RESULTS AND ANALYSIS OF A SLASH PINE SPACING AND THINNING STUDY IN THE SOUTHEASTERN COASTAL PLAIN

Plantation Management Research Cooperative

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Executive Summary.

Results are presented from a combined planting density and thinning study installed 28 years ago at 28 locations in the Southeastern Coastal Plain in plantations established on cutover land after mechanical site preparation. Stocking densities of 100 to 900 trees per acre are represented in the planting density component of the study, with **15-year** response data for thinning intensities ranging from 25 to 65 percent of the trees removed selectively from below in the thinning component of the study. Average site index was 60 and the average age at the time of thinning was 14 years.

A unique feature of this study is that plots were thinned to match the number of trees per acre of unthinned plots, so that it was possible to compare the growth of the thinned plots with that of unthinned counterparts that had the same number of trees per acre.

Per-acre basal area and volume prediction equations are presented for unthinned plantations, and for thinned plantations when a specified number of trees per acre is left after thinning. Survival and average dominant/codominant height prediction equations for both unthirmed and thinned plantations are presented, and a competition index is defined to account for the basal area growth response of thinned plantations relative to comparable unthinned plantations.

Application of the prediction equations is demonstrated with an example that shows the nature of the implied basal area and volume growth responses relative to a comparable unthinned plantation. These equations provide the information necessary to evaluate the desirability of different initial stocking densities and of thinning regimes

with one thinning of different intensities at about age 14 in similar slash pine plantations in the Coastal Plain.

Results and Analysis of a Slash Pine Spacing and Thinning: Study in the Southeastern Coastal Plain.

Several million acres of slash pine plantations have been planted in the lower coastal plain of Georgia and Florida (Bechtold and Ruark, 1988). Most of these plantations were established on cutover sites after some type of mechanical site preparation.

In this region where pulpwood production predominates, thinning has not been much in evidence. However, during the period 1964 through 1970, Union Camp Corporation and erstwhile St Regis Paper Company installed experimental plots throughout the region to provide information on the relationship between tree growth and growing space, and growth response to thinning. In 1978 these companies made the installations available to the Plantation Management Research Cooperative of the D.B. Warnell School of Forest Resources at the University of Georgia for imposition of thinning treatments, subsequent measurement and analysis.

Description of the Study.

Each installation consisted of a set of monumented plots established in 2- and 3-year old slash pine plantations on cutover and site-prepared land. Mechanical site preparation included single or double harrowing with and without bedding and single or double chopping with and without bedding. Based on soil profile descriptions, soil drainage classes varied from very poorly to somewhat excessively drained. A total of 28 installations represented one county in South Carolina, 8 counties in Georgia and 8 in north Florida.

Two types of plots were installed at each location: Basic Series (BS) plots represent planting survival densities of 100, 200, 300, 450, 700, and at a few locations, 900 trees per acre, as evenly spaced as possible when plots were installed in 2- and 3-year old plantations. BS plots remained unthinned for the duration of the study. Measurement plots within BS gross plots originally contained 25 trees with plot sizes varying accordingly. Suppression and release (SAR) plots were all 1/4 - acre gross plots with interior l/lo-acre measurement plots. These plots were intended to represent the same initial stocking levels as BS plots. Thinning intensities were determined by the surviving trees per acre of the BS plots at the thinning age. For example, if there were 3 SAR plots with a nominal stocking of 700 trees per acre, one was thinned to the same trees per acre surviving in the 450 BS plot at the thinning age, another to match the survival in the 300 BS plot, and the third to match the survival in the 200 BS plot. Thinnings were selective from below, aimed at a uniform distribution of desirable remaining trees.

Average site index for the 28 locations varied from 50 to 72, based on the last measurement and equation 3. Average site index for all locations was 60. Age at time of thinning varied from 10 to 17 years, with an average of 14. All plots were measured on a 2-year cycle since 1978 when the first thinning treatments were imposed, through 1988, with a final measurement in 1993, at which time only 19 installations remained.

Basal Area Prediction for BS Plots.

BS plot measurements averaged over all installations at the time of thinning and at the 1993 measurement are summarized in Table 1. At any given location higher stocking densities produced more basal area, and plots with the same number of surviving trees produced more basal area, the higher the average dominant/codominant height.

BS and SAR plot measurements (before thinning) at the time of thinning and BS plot measurements in 1988 and 1993 were used to estimate the parameters in the following basal area prediction equation:

$$B = e^{-4.279 - 17.461(1/A)} H^{1.400 + 3.099(1/A)} N^{.536 + 1.235(1/A)} \tag{1}$$

n = 599 R^2 = .95 s.e. = 7.6 ft^2/ac

Where B = basal area (ft^2/ac)

A = plantation age (years)

H = average dominant/codominant height (ft)

N = surviving trees per acre

e = base of natural logarithms

n = number of observations

R^2 = 1- [Residual sum of squares/corrected total sum of squares]

s.e. = asymptotic standard error

Equation 1 predicts basal area per acre with age, average dominant/codominant height and number of trees as predictor variables. It can be used to predict future basal area of an existing plantation if estimates of future survival and average dominant/codominant height are available.

Table la. Summary of Unthinned (BS) and Thinned (SAR) Plot Measurements at Time of Thinning and at Last Measurement

Plot Type	At Time of Thinning						At Last Measurement					
	No. Plots	Av. Age (yrs)	Av. Surv.	Av. BA (ft^2/ac)	Av. DBH (in)	Av. Ht.* (ft)	No. Plots	Av. Age (yrs)	Av. Surv.	Av. BA (ft^2/ac)	Av. DBH (in)	Av. Ht.’ (ft)
BS 100	28	13.7	87	20.9	6.6	37	19	27.4	73	43.6	10.5	63
SAR 200-100	20	12.9	86	18.0	6.2	36	18	27.3	77	47.6	10.6	62
SAR 300-100	28	13.7	87	19.1	6.3	40	19	27.4	78	50.2	10.9	64
BS 200	28	13.7	171	37.5	6.3	38	19	27.4	141	73.5	9.8	63
SAR 300-200	28	13.7	171	34.8	6.1	39	19	27.4	148	76.2	9.7	64
SAR 450-200	28	13.7	170	30.0	5.7	38	19	27.4	149	72.0	9.4	63
SAR 700-200	17	13.2	166	27.9	5.6	38	15	27.5	143	64.4	9.1	62
BS 300	28	13.7	256	47.5	5.8	38	19	27.4	207	89.3	8.9	64
SAR 450-300	28	13.7	258	43.2	5.5	38	19	27.4	221	91.4	8.7	63
SAR 700-300	23	13.8	256	40.5	5.4	39	16	27.5	216	92.0	8.8	64
BS 450	28	13.7	379	58.5	5.3	38	19	27.4	270	93.9	8.0	63
SAR 700-450	23	13.8	364	56.4	5.3	39	17	27.4	322	105.3	7.7	63
BS 700	28	13.7	587	80.0	5.0	38	19	27.4	407	117.9	7.3	63
BS 900	9	14.8	768	101.5	4.9	40	3	29.7	564	179.6	7.6	68

*Dominant and Codorninant trees only

Table lb. Number of unthinned (BS) and thinned (SAR) plots measured

Plot Type	Number of plots measured in year			
	1978	1980	1988	1993
BS	115	35	144	98
SAR	155	52	200	126

Survival Prediction.

Plots thinned selectively from below had a higher subsequent survival than unthinned plots with the same number of trees per acre. Average survival over all installations for the BS plots since establishment and for the SAR plots since thinning are summarized in Table 1. These data were used to estimate the parameters in a survival prediction equation based on a generalized exponential decline function:

$$N_2 = N_1 e^{-(.0041 - .0019Z)(A_2^{1.345} - A_1^{1.345})} \tag{2}$$

n = 477 R^2 = .97 s.e. = 31 trees/ac

where N_i = surviving trees per acre at age A_i (i = 1, 2)

Z = 0 if plantation had not been thinned

= 1 if thinned at, or prior to, age A_1

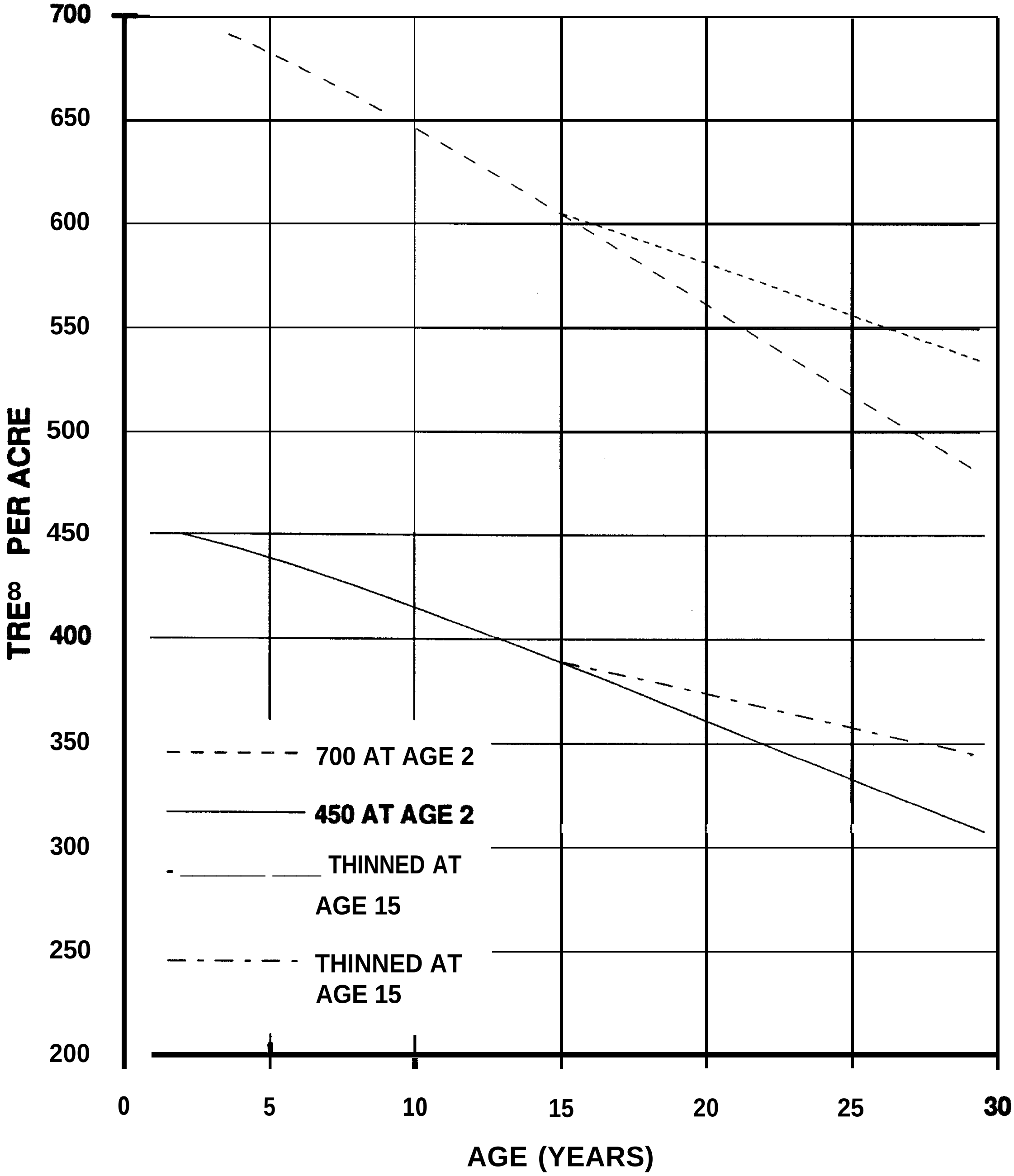
n, R^2, s.e. as previously defined.

The survival curves in Figure 1 for unthinned plantations with initial (Age 2) stockings of 700 and 450 trees per acre were generated with equation 2, as were the survival curves for plantations thinned at age 15 to match the survival in unthinned plantations at that age, as shown in Figure 1.

Average Dominant /Codominant Height Growth.

Average height of all trees classified as dominant or codominant was calculated for each BS and SAR plot at the thinning age and at the 1988 and 1993 measurements. From Table 1 it is clear that different stocking levels and thinning intensities did not

FIGURE 1. SURVIVAL CURVES FOR DIFFERENT STOCKING DENSITIES AND FOR THINNED PLANTATIONS



have a significant effect on average dominant/codominant height for the range of densities represented in this study. Average dominant/codominant heights over allinstallations for the BS and SAR piots are summarized in Table 1. A height projection equation based on a growth model proposed by Richards (1959) was fitted to this data.

$$H_2 = H_1\left[\left(1 - e^{-.045A_2}\right)/\left(1 - e^{-.045A_1}\right)\right]^{1.133} \tag{3}$$

n = 345 R^2 = .60 s.e. = 4.7 ft

where H_i is average dominant/codominant height at age A_i (i = 1, 2). An anamorphic site index equation with index age 25 is derived from equation 3.

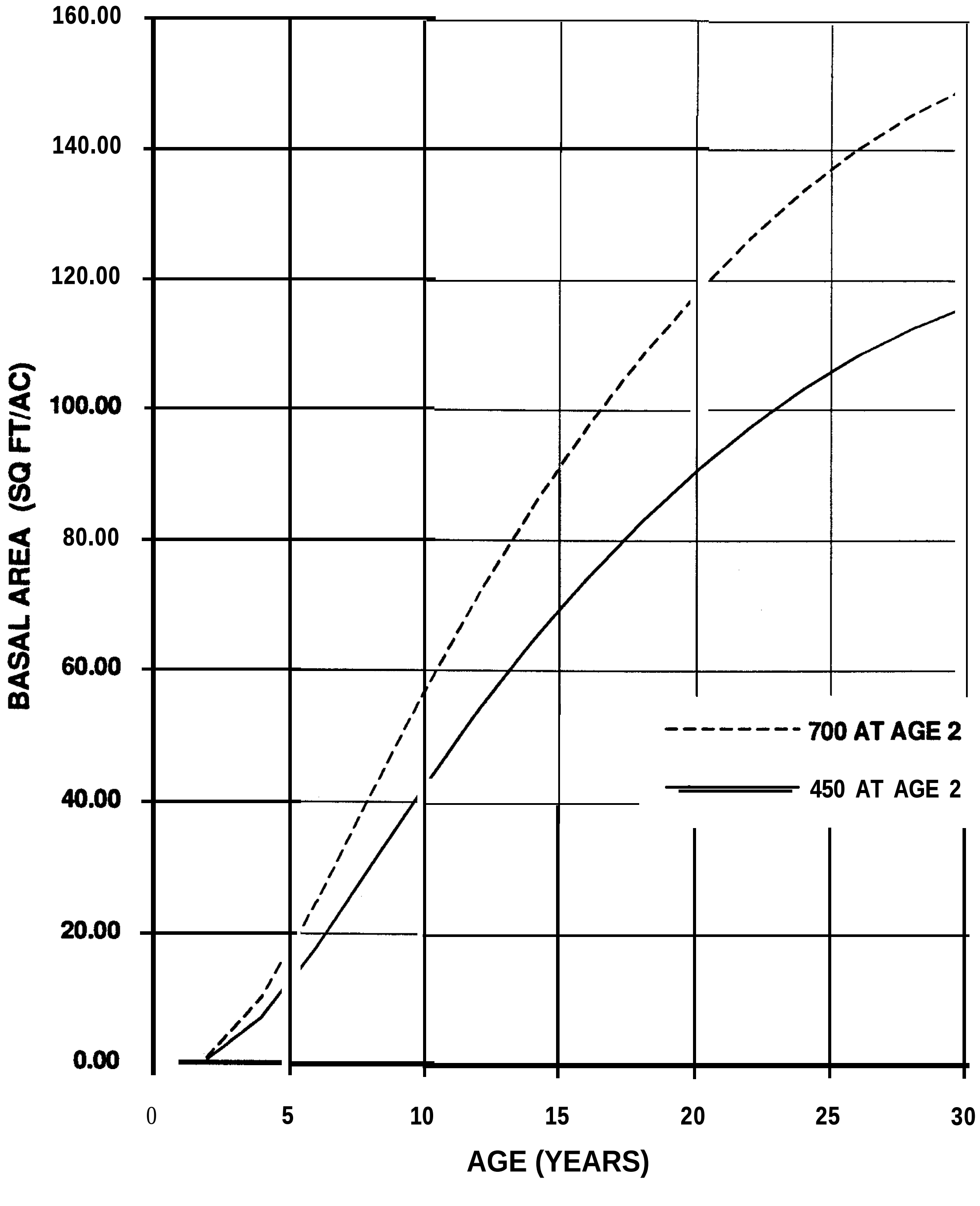
$$H = 1.560\ S\ (1 - e^{-.045A})^{1.133} \tag{4}$$

where S is the site index. Equation 4 with S = 60 and equation 2 with age 2 survival of 700 and 450, and equation 1 were used to generate the basal area growth curves in Figure 2.

Basal Area Prediction for SAR Plots.

Thinning treatments in this study were designed to allow a comparison of the growth of plots that had been thinned with that of unthinned plots at the same location and with the same number of surviving trees per acre as the thinned plots. For example, if a BS 300 plot had 250 surviving trees per acre at the thinning age, SAR plots with initial stockings of 700 and 450 trees per acre were thinned to 250. All thinnings were

FIGURE 2. BASAL AREA GROWTH CURVES FOR DIFFERENT STOCKING DENSITIES. SITE INDEX 60



selective from below in the sense that suppressed, deceased or malformed trees had the highest priority while attempting to leave desirable crop trees reasonably uniformly spaced. Thinning ages varied from 10 to 17 years.

Plot measurements for BS and SAR plots, averaged over all installations, are summarized in Table 1 at the time of thinning and for the last measurement. A model to predict the basal area removed in this type of thinning was proposed by Field and others (1978). Data from SAR plots were used to estimate the parameter in this model:

$$B_t = B_b \left(N_t / N_b\right)^{1.268} \tag{5}$$

n = 207 $\quad R^2 = .96 \quad$ s.e. = 3.2 ft^2/ac

where B_t and N_t are the basal area and trees per acre removed in thinning, and B_b and N_b the basal area and trees per acre before thinning, and n, R^2 and s.e. are as previously defined.

The difference in basal area per acre (or average basal area) between a thinned stand and an unthinned one of the same age, on the same site and with the same number of surviving trees per acre, is a measure of the effect of the higher level of competition that the thinned stand had experienced relative to the unthinned one. A competition index, originally proposed by O'Connor (1935), is defined as the difference in basal area between such a thinned and unthinned stand, relative to the basal area in the unthinned counterpart, that is

$$CI = \frac{B_u - B_{at}}{B_u} = 1 - \frac{B_{at}}{B_u} \tag{6}$$

where B_{at} is the basal area per acre in the thinned stand after thinning, and B_u the basal area in the unthinned counterpart.

If the basal area in a thinned stand equals the basal area in its unthinned counterpart with the same number of trees per acre, the competition index is zero*. When the basal area in the thinned stand is less than in the unthirmed counterpart, as is generally the case in operational thinnings, the competition index is not zero, but approaches zero over time as the basal area in the thinned stand converges to that of its unthinned counterpart.

A competition index as defined by equation 6 was calculated for each SAR plot at the time of thinning and again at the 1988 and 1993 measurements. An equation to predict the expected asymptotic trend of the competition index was fitted to this data, namely

$$CI_2 = CI_1 e^{-0.093(A_2 - A_1)} \tag{7}$$

n = 497 R^2 = 0.47 s.e. = .06

where CI_i is the competition index at age A_i (i = 1, 2) and n, R^2 and s.e. are as previously defined. Basal area in the thinned stand at age A_2 is then estimated as

$$B_{t_2} = B_{u_2}(1 - CI_2) \tag{8}$$

where B_{t_2} and B_{u_2} are basal areas in the thinned stand and its unthinned counterpart at age A_2. B_{u2} is predicted with equations 1, 2 and 3.

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*Note that the unthinned counterpart is always an unthinned stand of the same age and with the same number of surviving trees and site.

For example, a 15-year old plantation with 700 surviving trees per acre and average dominant/codominant height of 45 ft is predicted to have 112.6 ft^2/ac of basal area (equation 1). If it is thinned to 300 trees per acre the basal area after thinning is predicted as 57.2 ft^2/ac (equation 5). Basal area in an unthinned plantation with 300 trees per acre at age 15 and average dominant/codominant height of 45 ft is predicted as 66.7 ft^2/ac (equation 1). The competition index for the thinned plantation at age 15, relative to its unthinned counterpart, is calculated as 0.142 (equation 6). At age 30 the competition index is projected to be 0.035 (equation 7). In the thinned plantation, survival at age 30 is predicted as 264 trees (equation 2), the average dominant/codominant height as 72 ft (equation 3). Its unthinned counterpart with 264 trees per acre at age 30 is predicted to have 119.9 ft^2/ac (equation 1). Basal area in the thinned plantation is therefore predicted to be 114.9 ft^2/ac (equation 8)**.

Figure 3 shows the predicted basal area development for the unthinned plantations with 700 and 300 surviving trees per acre and average dominant/codominant height of 45 ft at age 15, as well as for the plantation thinned from 700 to 300 at age 15.

Volume Prediction for BS and SAR plots.

Tree dbh and height measurements at the time of thinning, and at the 1988 and 1993 measurements were used to calculate individual tree volumes with an existing standard volume equation (Pienaar et al., 1988). BS and SAR plot volumes were used to

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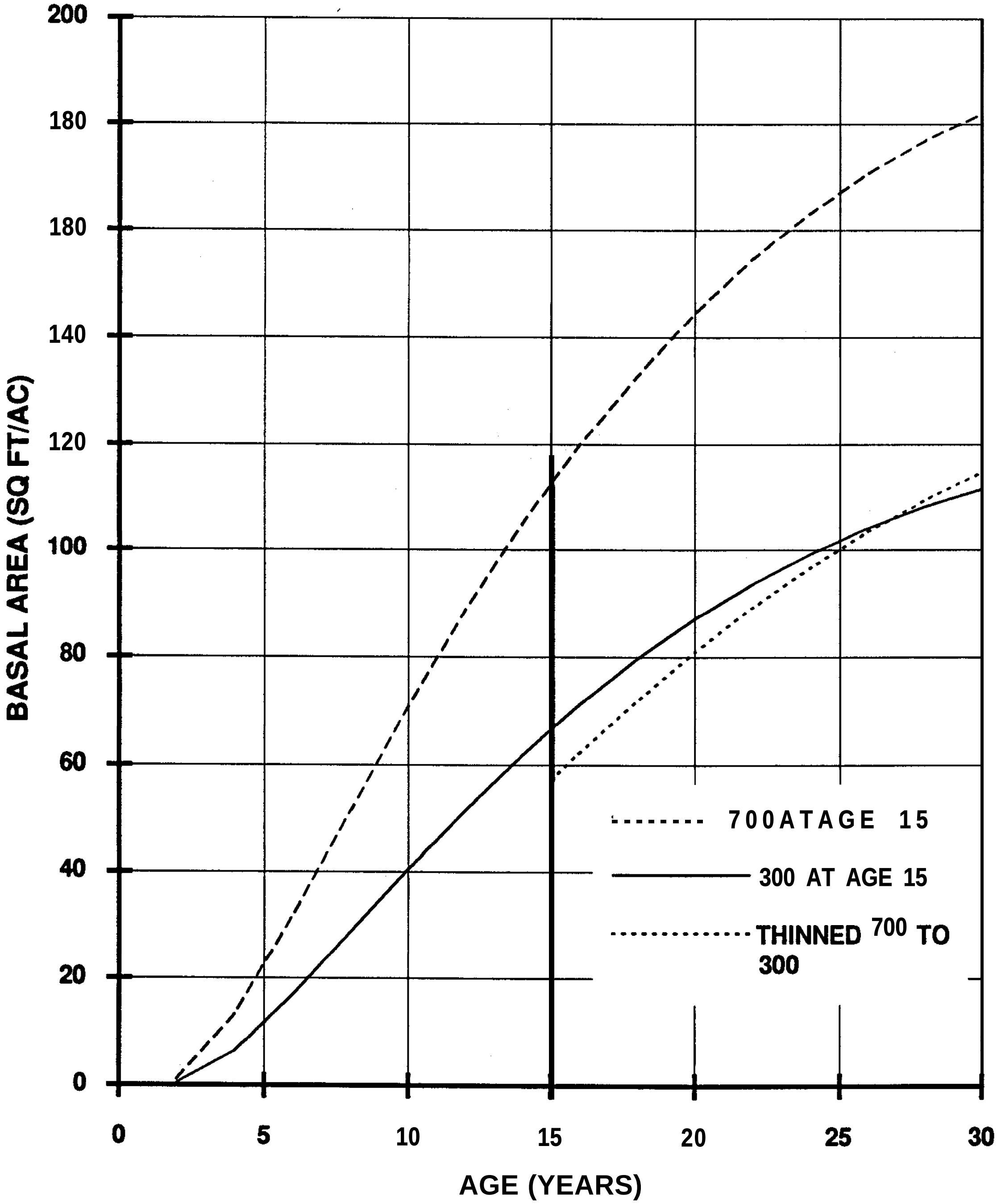
**The unthinned plantation with 300 trees per acre at age 15 is predicted to have 236 surviving trees at age 30 (equation 2), and with an average dominant/codominant height of 72 ft is predicted to have 112.4 ft^2/ac (equation 1) at age 30.

FIGURE 3. BASAL AREA GROWTH IN THINNED AND UNTHINNED STANDS



estimate the parameters in the following per-acre volume prediction equation:

$$V = H^{.820} N^{-.017-.320(1/A)} B^{1.016+.501\ (1/A)} \tag{9}$$

n = 747 $\quad$ R^2 = .99 $\quad$ s.e. = 36 ft^3/ac

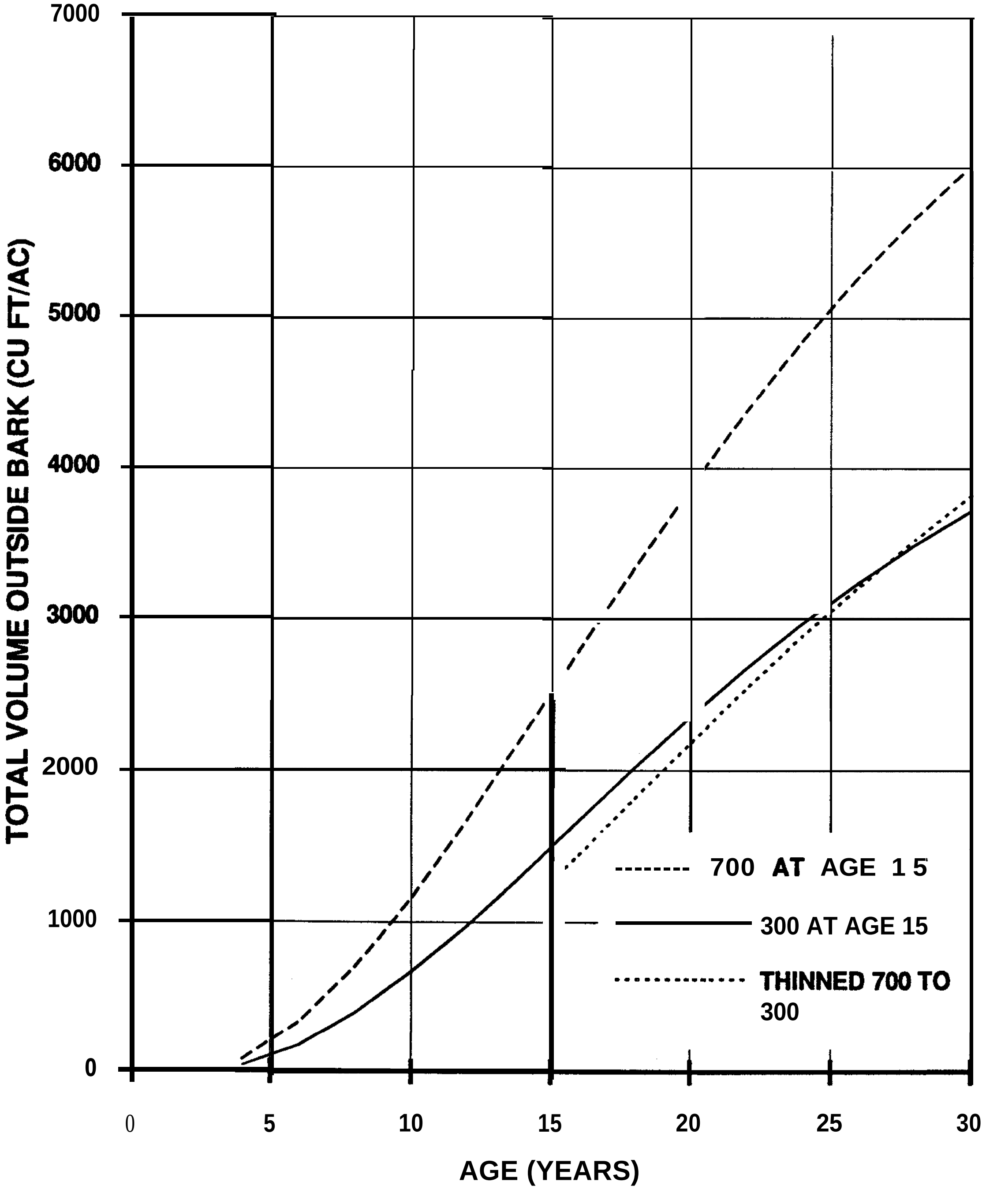
where V is total outside bark stem volume in ft^3/ac, H is average dominant/codominant height, N is surviving trees per acre, B is basal area per acre, A is plantation age, and n, R^2 and s.e. are as previously defined. Separate parameter estimates were calculated for BS and for the thinned SAR plots but the reduction in residual sum of squares was not statistically significant (a = .05).

Figure 4 shows the predicted volume yield for unthinned plantations with 700 and 300 trees per acre and average dominant/codominant height of 45 ft at age 15, and for a plantation thinned from 700 to 300 trees per acre at age 15.

Summarv.

Results are presented from a combined planting density and thinning study in cutover, mechanically site-prepared slash pine plantations in the southeastern coastal plain. Unlike most previous thinning studies in which different thinning intensities were specified in terms of residual basal areas, different thinning intensities were specified in terms of the desired number of trees per acre to remain after thinning. Another unique feature of this study is that plots were thinned (selectively from below) to match the number of trees per acre of unthinned plots in the planting density component of the study, so that it was possible to compare the growth of the thinned plots with that of unthinned counterparts that had the same number of trees per acre.

FIGURE 4. VOLUME GROWTH IN THINNED AND UNTHINNED STANDS



A variable density basal area prediction model for unthirmed plantations (Pienaar and Rheney, 1993) in which trees per acre is a predictor variable, in addition to age and average dominant/codominant height, was fitted to data from the unthinned plots. For each thinned plot a competition index was then defined, based on its basal area relative to that predicted for its unthinned counterpart which had the same number of trees per acre. An equation is presented to predict the basal area removed in selective thinning from below, given the proportion of trees removed and the basal area before thinning.

Equations are also presented to predict future average dominant/codominant height and future survival in order to predict future basal area per acre for unthinned stands. The competition index, which is a measure of the effect of competition in the thinned stand relative to its unthirmed counterpart, is assumed to asymptotically approach zero over time, based on observed trends over the 15-year post-thinning period. Predicted future values of the competition index provide estimates of future basal area per acre of the thinned stand derived from that of its unthinned counterpart.

A single volume per acre yield prediction equation is presented for both unthinned and thinned stands, based on age, average dominant/codominant height, surviving trees per acre, and basal area per acre.

In application, for a selective thinning from below specified in terms of the number of trees left after thinning, the basal area per acre is predicted for an unthinned stand with this number of trees per acre. Basal area left after thinning, and a competition index are then calculated for the thinned stand. Survival in the thinned stand is projected to the desired future age, as are the other stand variables used as predictor variables in the yield prediction equations. Future basal area per acre for the unthinned counterpart with the same survival is calculated, the competition index is projected to the future age and future basal area of the thinned stand is calculated. This basal area together with the other predictor variables are used to predict future volume per acre.

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