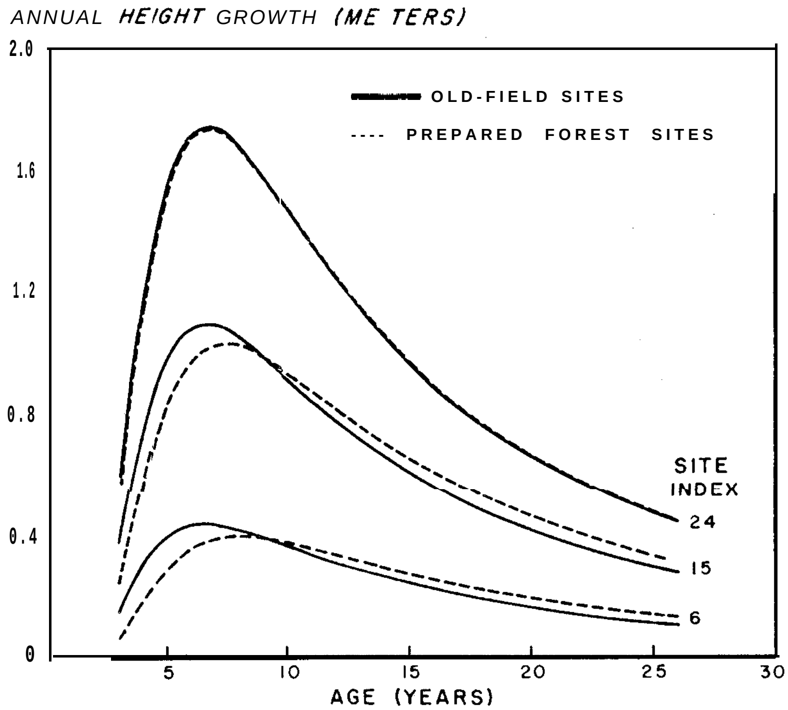

FIGURE 6. Annual height-growth pattern of plantations on old fields compared with those on mechanically prepared sites; 2,000 trees/ha.

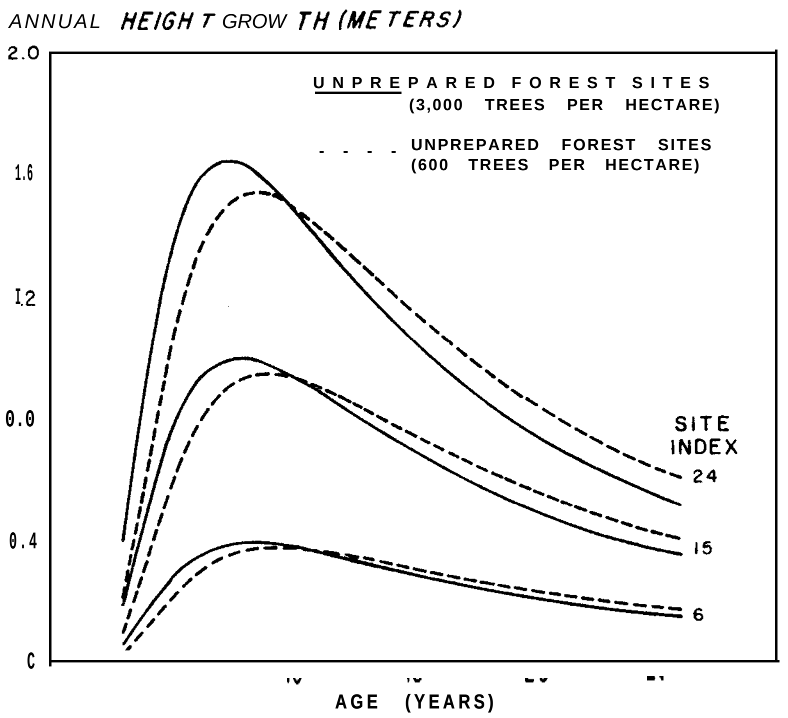

FIGURE 7. Annual height-growth pattern of plantations on unprepared forest sites. Comparison of densities of 3,000 with 600 trees/ha.

growth on old fields exceeded growth on unprepared forest sites through age 9-10. Thereafter, annual height increment on unprepared sites exceeded that on old fields. Annual height increment on prepared forest sites was similar to that on unprepared sites when site quality was poor and was nearly identical to the old-field pattern when site quality was good (Fig. 6).

Stand density similarly affected growth curves for all three planting-site conditions. On unprepared forest sites, for example, annual increment for high-density stands (3,000 trees/ha) was greater than for low-density stands (600 trees/ha) through age 9-10 and less thereafter (Fig. 7). Within a site class, peak annual height growth was reached earlier in high-density stands than in low-density stands. The peak in annual height growth was also reached earlier on good sites than on poor sites whatever the density.

DISCUSSION

The form of height-over-age curves recorded in young longleaf pine plantations was related mainly to planting-site conditions. But the actual intensity of site preparation within each planting-site condition varied greatly. For old fields, time since abandonment and intensity of planting-site preparation significantly affected curve form. Fields cultivated before planting or abandoned from cultivation only 1 or 2 years had the smallest coefficients. Old fields abandoned long enough to grow a stand of trees requiring removal had coefficients similar to those from unprepared cutover sites. Wilhite and Jones (1981), following stem analyses of dominant slash pines (*Pinus elliottii* Engelm. var. *elliottii)* in 35- and 45-year-old plantings, reported that annual height increment of trees planted on beds culminated 3-4 years earlier than that of trees in an adjacent unbedded planting. The height advantage of trees on beds was greatest (3.3 m) at age 17 and had diminished continuously thereafter. Bennett (1972) observed that current annual height increment of planted slash pine culminated later on old fields than on soil bank plantings, which were usually established directly on cultivated cropland.

The degree of competition from low vegetation was mostly responsible for the differences in growth curves, because all overtopping hardwoods were removed. With reduced competition, plantings on old fields and prepared sites had comparatively rapid early height growth, with annual increment culminating about 2 years ahead of plantings on unprepared cutover land. As canopies close and understory competition is shaded out, growth performance of the plantations should be governed more closely by the productive potential of the site itself.

The shape of height-growth curves was related to stand density on all three planting-site conditions. If site index at age 25 were the same for a high- and a low-density stand, then in the early years the high-density stand would grow faster than the low-density stand. Sometime between the ages of 7 and 10 the annual height increment of the high-density stand would fall below that of the low-density stand. This crossover occurs sooner on good sites than on poor ones. In fact, high- and low-density stands established on the same site should actually grow at the same rate during the first few years. The earlier culmination of height increment and slowdown in growth rate of the high-density stand will result in a lower apparent site index for the high-density stand than for the low-density stand on the same site. Site-index curves should be adjusted for large differences in stand density in order to obtain a better estimate of actual site quality.

Curve shape was also related to apparent site quality (height at age 15) on prepared and unprepared sites but not on old fields, in part, possibly, because of the relatively few plots on "poor" sites. Annual height increment culminates earlier on good sites than on poor sites. So, site-index curves for prepared and unprepared cutover sites should be polymorphic.

Because site and stand conditions markedly influence the form of height-over-age curves for longleaf pine plantations, no single set of site-index curves will have broad application. Use of a single set of curves for longleaf plantations, particularly in the 10- to 15-year age range, may result in large errors in estimated site index. For example, an old-field plantation averages 7 m tall at age 10 with 2,000 trees/ha. Unprepared-forest curves give a site index (age 25) of 17.6 m, and old-field curves give a site index of 14.4 m-a difference of 3.2 m. Because site index is a major variable in volume yield tables, errors in site-index estimations can lead to large errors in estimated productivity.

Interim site-index (age 25) curves developed from this study have been reported elsewhere (Boyer 1980). Their applicability will be tested on other remeasured plantations as data become available. As a start, height growth of longleaf pines planted on a mechanically prepared flatwoods site in northeast Florida was reported by Wilhite (1976). Tree heights were measured at age 1, 3, 5, 8, 10, 15, and 20. Fitting the height-over-age curve to the model Log HT = $b_0 + b_1(\text{Age})^{-1}$ resulted in a growth-curve coefficient (b_1) of -6.15, quite close to the average prepared-site coefficient of -6.48 derived from plots in this study. But, the flatwood plantings averaged 1,334 trees/ha, with an average height of 9.75 m at age 15. Including these two variables in the coefficient prediction equation for prepared sites results in a coefficient of -6.28. So results from this study seem applicable to the reported flatwoods conditions.

Increasing intensity of planting-site preparation should measurably accelerate early growth over plantings on similar sites with less intensive or no preparation. If the height-growth advantage of prepared sites over unprepared sites at, say, age 10 is less than the expected value, then a treatment-related increase in volume yield may not be realized at rotation age. This possibility must be considered in any economic evaluation of investments in site preparation. Similar relationships probably exist for plantations of other species of southern pine.

These results emphasize the need for a series of polymorphic plantation site-index curves, or height-growth models, that account for the major impact of site-specific variables on early height growth, especially those related to degree of competition on the planting site.

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