Summary

This publication describes several systems of equations for predicting the growth and yield of site-prepared slash pine plantations. It is a synthesis of the work of the Plantation Management Research Cooperative (PMRC) of the University of Georgia in slash pine stands over the last 20 years.

The publication includes equations to predict individual tree cubic foot volume and green and dry weight. The section on individual trees also includes inside and outside bark taper functions, which are necessary to merchandize individual volumes into various products. Equations in this individual tree section may be used in yield systems or they may be used separately as part of an inventory system.

Diameter distribution growth and yield systems became very popular with foresters who wanted a breakdown of volume per acre by products. Such a system is described here. In addition, a whole stand growth and yield system is described which allows for breakdown of volume per acre by merchantable diameter limits, but not by diameter class. This level of precision is acceptable for many uses. Necessary equations are presented to predict volumes and basal areas per acre of both unthinned and thinned stands.

A criticism of many growth projection systems is that only the initial age basal area is used to project future yields, ignoring inventory information as to the structure of the stand table at the initial age when it is available. This problem is addressed for slash pine plantations in chapter 5. If a stand table is known, it can be used directly from the inventory. Whatever the source, the stand table projection algorithm presented can be used to project the stand table.

Finally, a major problem in today's more intensive forest management is predicting the incremental yield obtained from cultural practices such as bedding, weed control, and fertilization. The system presented here uses information from PMRC designed studies to modify the basic yield system to predict the yield when these cultural practices are used.

Yield Prediction

for

Mechanically Site-Prepared Slash Pine Plantation

in

The Southeastern Coastal Plain

Plantation Management Research Cooperative

Daniel B. Warnell School of Forest Resources
The University of Georgia

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Preface

During the past 30 years over 4 million acres of slash pine (Pinus elliottii Engelm) Plantations have been established in the southeastern coastal plain in South Carolina, Georgia and north Florida, mostly on cutover forest land after some type of mechanical site preparation (Bechtold and Ruark, 1988).

In 1975 faculty at the School of Forest Resources of the University of Georgia launched an effort to provide management information for this plantation resource. Initial funding was provided by the School of Forest Resources from McIntire-Stennis funds, and since 1976, also by a changing number of timber companies in this region who agreed to participate in the University of Georgia Plantation Management Research Cooperative (PMRC). These cooperators have assisted in the establishment and maintenance of research plots on their land and have contributed funds and other resources to this effort. Current PMRC cooperators are Boise Cascade, Champion International Corporation, Georgia Pacific Corporation, Gilman Paper Company, Inland-Container Inc., International Paper Company, James River Timber Corporation, Jefferson Smufit Corporation, Kimberly-Clark Corporation, MacMillan-Bloedel Inc., Mead Coated Board, Packaging Corporation of America, Rayonier Inc., Scott Paper Company, Union Camp Corporation, Westvaco and Weyerhauser Company.

Over the years many School of Forest Resources students, technicians and faculty have participated in data acquisition and analysis.

Research Bulletin 291, published in 1982 by the University of Georgia, College of Agriculture Experiment Stations, provided the first yield prediction capability for unthinned and unfertilized slash pine plantations established in this region on cutover and mechanically site-prepared forest land. This publication was based on analyses of measurements of felled sample trees and of temporary sample plots. Since its publication, the felled sample tree data base has been augmented in the older age and larger size classes, sampling was extended and monumented growth and yield sample plots have been remeasured. In addition, results from several designed experimental studies have become available.

This revised and updated publication is a summary and synthesis of more recent analyses of PMRC data sets that have been reported in greater detail in PMRC technical reports to cooperators.

Updated tree volume and weight prediction equations are presented in Chapter 1. Stand level basal area and volume growth models for unthinned plantations, a survival prediction, average dominant/codominant height growth model, and a general merchandizing equation to apportion total per-acre volume into specified product size classes, are presented in Chapter 2. In Chapter 3, per-acre basal area and volume yield prediction equations are presented to predict yield for existing plantations as well as future yields for both unthinned and thinned plantations. In Chapter 4 we present a revised and updated diameter distribution based yield prediction system for unthinned plantations. Stand tables are derived from predicted diameter distributions, and a tree height prediction equation is provided to obtain predicted stock tables. A stand table projection procedure is presented in Chapter 5, to project the stand and stock table for unthinned as well as thinned plantations. Growth and yield prediction models that account for the effect of silvicultural treatments to control competing vegetation and to increase productivity are presented in Chapter 6.

Chapter 1
Stem Volume and Weight Equations

Data used to develop volume and weight prediction equations were collected from 838 felled sample trees from 229 mechanically site-prepared plantations on cutover sites, representing 19 counties in the coastal plain region of Georgia and 17 counties in north Florida. These plantations were all unthinned and unfertilized. In general, four sample trees without any obvious stem abnormalities were felled in each plantation: two were selected from the larger than average dbh classes and in the dominant or codominant height classes; one of approximately average dbh; and one from a smaller than average dbh class and in the intermediate or suppressed height class.

Table 1.1 shows the distribution of sample trees by age and site index classes, and Table 1.2 shows their distribution by dbh and total height classes.

Tree Measurements, Volume and Weight Calculations

Each sample tree was measured for dbh with a diameter tape, and after felling, for total height with a measuring tape.

Felled stems were cut into 5 ft bolts, measured from ground level, to a top diameter ≤ 2 inches. Average stump height was 0.5 ft. On the butt bolt midpoint diameters, outside and inside bark, were measured. A one-inch disc was sawn from the butt end of each bolt, including the tip bolt. Each disc was weighed and measured for diameter, with and without bark. Volume of each disc was obtained by water displacement and each disc was then dried in an oven to a constant weight.

Table 1.1 Number of Volumes and Weight Sample Trees by Age and Site Index Classes

Age Class	Site Index Class						
	30	40	50	60	70	80	Total
9		4	4	4	5	2	19
12		8	60	100	31		199
15			30	86	27		143
18	6	8	40	126	54	10	244
21		34	34	71	23	6	168
24			8	14	28		50
27			2	10	3		15
Total	6	54	178	411	171	18	838

Table 1.2 Number of Volume and Weight Sample Trees by Dbh and Total Height Classes

Dbh Class	Total Height Class												
	20	25	30	35	40	45	50	55	60	65	70	75	Total
3	5	31	42	25	4								107
4		15	27	37	30	5							114
5		5	16	40	40	38	14	1					154
6			5	18	36	31	17	10	2	1			120
7				6	18	28	35	32	6				125
8					1	5	36	24	6	5			77
9					1	1	6	14	16	9	2		49
10							1	6	10	16	9	1	43
11								1	3	24	12	2	42
12										3		3	6
14										1			1
Total	5	51	90	126	130	108	109	88	43	59	23	6	838

For each sample tree cumulative stem volumes, outside and inside bark, were calculated to successive bolt heights and for the total stem. Volume of the tip bolt was calculated as a cone. Individual bolt volumes were calculated with a generalization of Newton's equation applied to successive pairs of bolts, starting with the tip bolt, and then subtracting the volume of the last individual bolt from the volume for the pair (Bailey, 1995).

Cumulative stem green weight with bark to successive bolt heights and for the total stem was calculated as follows for each bolt:

$$GW = L/6\,[2D_1A_1 + D_1A_2 + D_2A_1 + 2D_2A_2]$$

where GW = green weight of the bolt with bark in lbs

L = length of the bolt in ft

D_1, D_2 = densities in pounds of green wood and bark per cubic foot of green wood for the discs at the base and top of each bolt respectively.

A_1, A_2 = cross-sectional area inside bark for the two discs respectively in ft^2

Green weight with bark for the tip was calculated as

$$GW = D \times V$$

where D = density in pounds of green wood and bark per cubic foot of green wood as determined for the disc at the tip.

V = green wood volume of the tip in cubic ft

Cumulative stem green and dry wood weight, that is, without bark, to successive bolt heights and for the total stem were calculated in a similar manner. For each bolt and the tip the densities were calculated from the green wood weight and green wood volume of the respective discs to obtain green wood weight of the bolt. In the case of dry wood weight the respective densities were calculated from the dry wood weights of the discs and their green volumes respectively.

Stem Volume and Taper Equations

Stem volume data to successive bolt heights and for the total stem were used to fit the following volume equations. A weighted nonlinear least squares procedure was used to estimate the parameters with weights equal to the inverse of the volume.

$$VOB_m = .00456D^{2.0726} H^{.8114} - .00265(D_m^{3.8846}/D^{1.8846})(H - 4.5) \quad (1.1)$$

$$D_m = D[(H - M) / (H - 4.5)]^{.5306} \quad (1.2)$$

$$M = H - (H - 4.5)(D_m/D)^{1.8846} \quad (1.3)$$

Where VOB_m = stem volume outside bark in cubic ft to a top diameter limit D_m inches, Outside bark.

D = dbh in inches

H = total height in ft

Dm = top diameter limit outside bark in inches

M = height above ground in ft to an outside bark diameter D_m inches.

Equation 1.2 and 1.3 can be used to calculate the outside bark diameter at a specified height $4.5 \le M \le H$ ft, and the height above ground to a specified outside bark diameter $0 \le D_m \le D$ inches.

$$VIB_m = .001735\ D^{2.0586}\ H^{1.0026} - .00200\ (D_m^{3.6994}/D^{1.6994})(H - 4.5) \quad (1.4)$$

$$D^{im} = \{.7198D^2[(H - M) / (H - 4.5)]^{.9630}\}^{0.5} \quad (1.5)$$

$$M = H - (D_{im}/D)^{2.0768}\ (H - 4.5)/.7108 \quad (1.6)$$

Where VIB_m = stem volume inside bark in cubic ft to a top diameter limit of D_m inches, outside bark.

D_{im} = inside bark diameter at a height M ft above ground in inches.

Stem Weight Equations

Stem weight data to successive bolt heights and for the total stem were used to estimate the parameters in the following stem weight prediction equations, using a weighted nonlinear least squares procedure with weights equal to the inverse of (D^2H).

$$GWOB_m = .1763D^{1.9604}H^{.9761} - .1167\ (D_m^{3.6422}/D^{1.5441})\ (H - 4.5) \quad (1.7)$$

where $GWOB_m$ = stem green weight with bark in pounds to a top diameter of D_m inches outside bark

$$GWIB_m = .1047D^{2.0544}\ H^{1.0224} - .0892\ (D_m^{3.6729} / D^{1.5156})\ (H - 4.5) \quad (1.8)$$

where $GWIB_m$ = stem green wood weight in pounds to a top diameter D_m inches outside bark.

$$DWIB_m = .0373\ D^{1.8670}\ H^{1.2070} - .0458\ (D_m^{3.9416} / D^{1.7984})\ (H - 4.5) \quad (1.9)$$

where DWIBm = stem dry wood weight in pounds to a top diameter Dm inches outside bark.

Unlike green weight, tree age was a significant predictor variable for dry wood weight, in addition to D and H. For trees of known age the following equation is a better predictor of DWIBm:

$$DWIB_m = .0383\ D^{1.8831}\ H^{1.1340}\ A^{.0795} - .0454\ (D_m^{3.9375}/D^{1.7864})(H - 4.5) \qquad (1.10)$$

A selection of tables of predicted stem volumes and weights, with and without bark, and to selected merchantable diameter limits, appear in Appendix 1.

Illustrative Example

Use of the volume, taper and weight equations are illustrated below for a tree with D = 10 inches and H = 60 ft. The equation used to obtain the estimate is given in parentheses.

Volume:

$VOB_0 = 14.94\ ft^3$	(1.1)	$VIB_0 = 12.04\ ft^3$	(1.4)
$VOB_0 = 14.52\ ft^3$	(1.1)	$VIB_4 = 11.67\ ft^3$	(1.4)
$VOB_8 = 8.76\ ft^3$	(1.1)	$VIB_8 = 7.18\ ft^3$	(1.4)

Outside Bark		Inside Bark	
Given M = 17 ft;	D_m = 8.73 in (1.2)	M = 17 ft;	D_{im} = 7.50 in (1.5)
Given M = 33 ft;	D_m = 6.82 in (1.2)	M = 33 ft;	D_{im} = 6.00 in (1.5)
Given D_m = 4 in;	M = 50.1 ft (1.3)	D_{im} = 4 in;	M = 10.9 ft (1.6)
Given D_m = 8 in;	M = 23.6 ft (1.3)	D_{im} = 8 in;	M = 10.9 ft (1.6)

Green Weight:

$GWOB_0$ = 875.6 lbs (1.7)	$GWIB_0$ = 780.4 lbs (1.8)
$GWOB_4$ = 846.8 lbs (1.7)	$GWIB_4$ = 755.8 lbs (1.8)
$GWOB_8$ = 515.4 lbs (1.7)	$GWIB_8$ = 467.1 lbs (1.8)

Dry Weight:

	Age 15	Age 25
$DWIB_0$ = 384.5 lbs (1.9)	376.9 lbs (1.10)	392.5 lbs (1.10)
$DWIB_4$ = 374.9 lbs (1.9)	367.2 lbs (1.10)	382.8 lbs (1.10)
$DWIB_8$ = 236.6 lbs (1.9)	228.7 lbs (1.10)	244.3 lbs (1.10)

Chapter 2

Stand Level Growth Models for Unthinned Plantations

Sample Plot Data

Yield prediction methodology presented in this and subsequent chapters for mechanically site-prepared plantations on cutover sites is base on two data sets: One data set consists of measurements of 691 temporary growth and yield sample plots and of 254 monumented plots with a 4-year remeasurement. These plots were established in unthinned and unfertilized plantations that were at least 10 years old and represent 4 counties in South Carolina, 26 in Georgia and 23 in north Florida. Plots were rectangular in shape designed to include approximately 64 original planting spots, thus varying in size. Average plot size was approximately one tenth acre in size. The range of ages, average dominant/codominant heights and stand densities (trees per acre) of these plots are shown in Table 2.1.

The second data set is from a spacing and thinning study installed at 114 locations in the same physiographic region in 2- and 3-year-old mechanically site-prepared and unfertilized plantations. Planting survival densities of 100, 200, 300, 450 and 700 trees per arce were represented at each location, and 900 per acre at a few locations, with as many as 8 measurements at 3-year intervals since age 5. Measurement plots with 25 measurement trees varied in size depending on density. At 28 locations additional plots were available, representing different planting densities and the plots were thinned selectively from below with different thinning intensities at ages ranging from 10 to 17 years. Thinned plots were 0.25 acre in size with tenth acre measurement plots and were remeasured periodically with the last measurement 15 years after thinning. Average site index of these installations was 60 and ranged from 50 to 72.

Height Growth Model

Four-year remeasurement data for the 254 monumented growth and yield sample plots were used to fit the following algebraic difference form of the Chapman-Richards growth model to the average heights of all trees classified as dominant or codominant on each plot:

$$H_2 = H_1[(1 - e^{-.0456\,A2})/(1 - e^{-.0456\,A1})]^{1.183} \tag{2.1}$$

where H_1 and H_2 are the average dominant/codominant heights at ages A_1 and A_2 respectively. The implied anamorphic site index equation with an index age of 25 years is:

$$H = 1.5776\ S\ (1 - e^{-.0456A})^{1.183} \tag{2.2}$$

where S is the site index. Equation 2.2 was used to generate the site index curves in Figure 2.1.

Survival Prediction Equation

Remeasurement data from the 254 monumented growth and yield sample plots and from the spacing and thinning study plots were used to estimate the parameters in the following survival prediction equation:

$$N_2 = N_1 e^{-(.0041\ -\ .0019Z)\ (A_2^{\ 1345} - A_1^{\ 1345})} \tag{2.3}$$

FIG 2.1 SITE INDEX CURVES

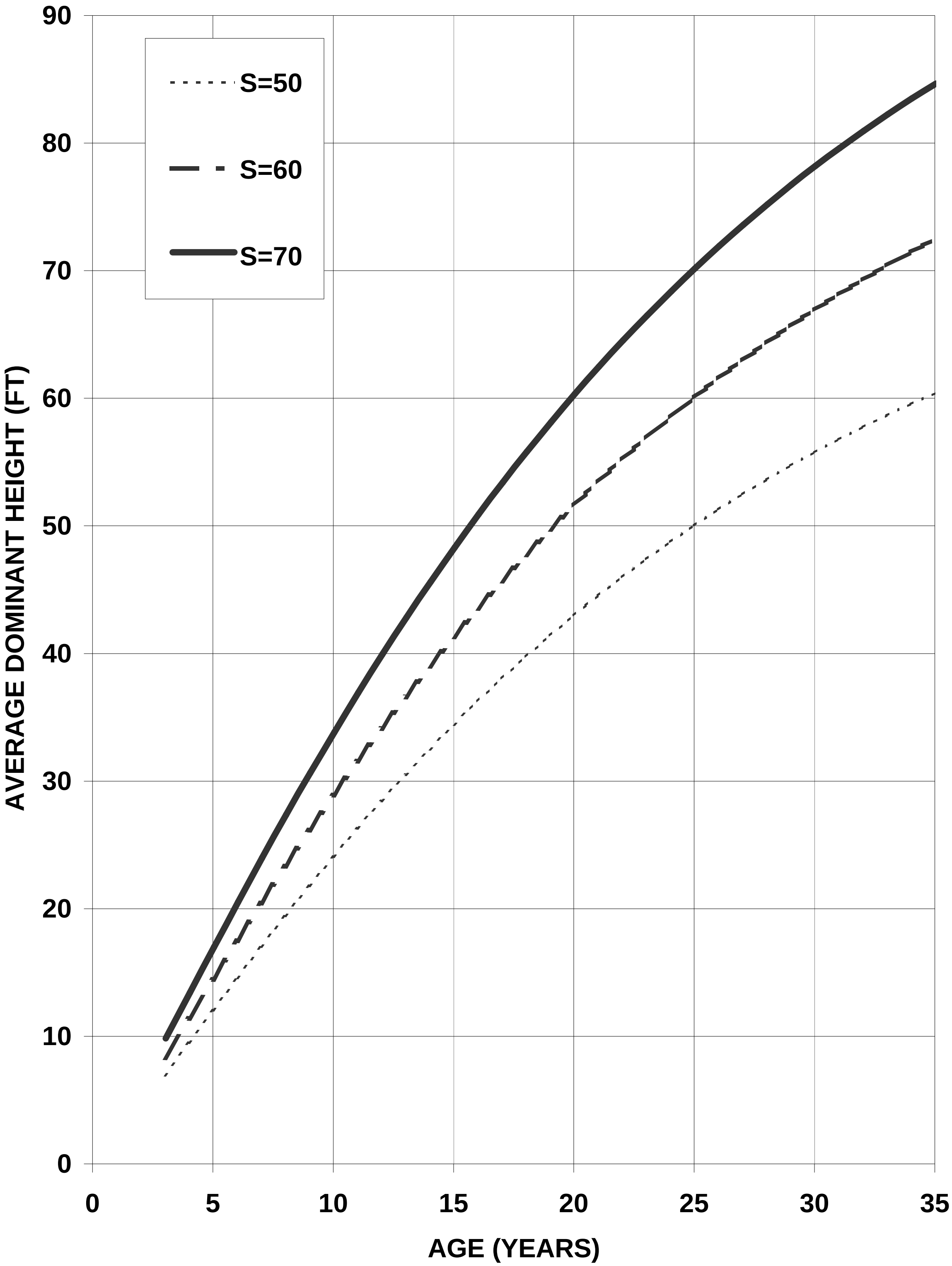


Table 2.1 Distribution of sample plot measurements by age, average dominant/codominant height and trees per acre.

		Average dominant/codominant height					
Age	Trees/acre	21-30	31-40	41-50	51-60	> 60	Total
≤ 15	≤ 300	11	10	3			24
	301-400	14	22	8	2		46
	401-500	27	45	17	1		90
	501-600	17	36	18	3		74
	> 600	22	40	24			86
16-20	≤ 300	9	4	20	16	2	51
	301-400	1	10	51	33	1	96
	401-500	2	29	59	28	2	120
	501-600		20	64	23	1	108
	> 600		17	55	15		87
21-25	≤ 300		3	20	36	11	70
	301-400		6	29	48	14	97
	401-500		4	30	26	9	69
	501-600		5	18	19	1	43
	> 600		5	12	6	2	25
> 25	≤ 300			4	5	12	21
	301-400		1	7	10	16	34
	401-500			2	20	9	31
	501-600			4	8	8	20
	> 600			5	1	1	7
	Total	103	257	450	300	89	1199

Where N1 and N2 are surviving trees per acre at ages A1 and A2 respectively, and Z = 0 if the plantation had not been thinned or had been row-thinned only, and Z = 1 if the plantation had been thinned selectively from below at age A1 or earlier.

Expected survival curves in Figure 2.2 were generated with equation 2.3 for an unthinned plantation with 300 surviving trees per acre at age 15 and for one that was thinned selectively from below to 300 trees per acre at age 15.

Growth Models for Unthinned Plantations

The spacing study provided longterm remeasurement data where individual plots had been remeasured as many as 8 times at 3-year intervals since age 5. A Chapman-Richards growth model was used to describe the growth of these unthinned plots representing a wide range of stocking densities and site indexes. These data were used to estimate the parameters in the following basal area and volume growth models:

$$B = 2.041\, S^{1.13} \left[1 - 1.108\, e^{-(.0155 + .000069\,(TP)^{.950})\,A}\right]^{1.208} \qquad (2.4)$$

$$V = 4.40\, S^{1.70} \left[1 - 1.058\, e^{-(.00825 TP^{.349})\,A}\right]^{3.187} \qquad (2.5)$$

where B = per-acre basal area (ft^2)

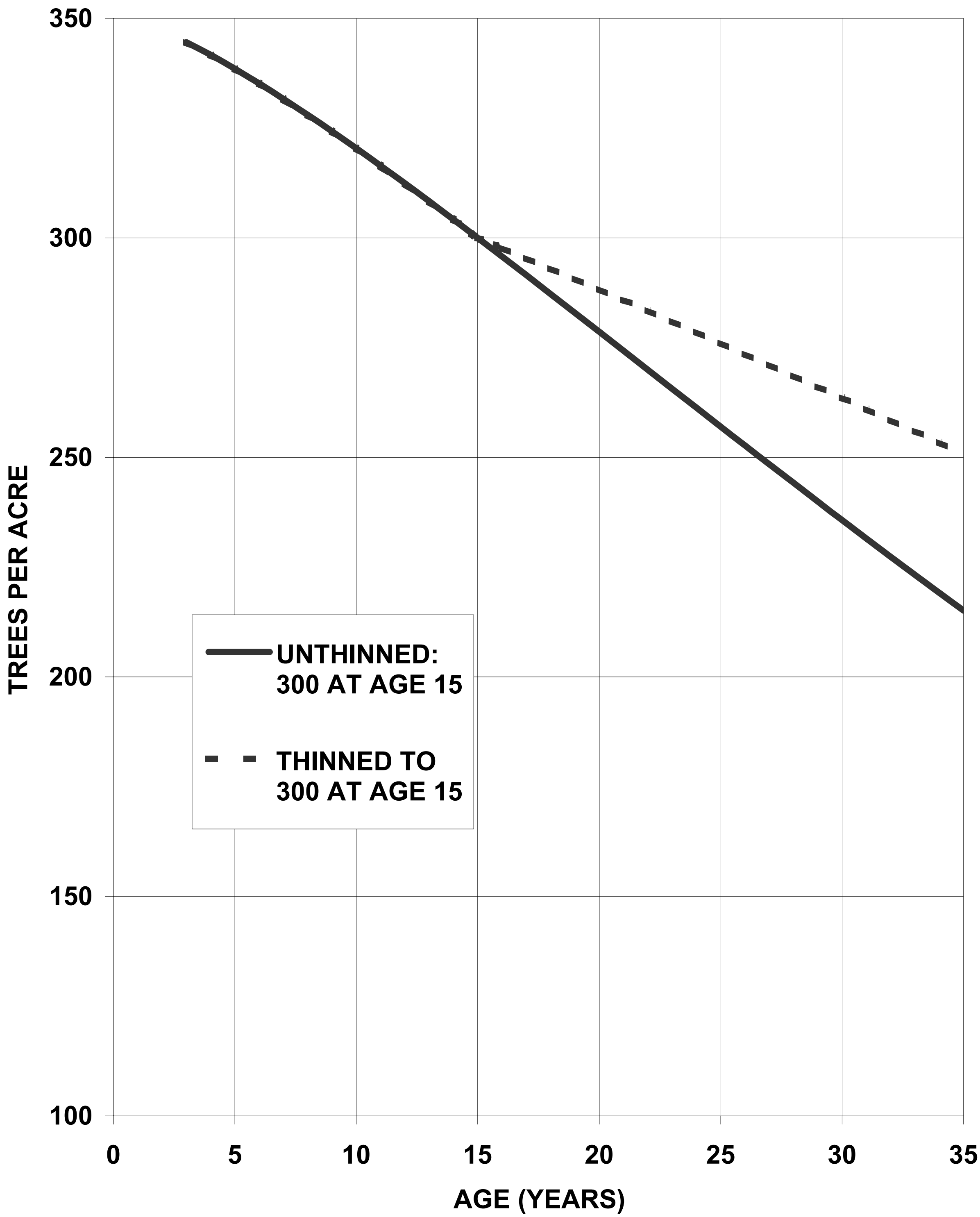
V = per-acre stem wood volume (ft^2)

S = site index

TP = survival at age 2 as trees per acre

A = plantation age in years

FIG 2.2 SURVIVAL CURVES FOR THINNED AND UNTHINNED PLANTATIONS



This volume growth model predicts per-acre yield for unthinned plantations with different planting densities and for sites of different productive capacities expressed in terms of site index. It can be used to analyze management alternatives without any thinnings when plantations are established and decisions must be made as to the optimum planting density and harvest age. For management alternatives that include thinnings, and for plantations already in existence, more appropriate yield prediction models are provided in subsequent chapters. For site index 60 and an age 2 stocking of 800 trees per acre, the basal area and volume growth models are:

$$B = 209\,[1 - 1.108\, e^{-.0550A}]^{1.208} \qquad ft^2/ac \qquad (2.6)$$

$$V = 4640\,[1 - 1.058\, e^{-.0850A}]^{3.187} \qquad ft^3/ac \qquad (2.7)$$

Per-acre volume growth curves generated with equation 2.5 for site indexes 60 to 70 and age 2 survival of 400 and 800 trees per acre are shown in Figure 2.3. Corresponding mean annual increment curves are shown in Figure 2.4. The age when the mean annual increment reaches a maximum can be determined for any specified initial stocking density and site index by solving for the age, A, when the derivative of the mean annual increment (V/A is zero. For example, for the age 2 stocking density of 800 and site index 60, that is, for equation 2.7, it occurs at age A when

$$4640\,(1.058)\, e^{-.0850A}\,[.0850(3.187)\,A + 1] = 4640$$

which is at age A = 24.5 years. Harvest ages that will maximize volume production (mean

FIG 2.3 VOLUME GROWTH CURVES FOR DIFFERENT STOCKING DENSITIES AND SITE INDEXES

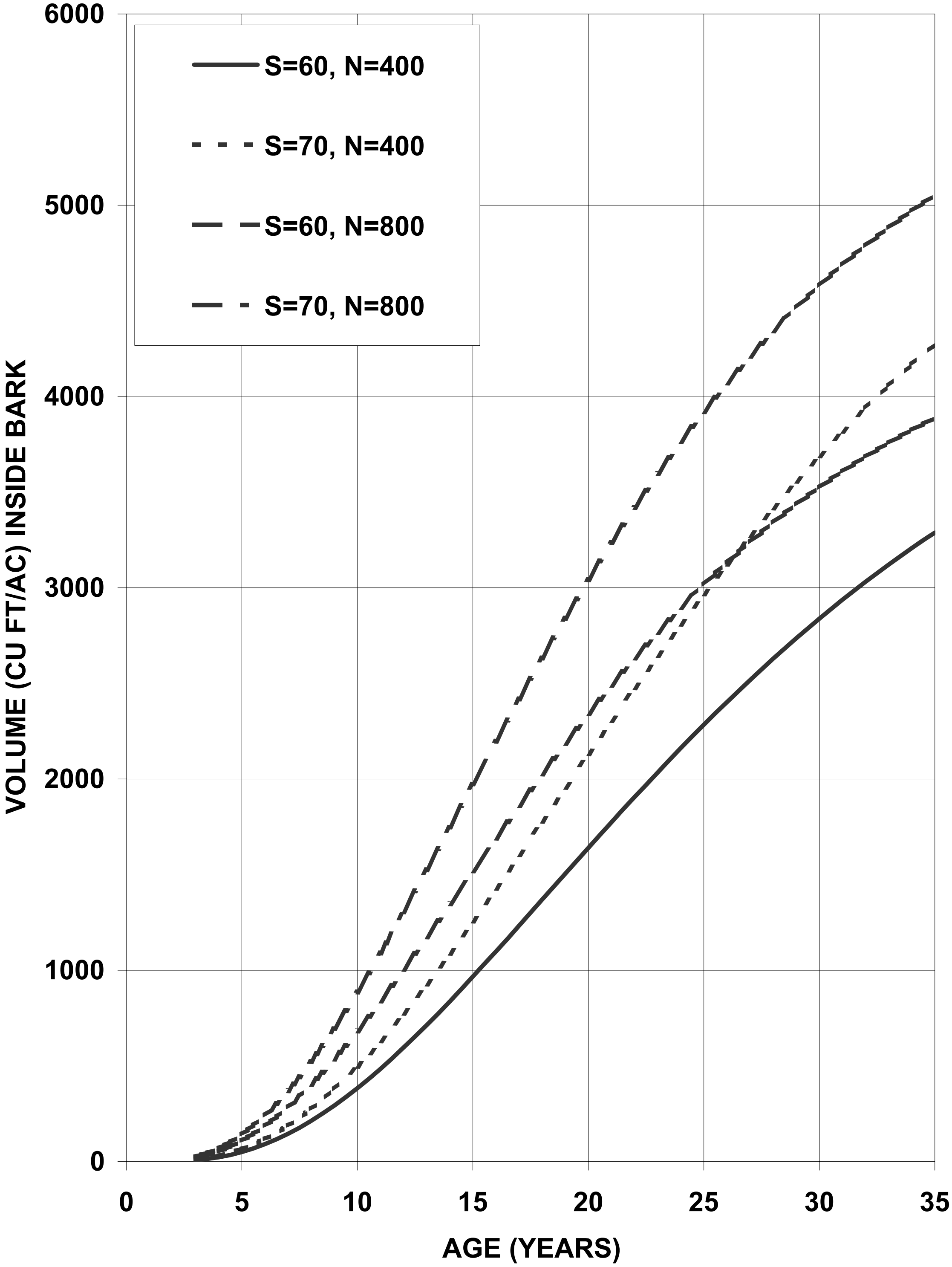
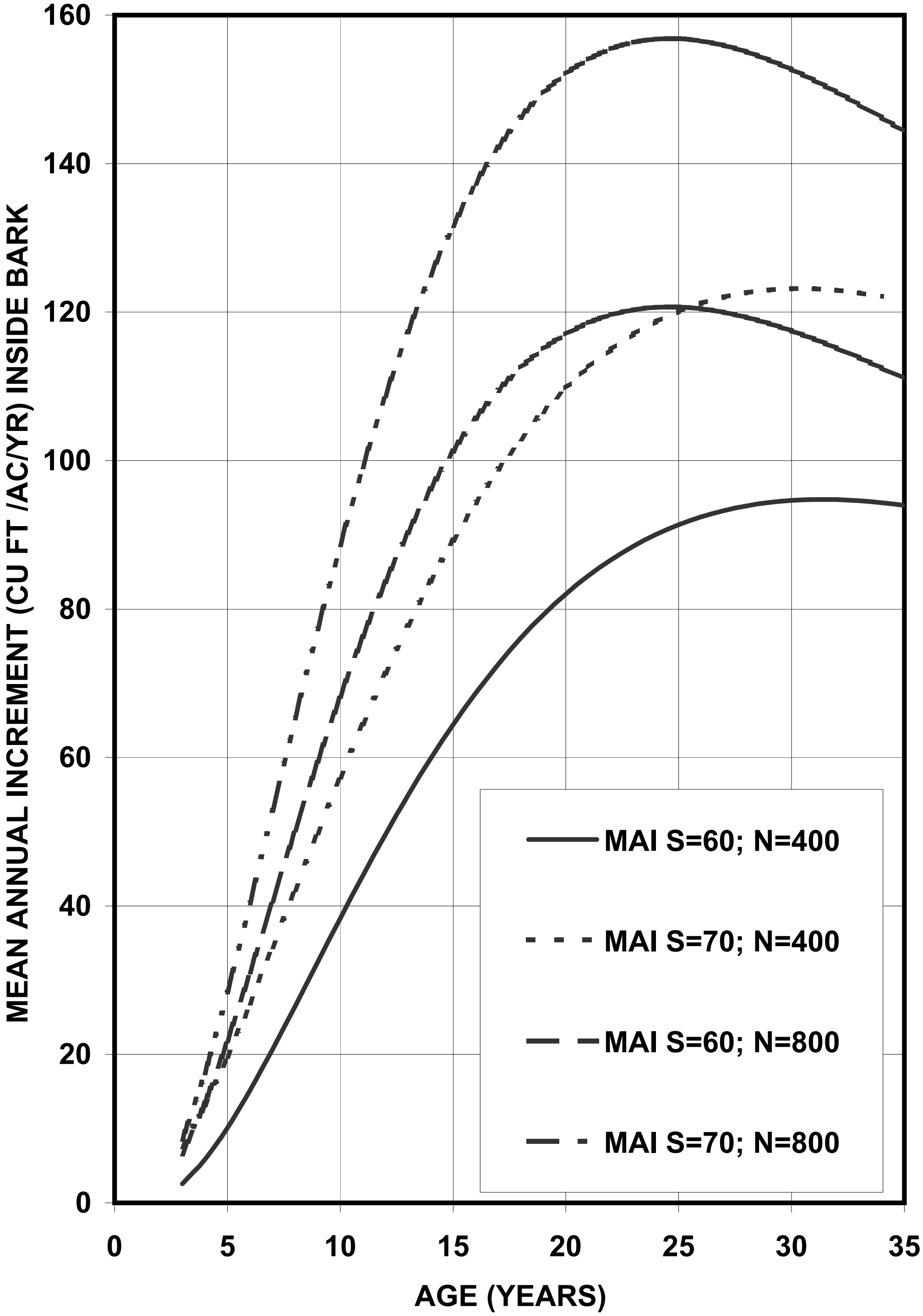


FIG 2.4 MEAN ANNUAL VOLUME INCREMENT CURVES FOR DIFFERENT STOCKING DENSITIES AND SITE INDEXES



Annual increment for initial stocking densities and/or site indices can be obtained in a similar manner with the appropriate set of parameter values.

Merchandizing Equation

An equation to apportion the total per-acre volume into various product categories such as pulpwood, small sawtimber and large sawtimber, was fitted to product category volumes calculated for the growth and yield sample plot data:

$$V_{d,t} = V\, e^{-.52(t/\bar{D})3.84\ -\ .69N\ -.12\ (d/\bar{D})\ 5.72} \qquad (2.8)$$

Where Vd,t = per-acre volume to a t-inch top diameter outside bark for trees with dbh ≥ d inches

V = total per-acre volume

$\bar{D}$ = quadratic mean dbh (in)

N = surviving trees per acre

For example, according to equation 2.7 a plantation with site index 60 age 2 survival of 800 trees per acre is expected to yield total stem wood volume at age 30 of

$$V = 3525\ ft^3/acre$$

The survival equation 2.3 predicts 543 trees per acre at age 30, and equation 2.6 predicts 156.5 ft2 of basal area, so that $\bar{D}$ = 7.3 inches.

$$\bar{D} = \sqrt{B/.005454N} \qquad (2.9)$$

If we define large sawtimber volume as $V_{10,8}$, small sawtimber volume as $V_{8,6}$ - $V_{10,8}$, and pulpwood volume as $V_{4,2} – V_{8,6}$ equation 2.8 can be used to apportion the total stem wood volume as follows:

Large sawtimber = $V_{10,8}$ = 223 ft^3

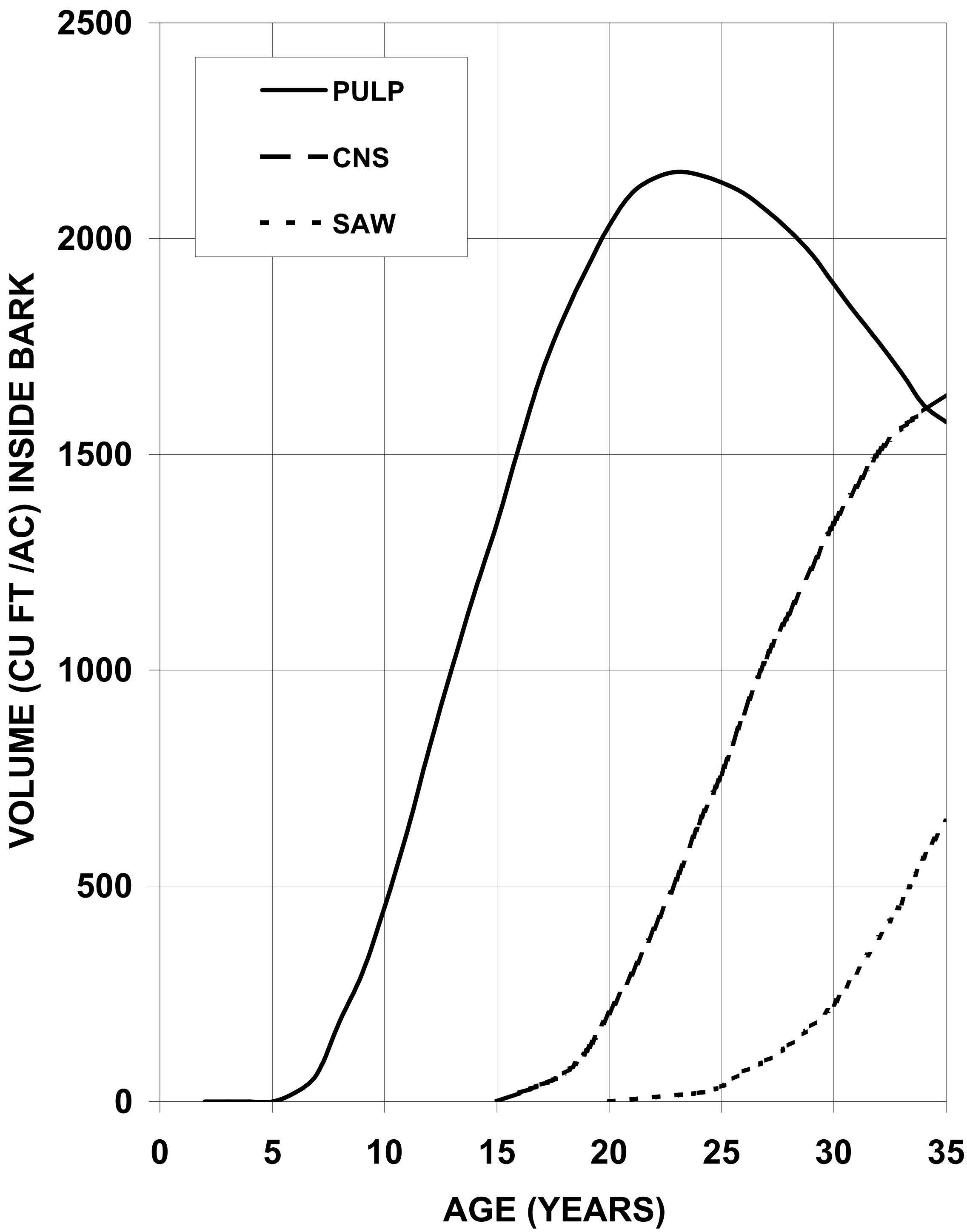
Small sawtimber = $V_{8,6} – V_{10,8}$ = 1569 – 223 = 1346 ft^3

Pulpwood = $V_{4,2} – V_{8,6}$ = 3475 – 1569 = 1906 ft^3

3475 ft^3

The expected development, obtained by using equations (2.4) and (2.8) of these 3 product class volumes in this plantation is shown in Figure 2.5.

FIG 2.5 PREDICTED DEVELOPMENT OF PRODUCT VOLUMES. SITE INDEX 60, 800 TREES PER ACRE



Chapter 3

Stand Level Yield Prediction Equations

Data from the growth and yield sample plots and from the spacing and thinning study were used to develop per-acre basal area and volume prediction equations for unthinned as well as thinned plantations of known age, average dominant/codominant height and trees per acre.

For unthinned plantations the following basal area prediction equation was obtained:

$$\begin{aligned} \text{In}(B) &= -4.807 - 26.273/A + 1.512\ \text{In}(H) + .527\ \text{In}(N) \\ &= 4.129\ \text{In}(H)/A + 2.497\ \text{In}(N)/A \end{aligned} \tag{3.1}$$

where B = per=acre basal area (ft^2)

A = plantation age in years

H = average dominant/codominant height (ft)

N = surviving trees per acre

In() = natural logarithm of the argument

A common per-acre volume prediction equation that applies to both unthinned and thinned plantations was derived from the same two data sets:

$$\text{In}(V) = 2.994 - 1.145\ \text{In}(H)/A - .337\ \text{In}(N) + 1.481\ \text{In}(B) \tag{3.2}$$

where V = per-acre total stem wood volume (ft3)

Other variables are as defined above.

Equation 3.1 predicts more basal area for plantations with the same average dominant/codominant height as the number of trees per acre, as the average dominant/codominant height increases. On a given site the basal area per acre will increase asymptotically to the extent that both average dominant/codominant height and the surviving trees per acre develop asymptotically. The equation can also be used to predict future basal areas of unthinned plantations if estimates of future average dominant/codominant height and survival are available.

Equation 3.1 can be used to generate implied growth curves for unthinned plantations with different initial stocking densities and site indexes. For example, for site index 60, equation 2.2 is used to predict average dominant/codominant height at any A years as:

$$H = 94.7\,(1 - e^{-.0456A})^{1.183} \text{ ft.}$$

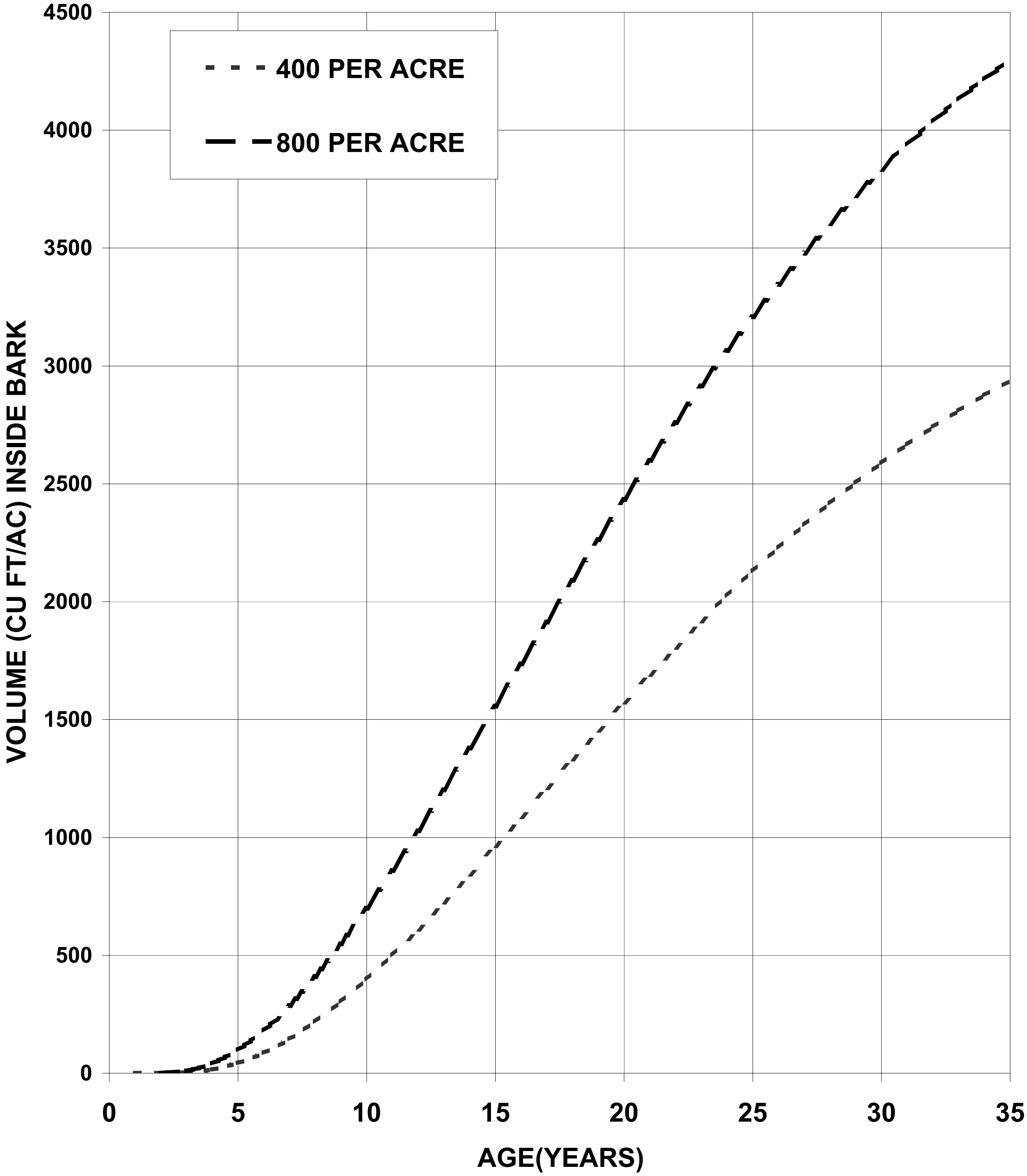
Expected survival at any age A_2, given a survival of N_1 at prior age A_1 is given by equation 2.3 for unthinned plantations as:

$$N_2 = N_1\, e^{-.0041\,(A_2^{\;1345} - A_1^{\;1345})}$$

Implied per-acre volume growth curves for unthinned plantations with site index 60 and age 2 survival of 400 and 800 trees per acre, as shown in Figure 3.1, were generated with equation 3.2. Implied volume growth curves for other site indexes and/or initial stocking densities can be generated in a similar manner.

In the PMRC thinning study, trees were thinned selectively from below and the thinning intensity was specified in terms of the number of trees to be left. An equation to convert the percentage of trees removed to a percentage of basal area removed was derived

FIG 3.1 IMPLIED VOLUME GROWTH CURVES FOR UNTHINNED PLANTATIONS WITH DIFFERENT STOCKING DENSITIES. SITE INDEX 60



from the thinning study data, namely

$$(B_t/B) = (N_t/N)^{1.2248} \qquad (3.3)$$

where B_t = per-acre basal area removed in thinning (ft^2)

B = per-acre basal area before thinning (ft^2)

N_t = trees per acre removed in thinning

N = trees per acre before thinning

A general conversion equation to accommodate row thinnings, selective thinnings from below, or a combination of row and selective thinnings, is given below:

$$(B_t/B) = N_r/N + [1 - (N_rN)\{N_s/(N - N_r)\}^{1.2248}] \qquad (3.4)$$

where N_r = trees per acre removed in row thinning

N_s = trees per acre removed selectively from below

As an example, consider a 15-year-old plantation with site index 60, an average dominant/codominant height H = 41 ft (equation 2.2), and 700 trees per acre. Equation 3.1 is used to predict the basal area, and equation 3.2 to predict total stem wood volume per acre as:

$$B = 101.7 \text{ ft}^2$$

$$V = 1553 \text{ ft}^3$$

A row thinning that removes every third row will remove 1/3 of the trees, that is, 233 trees per acre, and 1/3 of the basal area, as well as the volume, so that

B_t = 33.9 ft2 (equation 3.4 with $N_s = 0$)

$$V_t = (1.3) \text{ of } 1553 = 518 \text{ ft}^3$$

Where Vt is the per-acre volume removed in thinning.

A selective thinning from below that removes 233 trees per acre, and assuming that the same proportion of the volume will be harvested, will yield

$$B_t = 26.4 \text{ ft}^2 \text{ (equation 3.4 with } N_r = 0)$$

$$V_t = (26.4/101.7) \times 1553 = 403 \text{ ft}^3$$

A combination row and selective thinning in which every fifth row is harvested will remove 700 x (1/5) = 140 trees per acre, and 93 trees per acre are selectively thinned from the remaining rows for a total of 233 trees:

$$B_t = 29.4 \text{ ft}^2 \text{ (equation 3.4 with } N_r = 140, N_s = 93)$$

$$V_t = (29.4/101.7) \times 1553 = 449 \text{ ft}^3$$

At age 30, the expected average dominant/codominant height, survival, basal area and total stem wood per acre are predicted as follows for the unthinned plantation:

	H	=	67 ft	(equation 2.2)
	N	=	550 per acre	(equation 2.3)
	B	=	164.7 ft^2	(equation 3.1)
	V	=	3890 ft^2	(equation 3.2)
Large sawtimber	$V_{10,8}$	=	321 ft^3	(equation 2.8)
Small sawtimber	$V_{8,6} - V_{10,8}$	=	1848 ft^3	(equation 2.8)
Pulpwood	$V_{4,2} - V_{8,6}$	=	1971 ft^3	(equation 2.8)
Total merchantable	$V_{4,2}$		3840 ft^3	(equation 2.8)

In thinned plantations, per-acre basal area after thinning is used to calculate a competition index, CI, by comparing this basal area to that of an unthinned plantation of the same age and site index (average dominant/codominant height) and with the same number of trees per acre as the thinned stand after thinning. The competition index is a measure of the extent to which competition had affected average tree basal area in the plantation that had been thinned, relative to the unthinned plantation, and is defined as follows:

$$CI = (B_u - B_{at})/B_u = 1 - (B_{at}/B_u) \tag{3.5}$$

where B_{at} = per-acre basal area in the thinned plantation (ft^2)

B_u = per-acre basal area in the unthinned counterpart.

Due to differential growth rates and mortality for thinned and unthinned stands, the competition index will change over time after thinning.

An equation to predict the observed time trend of the competition index in the thinning study data was derived:

$$CI_2 = CI_1\ e^{-.093\ (A_2 - A_1)} \tag{3.6}$$

where CI_i = competition index at age A_i (I = 1,2)

Per-acre basal area in the thinned plantation at age A_2 is then estimated as follows:

$$B_{t_2} = B_{u_2}\ (1 - CI_2) \tag{3.7}$$

where B_{t_2} = per-acre basal area in the thinned plantation at age A_2

B_{u_2} = per-acre basal area in its unthinned counterpart at age A_2

For the third row thinning of the 15-year-old plantation with site index 60 and 700 trees per acre before thinning, projected to age 30:

B_u = 76.8 ft^2 (equation 3.1 with N = 467, H = 41, A = 15)

B_t = 67.8 ft^2 (equation 3.4 with N_t = 233, N_s = 0)

CI_1 = 1 – (67.8/76.8) = .1172 (equation 3.5)

CI_2 = .0290 (equation 3.6)

N = 367 at age 30 for unthinned stand with 467 at age 15

B_{u_2} = 128.6 ft^2 (equation 3.1 with H = 67, N = 367, A = 30)

B_{t_2} = 124.9 ft^2 (equation 3.7)

V_{t_2} = 2960 ft^3 (equation 3.2 with H = 67, N = 367, B = 124.9)

For selective thinning from below:

CI_1 = 1 – (75.3/76.8) = .0195

CI_2 = .0109 (equation 3.6)

B_{u_2} = 137.6 ft^2 (equation 3.1 with H = 67, N = 410)

B_{t_2} = 136.1 ft^2 (equation 3.7)

V_{t_2} = 3238 ft^3 (equation 3.2 with H = 67, N = 410, B = 136.1)

For the combination of fifth row and selective thinning:

CI_1 = 1 – (72.3/76.8) = .0586

CI_2 = .0145 (equation 3.6)

B_{u_2} = 137.6 ft^2 (equation 3.1 with H = 67, N = 410, A = 30)

B_{t_2} = 135.6 ft^2 (equation 3.7)

V_{t_2} = 3221 ft^3 (equation 3.2 with H = 67, N = 410, B = 135.6)

Predicted per-acre wood volume growth for a thinned plantation is shown in Figure 3.2. In this case a 15-year-old plantation with site index S = 60 and with 700 trees per acre was thinned to 400 trees by a combined row-selective thinning with which every 5th row was harvested (Nr = 140) and Ns = 160 trees per acre were thinned selectively from below from the remaining rows. Also shown in Figure 3.2 are the implied volume growth curves for unthinned plantations with 700 trees per acre at age 15 (810 at age 2), as well as an unthinned plantation with 400 trees per acre at age 15 (463 at age 2), which is the unthinned counterpart with the same numbers of trees per acre at age 15 as the thinned plantation. The expected pulpwood yield, chip-n-saw yield, and sawtimber yield for these three plantations are shown in Figures 3.3, 3.4 and 3.5 respectively.

FIG 3.2 PREDICTED VOLUME GROWTH FOR A PLANTATION THINNED AT AGE 15. SITE INDEX 60

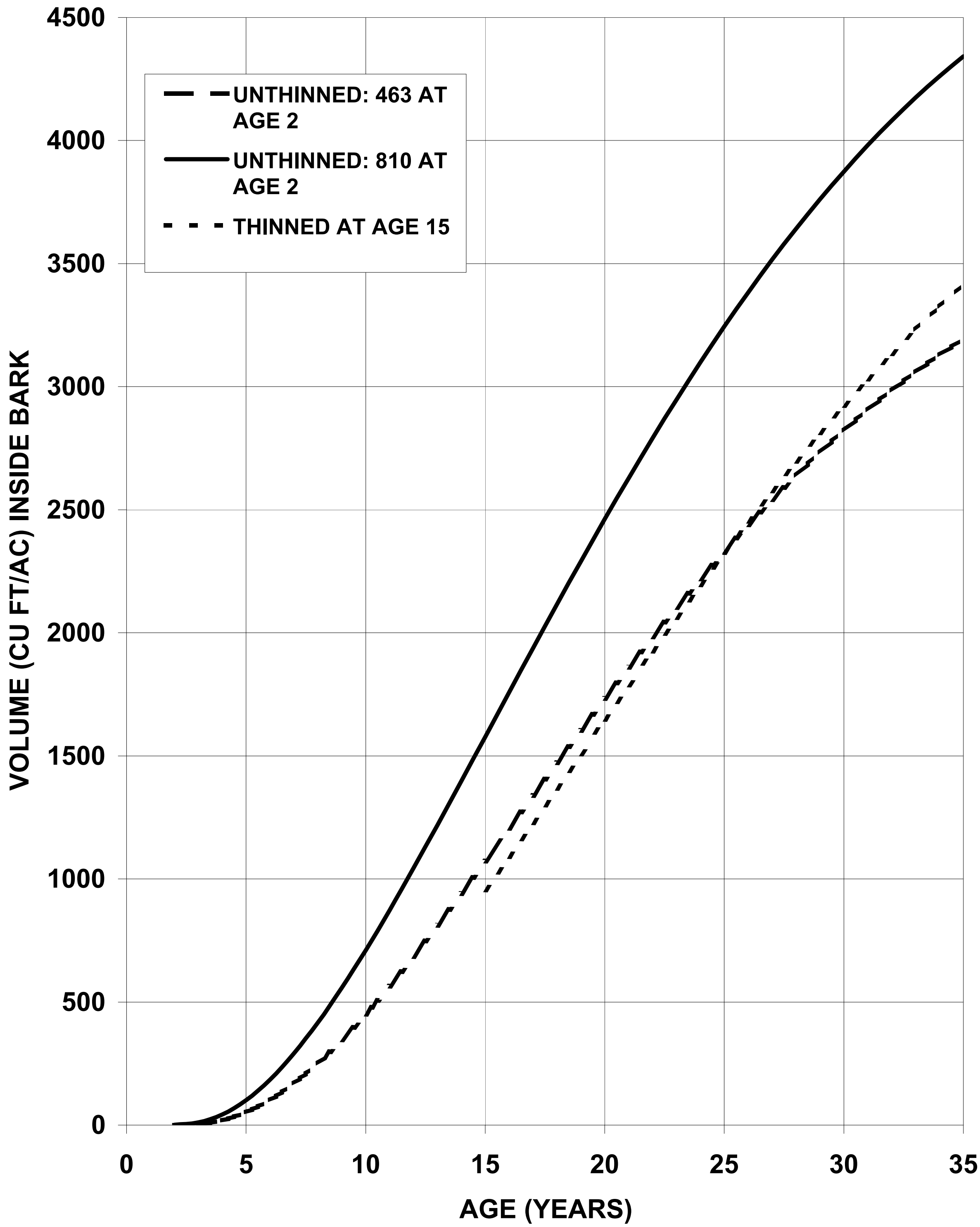


FIG 3.3 PREDICTED PULPWOOD YIELD FOR UNTHINNED AND THINNED PLANTATIONS. SITE INDEX 60

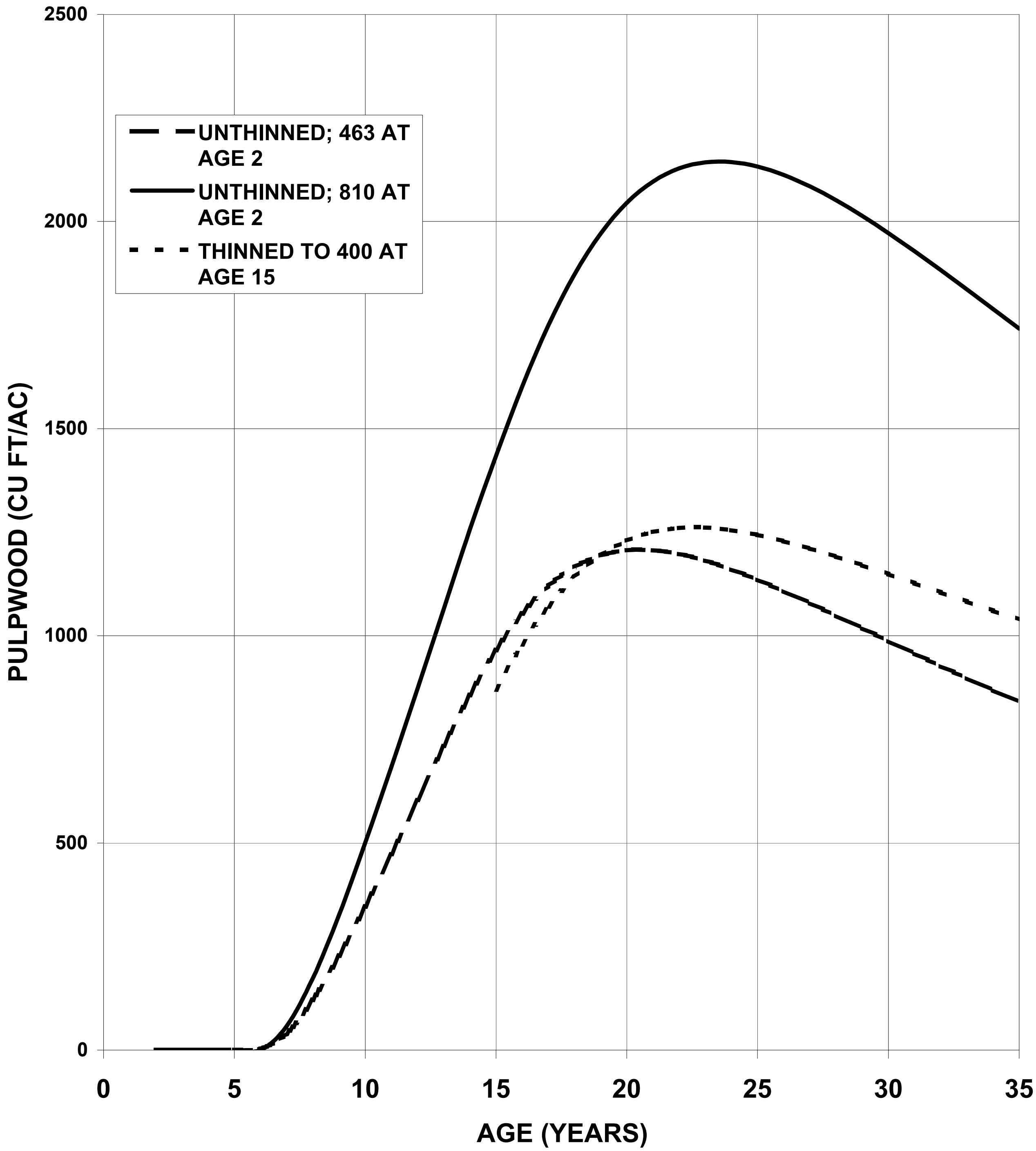


FIG 3.4 PREDICTED CHIP-N-SAW YIELD FOR UNTHINNED AND THINNED PLANTATIONS. SITE INDEX 60

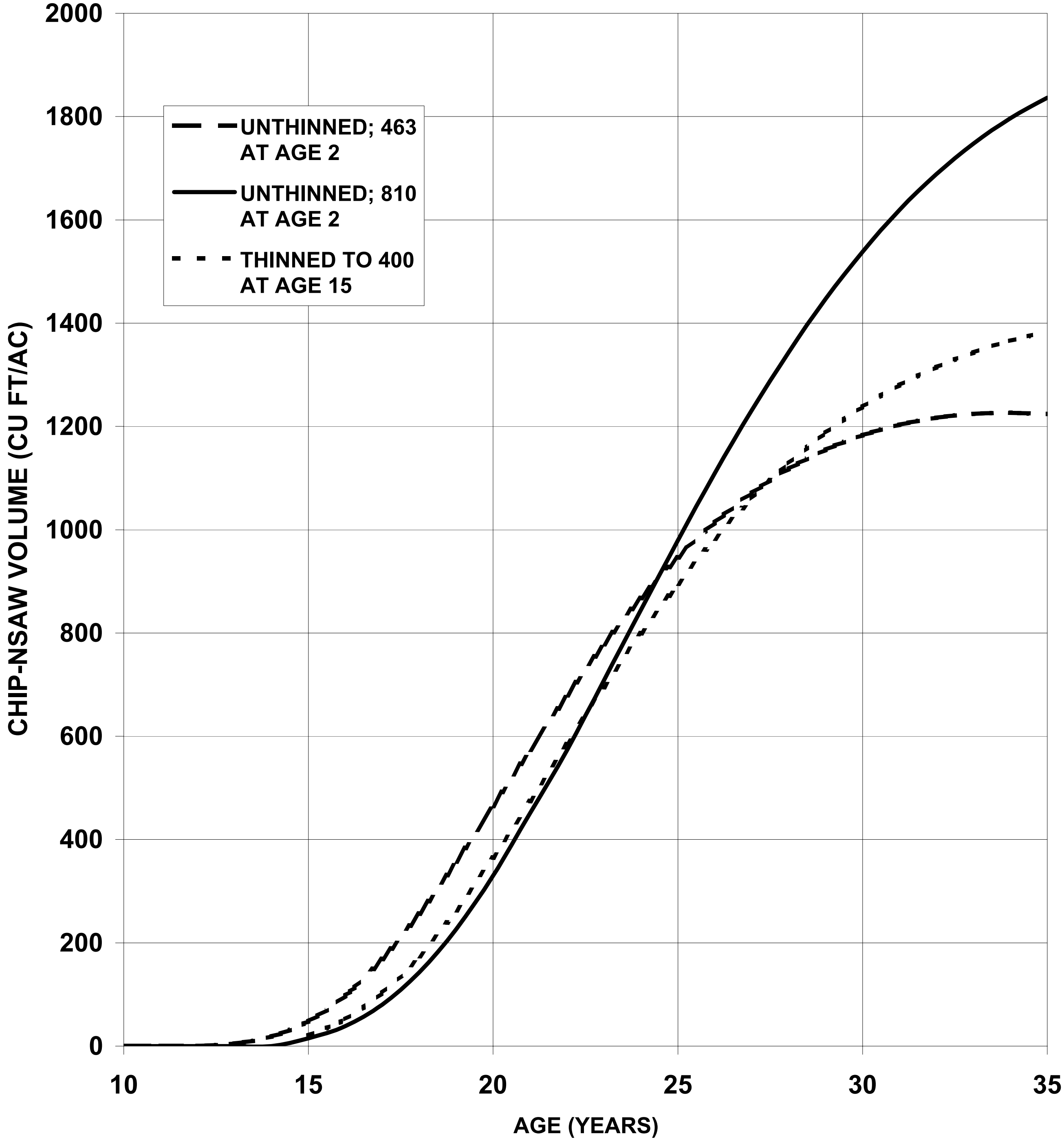
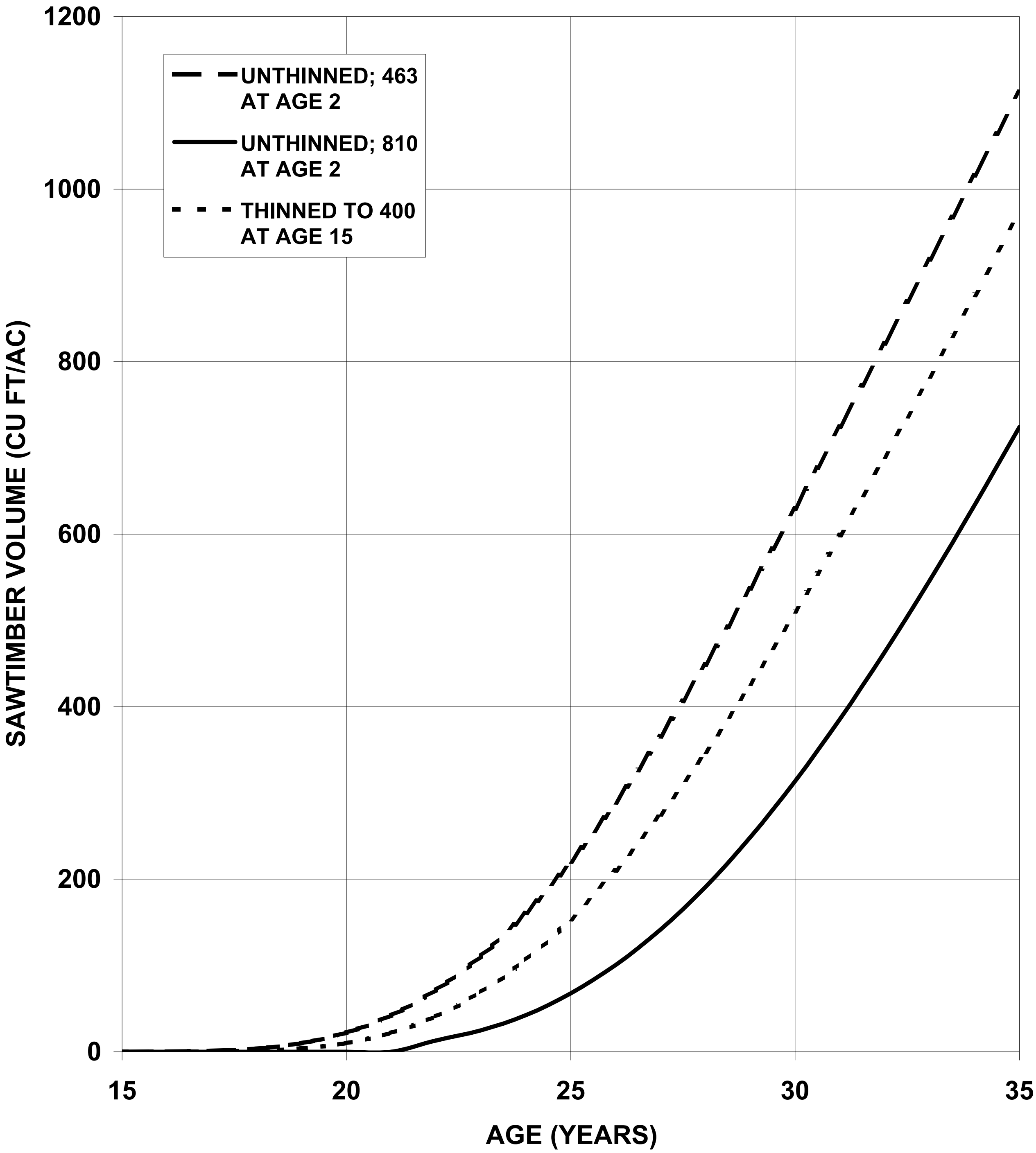


FIG 3.5 PREDICTED SAWTIMBER YIELD FOR UNTHINNED AND TINNED PLANTATIONS. SITE INDEX 60



Chapter 4

Diameter Distribution Based Yield Prediction

The Weibull probability distribution function is used to describe dbh distributions in unthinned plantations. Specified percentiles of the dbh distribution are predicted from commonly available stand variables and these percentiles are then used to recover the parameters of an assumed Weibull distribution.

Growth and yield sample plot data were used to estimate the parameters in the following dbh percentile prediction equations:

$$\text{In } D_0 = 2.7321 - .1401 \text{ In } N + .6418 \text{ In } (B/N) \quad (4.1)$$

$$\text{In } D_{24} = 4.0320 - .4244 \text{ In } H + .0725 \text{ In } N + .7756 \text{ In } (B/N) \quad (4.2)$$

$$\text{In } D_{93} = 1.7749 + .2902 \text{ In } H - .0572 \text{ In } N + .2991 \text{ In } (B/N) \quad (4.3)$$

Where D_0 = 0^{th} percentile

D_{24} = 24^{th} percentile

D_{93} = 93^{rd} percentile

N = surviving trees per acre

H = average dominant/comdominant height (ft)

B = per-acre basal area (ft^2)

In0 = natural logarithm of argument.

For the Weibull distribution

$$F(D) = 1 - e^{-[(D-a)/b]^c} \qquad \text{for } a \leq D \leq \infty \tag{4.4}$$

where F(D) = probability that dbh ≤ D inches

a,b,c, = parameters defining the distribution

Estimates of parameters of the Weibull distribution are obtained from the predicted percentiles as follows:

$$\hat{a} = D_0 - 1 \qquad \text{if } D_0 > 2.0 \text{ inches}$$
$$= D_0/2 \qquad \text{if } D_0 \leq 2.0 \text{ inches} \tag{4.5}$$

$$\hat{c} = 2.2711 / [\text{In}(D_{93} - \hat{a}) - \text{In}(D_{24} - \hat{a})] \tag{4.6}$$

$$\hat{b} = \hat{a}\,\Gamma_1/\Gamma_2 + [(\hat{a}/\,\Gamma_2)^2(\Gamma^2{}_1 - \Gamma_2) + \bar{D}^2 / \Gamma_2]^{0.5} \tag{4.7}$$

where $\Gamma 1$ = $[1+(1/\hat{c})]$

Γ_2 = $\Gamma\ [1+2/\hat{c})]$

$\Gamma[]$ = Gamma function of argument

$\bar{D}$ = quadratic mean dbh in inches

This parameter recovery procedure constrains the predicted dbh distribution to have the same quadratic mean dbh as that implied by the per-acre stand basal area and number of trees per acre.

The number of trees in a dbh class with lower limit D_1 and upper limit D_u is obtained as:

$$N[F)D_u) - F(D_1)] \tag{4.8}$$

For example, for the 15-year-old plantation of the previous examples with site index 60, average dominant/codominant height H = 41 ft, N = 700 surviving trees per acre and B = 101.7 ft^2 of basal area, predicted percentiles of the dbh distribution are:

D_0	=	1.8 inches	(equation 4.1)
D_{24}	=	4.2 inches	(equation 4.2)
D_{93}	=	6.7 inches	(equation 4.3)
$\bar{D}$	=	5.2 inches	(equation 2.9)
$\hat{a}$	=	0.9 inches	(equation 4.5)
$\hat{c}$	=	4.0272	(equation 4.6)
$\hat{b}$	=	4.5558	(equation 4.7)

The number of trees per acre in the 5 in. dbh class is obtained from equation 4.8 as follows:

$$700\{[1 - e^{-\left(\frac{5.5-.9}{4.5558}\right)^{4.0272}}] - [1 - e^{-\left(\frac{4.5-.9}{4.5558}\right)^{4.0272}}]\} = 700\ (.6464213 - .3211867) = 227.7$$

When tree heights are available the stem volume or weight equations of Chapter 1 can be used to obtain a stock table as shown above. A total tree height prediction equation was derived from the growth and yield sample plot data for this purpose:

$$H_i = 1.12\ H\ [1 - 1.257e^{-2.058(D_i/\bar{D})}] \qquad (4.9)$$

Where Hi = average total height in ft for trees with dbh = Di inches

H = average dominant/codominant height (ft)

Di = dbh-class midpoint (inches)

$\bar{D}$ = quadratic mean dbh (inches)

STAND AND STOCK TABLE			
Dbh Class	Trees/ac	Hi (ft)	Total Vol/ac (ft3 i.b.)
1	0.2	7.1	0
2	10.1	19.8	1.5
3	59.2	28.3	28.1
4	155.4	34.1	161.0
5	227.7	37.9	415.2
6	177.0	40.5	502.1
7	62.3	42.3	253.6
8	7.9	43.5	43.5
9	0.2	44.3	1.4
10	700		1406.4

At age 30, average dominant/codominant height is predicted with equation 2.2 as H = 67 ft, survival is predicted with equation 2.3 as N = 550 trees per acre, and the basal area with equation 3.1 as B = 164.7 ft^2. Percentiles of the dbh distribution at age 30 are predicted with equations 4.1, 4.2 and 4.3 as

D_0 = 2.9 inches D_{24} = 5.9 inches D_{93} = 9.7 inches

From these percentiles the following Weibull distribution parameters are obtained from equations 4.5, 4.6 and 4.7.

$\hat{a}$ = 1.9” $\hat{b}$ = 5.9068 $\hat{c}$ = 3.4007

$\bar{D}$ = 7.4

The resulting stand and stock tables at age 30 are calculated below with trees per acre rounded to the nearest integer:

Dbh Class	Trees/ac	H_i (ft)	Total Vol/ac (ft^3 i.b.)
3	6	34.1	3.4
4	27	44.0	36.1
5	60	51.6	149.1
6	98	57.3	393.7
7	120	61.6	711.9
8	111	64.8	912.0
9	76	67.3	826.6
10	37	69.2	514.0
11	12	70.6	207.0
12	3	71.7	59.4
Total	550		3753.8

H for the 5 inch class is obtained from equation 4.9 as

$$H_5 = 1.12\ (67)\ [1 - 1.257e^{-2.058\ (5/7.4)}] = 51.6$$

Total volume per acre (ib) for the 5 inch class was obtained using equation 1.4 with Dm = 0, D = 5, H = 51.6 and multiplying the result by the number of trees per acre (60). Heights and volumes per acre for other diameter classes were obtained in the same manner. Stand and stock tables in the Appendix were calculated in a similar manner for site indexes 5., 60 and 70 unthinned plantations at ages 10 through 35 at 5-year intervals and for a range of surviving trees per acre at each age.

Chapter 5

Stand Table Projection

In many instances an initial per-acre stand table will be available and the objective is to derive a future stand table. (The procedures described in Chapter 4 may be used to estimate a future stand table, but this table will not be consistent with the present stand table.) When estimates of survival and of future basal area per acre are available, the following stand table projection procedure will ensure that the future stand table is consistent with the predicted basal area per acre.

$$N_i\, b_{2i} = n\, \bar{b}_2\, n_i\, (b_{li}/\bar{b}_1)a / \sum_{i=1}^{k} n_i(b_{1i}/\bar{b}_1)^a \qquad (5.1)$$

Where ni = survivors in initial dbh-class i (I = 1,2 …, k)

n = total survivors (= $\sum_{i=1}^{k} n_i$)

b_{1i} = basal area corresponding to midpoint of dbh-class I at age A_1

b_{2i} = basal area corresponding to midpoint dbh of the n_i survivors at age A_2

$\bar{b}_1, \bar{b}_2$ = average basal area of the n survivors at ages A_1 and A_2

a = $(A_2/A_1)^{.05968}$

Remeasurement data from sample plots where trees had been individually identified were used to estimate the parameter (.05968). First, the trees predicted to die must be identified in the initial stand table. This is a accomplished by assuming that the probability that a tree in a given dbh-class will die during the projection interval is inversely proportional to its relative size defined as $(b/\bar{b})$. The procedure is illustrated below for the 15-year-old plantation of a previous example with 700 trees per acre, site index S = 60, with a stand table at age 15 as shown below, and where 150 trees were predicted to die by age 30. Predicted basal area per acre at age 30 was 164.7 ft^2.

Dbh Class	Trees/ac (1)	Basal Area	$\bar{b}$ /b_i (2)	(1) x (2)	Predicted Mortality	
2	10	.22	6.67	66.7	(66.7/914.3) x 150 = 10.9	10
3	59	2.90	2.97	175.2	(175.2/914.3) x 150 = 28.7	30
4	156	13.61	1.67	260.5	etc.	43
5	228	31.09	1.07	244.0		40
6	177	34.75	.74	131.0		21
7	62	16.57	.54	33.5		5
8	8	2.79	.42	3.4		1
	700	101.93		914.3		150

The average basal area, $\bar{b}$, is obtained as 101.93/700 = .1456143. The basal area of a 5 inch tree is $.005454(5)^2$ = .13635. Column (2) for the 5 inch class is then .1456143/.13635 = 1.07.

Having identified the predicted mortality, relative sizes of the survivors are calculated and the projected dbh-class midpoints obtained from equation 5.1 as illustrated below.

Dbh Class d_{1i}	Survivors n_i	Basal Area	$n_i(b_{1i}/\bar{b}_1)^{1.0422*}$	$n_i\ b_{2i}$	d_{2i}
3	29	1.42	8.8	2.625	4.1
4	113	9.86	62.1	18.525	5.5
5	188	25.64	164.6	49.103	6.9
6	156	30.63	199.7	59.574	8.4
7	57	15.23	100.6	30.011	9.8
8	7	2.44	16.3	4.863	11.3
	550	85.22	552.1	164.7	

$*1.0422 = (A_2/A_1)^{.05968} = (30/15)^{.05968}$

As an example of the calculations to obtain the class midpoint a time 2, d_{2i}, we will detail calculations for the 3 inch class. Using equation 5.1 n_3 b_{23} is estimated as

$\frac{550(.2994545)(8.8)}{552.1}$ = 2.625. The average basal area at time 2, $\bar{b}2$, was obtained as

$\frac{164.7}{550}$ = .2994545. To obtain the projected class midpoint, d_{23}, use the equality

established by equation 5.1 and solve for b_{23}:

$$N_3 b_{23} = 2.625$$

$$b_{23} = \frac{2625}{29} = .0905172$$

The diameter needed to obtain a basal area of .0905172 is

$$d23 = \sqrt{\frac{b23}{.005454}} = \sqrt{\frac{.0905172}{.005454}} = 4.1.$$

The project stand table is obtained by assuming that trees are uniformly distributed in eachdbh-class. For example, the 3 inch dbh-class midpoint is predicted to increase to 4.1 inches with class limits ± 0.7 inches ((5.5 – 4.1) ÷ 2), that is from 3.4 to 4.8 inches, and of the 29 survivors initially in the 3-inch dbh-class

$\frac{0.1}{1.4}$ x 29 = 2.1 trees will remain in the 3-inch class

$\frac{1.0}{1.4}$ x 29 = 20.7 trees will grow into the 4-inch class

$\frac{0.3}{1.4}$ x 29 = 6.2 trees will grow into the 5-inch class

etc.

The resulting projected stand table is shown below. Average tree heights are calculated with equation 4.9 and tree volumes with equation 1.4 to obtain the projected stock table as shown

Dbh Class	Trees/ac	Av. Height	Vol./ac (i.b.)
3	2	34.1	1.1
4	21	44.0	28.1
5	64	51.6	159.0
6	94	57.3	377.6
7	129	61.6	765.3
8	111	64.8	912.0
9	80	67.3	870.1
10	40	69.2	555.7
11	6	70.6	103.5
12	3	71.7	62.9
	550		3807.2

This stand table projection procedure can also be used to project the stand table in thinned plantations when estimates of future survival and basal area are available.

Given a stand table immediately before the thinning, the stand table after thinning is derived in straightforward manner in the case of row thinning. When trees are thinned selectively from below, either exclusively or in combination with row thinning, the trees that are removed selectively can be identified in a manner similar to mortality. For example, suppose the 15-year-old plantation of the previous example is thinned from 700 to 400 trees per acre by harvesting every 5th row and thinning remaining rows selectively from below. Trees removed selectively are identified in a manner identical to mortality with resulting stand and stock tables as shown below

Dbh Class	Trees/ac					Basal Area		Volume	
	N	N-N_r	N_s	N_t	N_a	B_t	B_a	V_t	V_a
2	10	8	11.7	10	0	.22	0	1.5	0
3	59	47	30.5	46	13	2.26	.64	21.9	6.2
4	156	125	45.7	77	79	6.72	6.89	79.5	81.5
5	228	182	42.6	88	140	12.00	19.09	160.3	254.9
6	177	142	23.0	59	118	11.58	23.17	167.3	334.8
7	62	50	6.0	18	44	4.81	11.76	73.6	180.0
8	8	6	.5	2	6	.70	2.09	10.9	32.6
	700	560	160	300	400	38.29	63.64	515.0	890.0

An unthinned 15-year-old plantation with site index S = 60 and with N = 400 trees per acre is predicted to have Bu = 69.0 ft^2 of basal area (equation 3.1), so that

$$CI_1 = 1 - (63.64/69.0) = 0.07768$$
$$CI_2 = .07768\ e^{-.093\,(30-15)} = .01925$$

Survival in the thinned plantation at age 30 is predicted as

N_2 = 351 trees per acre

with

$$B_{u_2} = 125.2 \text{ ft2 at age } 30$$

so that

$$B_{t_2} = (1 - .01925) \times 125.2 = 122.8 \text{ ft}^2$$

The projected stand table in the thinned plantation at age 30 is obtained by first identifying the predicted mortality of 49 trees in the stand table after thinning by the procedure outlined earlier. Results are summarized below. With the predicted number of survivors in each dbh class (ni) and the predicted total per-acre basal area at age 30 (122.8 ft^2) the same procedure as outlined previously is followed to derive the future stand table consistent with the predicted per-acre basal area. The stock table was obtained by using the height prediction equation 4.9 and stem volume prediction equation 1.4.

Dbh Class	Trees/ac N	Mortality	n_i	$n_i\ b_{2i}$	d_{2i}
3	13	4	9	.90	4.3
4	79	15	64	11.69	5.8
5	140	17	123	35.72	7.3
6	118	10	108	45.86	8.8
7	44	3	41	24.01	10.4
8	6	0	6	4.64	11.9
	400	49	351	122.8	

Dbh Class	Trees/ac n_{2i}	Volume/ac
4	6	7.5
5	22	51.9
6	43	165.5
7	80	458.1
8	76	607.0
9	70	743.5
10	31	417.5
11	18	305.5
12	4	82.7
13	1	24.7
	351	2863.9

Chapter 6

Response to Silvicultural Practices

As plantation growth and yield research lead to new and more intensive silvicultural practices, existing yield prediction models must be adapted to account for the expected responses to such practices. Data from the PMRC slash pine plantation site preparation study have been used to model the responses to several silvicultural treatments. This study was installed in 1979 with measurements through 14 growing seasons since establishment. While the models appear to be realistic, results are tentative and parameter estimates may change as longer term response measurements become available.

For the purpose of this analysis, standard site preparation treatment was assumed to consist of a single pass with a drum chopper after harvesting of the previous plantation, followed by a broadcast burn before planting. In addition to the standard treatment there was (1) a fertilizer treatment that consisted of 250 pounds of diammonium phosphate per acre, applied after the first growing season, and followed with a complete fertilizer application after the 12^{th} growing season; (2) a bedding treatment consisting of a double pass with a bedding plow before planting; and (3) a herbicide treatment to control all competing vegetation, and applied as needed.

Treatment plots, ½-acre in size with interior 1/5-acre measurement plots, were planted with genetically improved seedlings at an 8 ft x 10 ft spacing. Plot measurements after 2, 5, 8, 11 and 14 growing seasons were available from poorly to moderately well drained spodosols from 9 different locations, and from poorly to moderately well drained nonspodic soils from 7 different locations.

Results presented here are tentative, based on 14-year-old plantations, and should be extrapolated with caution.

Average Dominant/Codominant Height Growth

Two broad soil groups were represented in this study in anticipation of a need for site-specific silvicultural prescriptions. A basic Chapman-Richards height growth model was chosen to represent average upper canopy height growth for the standard treatment (Chop and Burn), with an added response term to represent the cumulative response due to additional silvicultural treatment.

Spodosols

$$H = 92\,(1 - e^{-.0678\,Age})^{1.8294} + (.8741\,Z_1 + .6455\,Z_2 + 1.8005\,Z_3 - .7132\,Z_1\,Z_3)\,Age\,e^{-.0733\,Age} \quad (6.1)$$

where H = average dominant/codominant height (ft)

Age = plantation age (years)

Z1 = 1 if fertilizer treatment, 0 otherwise

Z2 = 1 if bedding treatment, 0 otherwise

Z3 = 1 if herbicide treatment, 0 otherwise

Nonspodosols

$$H = 104\,(1 - e^{-.0658\,Age})^{1.7155} + (.5668Z1 + .5068Z2 + 1.1533Z3)\,Age\,e^{-.1054\,Age} \quad (6.2)$$

On the spodosols the average effects of the fertilizer and the bedding treatment are additive, as are the bedding treatment and the herbicide treatment, but the effects of the fertilizer and herbicide treatments are less than additive. On nonspodosols all 3 treatments appear to have additive effects.

Equations 6.1 and 6.2 were used to generate the expected cumulative height growth responses to bedding, to the herbicide treatment, and to bedding plus herbicide plus fertilizer treatments, as shown in Figures 6.1 and 6.2 for spodic and for nonspodic soils respectively.

Basal Area Per Acre

A stand level of basal area prediction model that uses average dominant/codominant height as a predictor variable was fitted separately for each of the 2 broad soil groups. Chopping and burning was considered the standard treatment, and a term was added to the model to account for possible additional treatment effects.

Spodosols

$$B = e^{-2.532 - 34.057/Age} H^{1.241 + 4.813/Age} N^{.318 + 3.305/Age} + (.419\, Z1 + 2.763 Z3)\, Age\, e^{-.096\, Age} \quad (6.3)$$

where B = basal area per acre (ft2)

Age = plantation age in years

H = average dominant/codominant height (ft)

N = surviving trees per acre

Z1, Z3 as defined previously

Both the fertilizer and herbicide treatments required an additive adjustment to the predicted basal area.

FIG 6.1 AVERAGE DOMINANT/CODOMINANT HEIGHT GROWTH FOR DIFFERENT TREATMENTS. SPODOSOLS

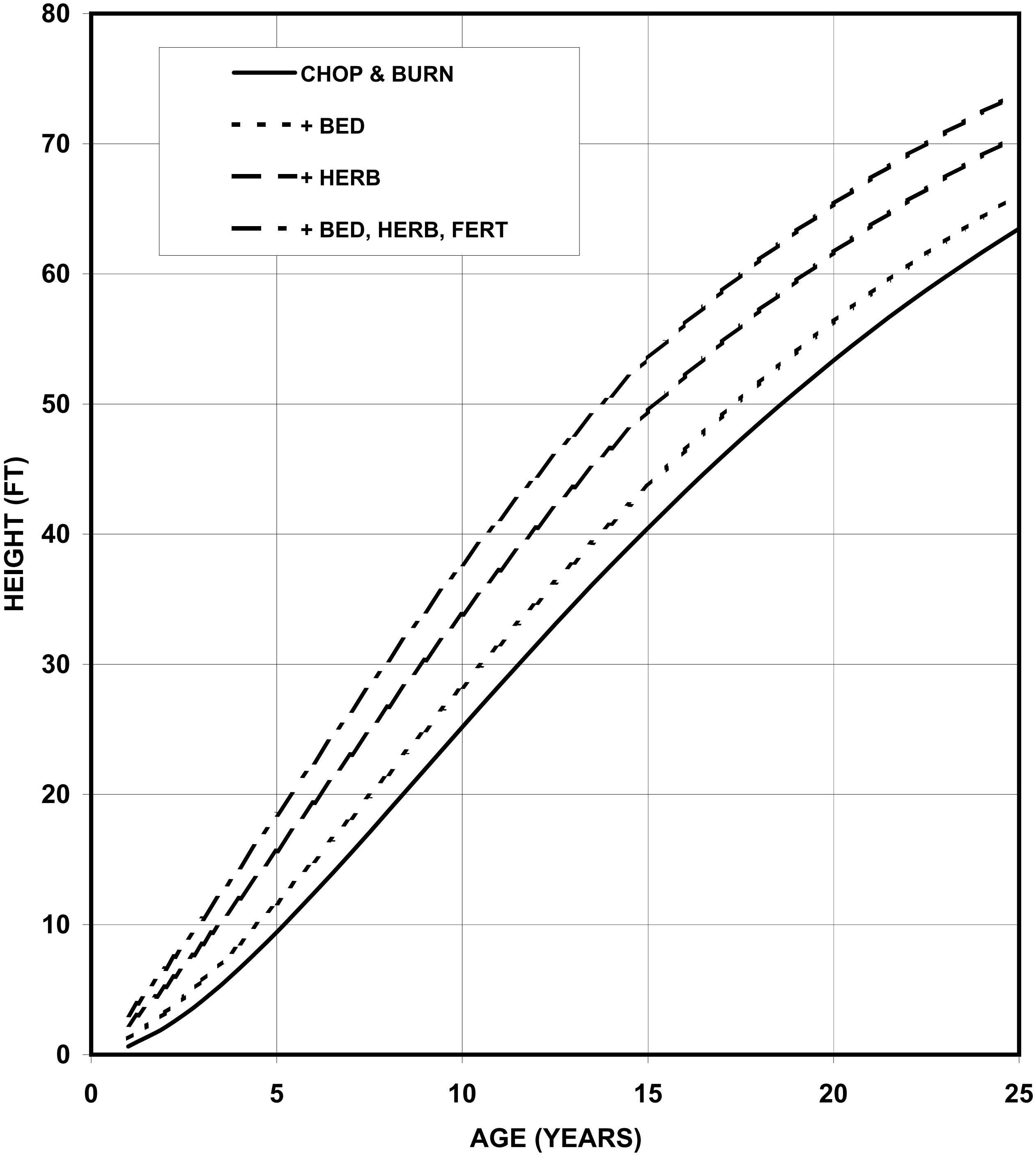
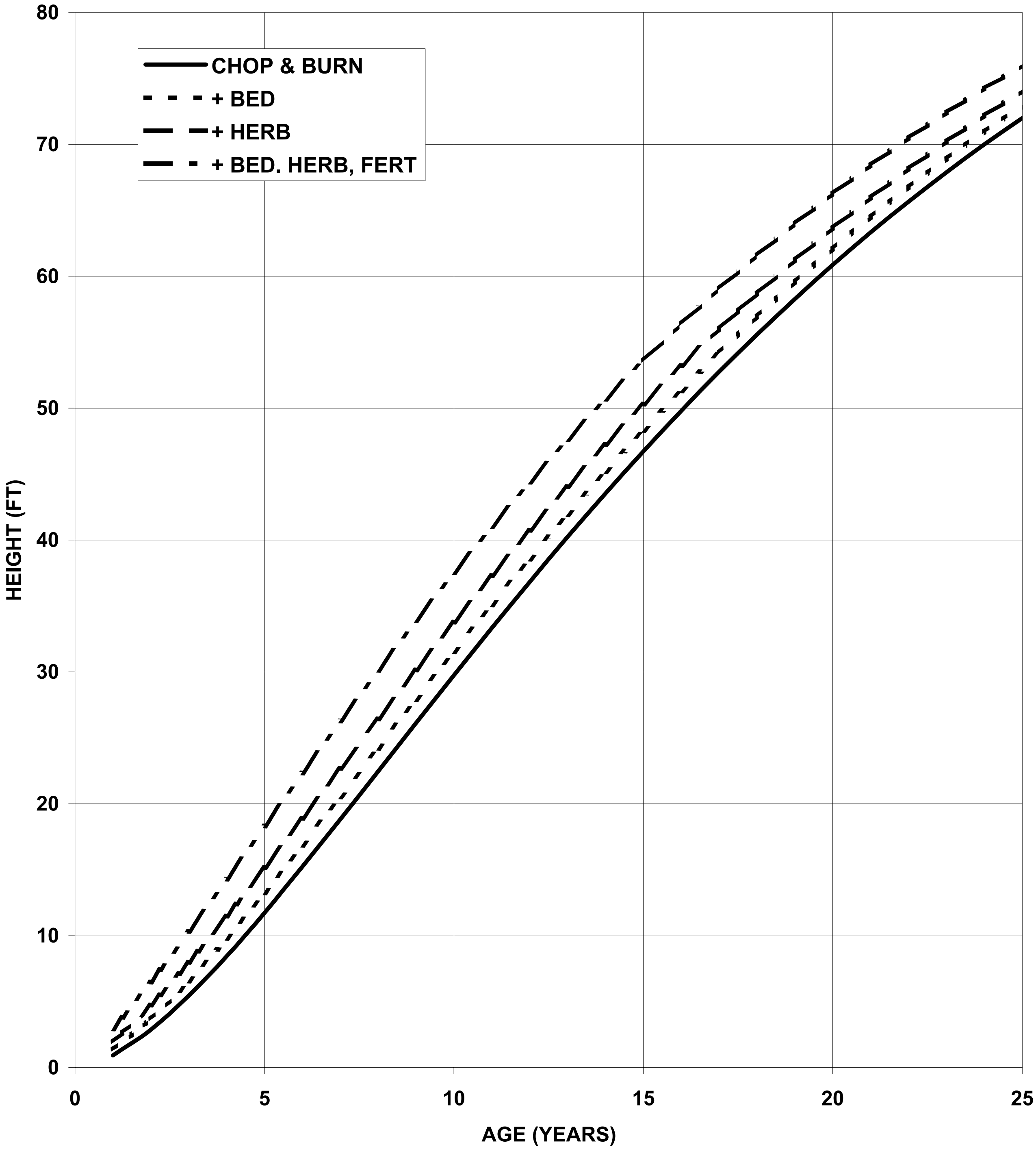


FIG 6.2 AVERAGE DOMINANT/CODOMINANT HEIGHT GROWTH FOR DIFFERENT TREATMENTS. NONSPODOSOLS



Nonspodosols

$$B = e^{-5.858 - 14.014/Age} H^{1.458 + 6.097/Age} N^{.680} + 1.582 Z_3 \, Age \, e^{-.083 \, Age} \quad (6.4)$$

In this case only the herbicide treatment required an adjustment to the predicted basal area.

Equations 6.1 and 6.3 were used to generate the expected basal area yield curves for spodosols, for the standard treatment and with the addition of the bedding treatment, the herbicide treatment, and with the fertilizer treatment in addition to the bedding and herbicide treatments, as shown in Figure 6.3. Equations 6.2 and 6.4 were used to generate the curves for nonspodosols in Figure 6.4. Survival prediction equation 2.3 was used in both cases.

Volume Per Acre

A single stand level volume prediction equation with average dominant/codominant height and basal area per acre as predictor variables can be used for both soil groups and without any further adjustments to account for treatment effects.

$$V = e^{-.173} H^{.836} B^{1.018} \quad (6.5)$$

where V = total outside bark volume per acre (ft^3)

H = average dominant/codominant height (ft)

B = basal area per acre (ft^2)

Equations 6.1, 6.3 and 6.5 were used to generate the volume yield curves for spodosols shown in Figure 6.5. Equations 6.2, 6.4 and 6.5 were used to generate the curves for nonspodosols in Figure 6.6. Partitioning of the total volume into product classes can be accomplished with equation 2.8.

FIG 6.3 BASAL AREA PER ACRE FOR DIFFERENT TREATMENTS. SPODOSOLS

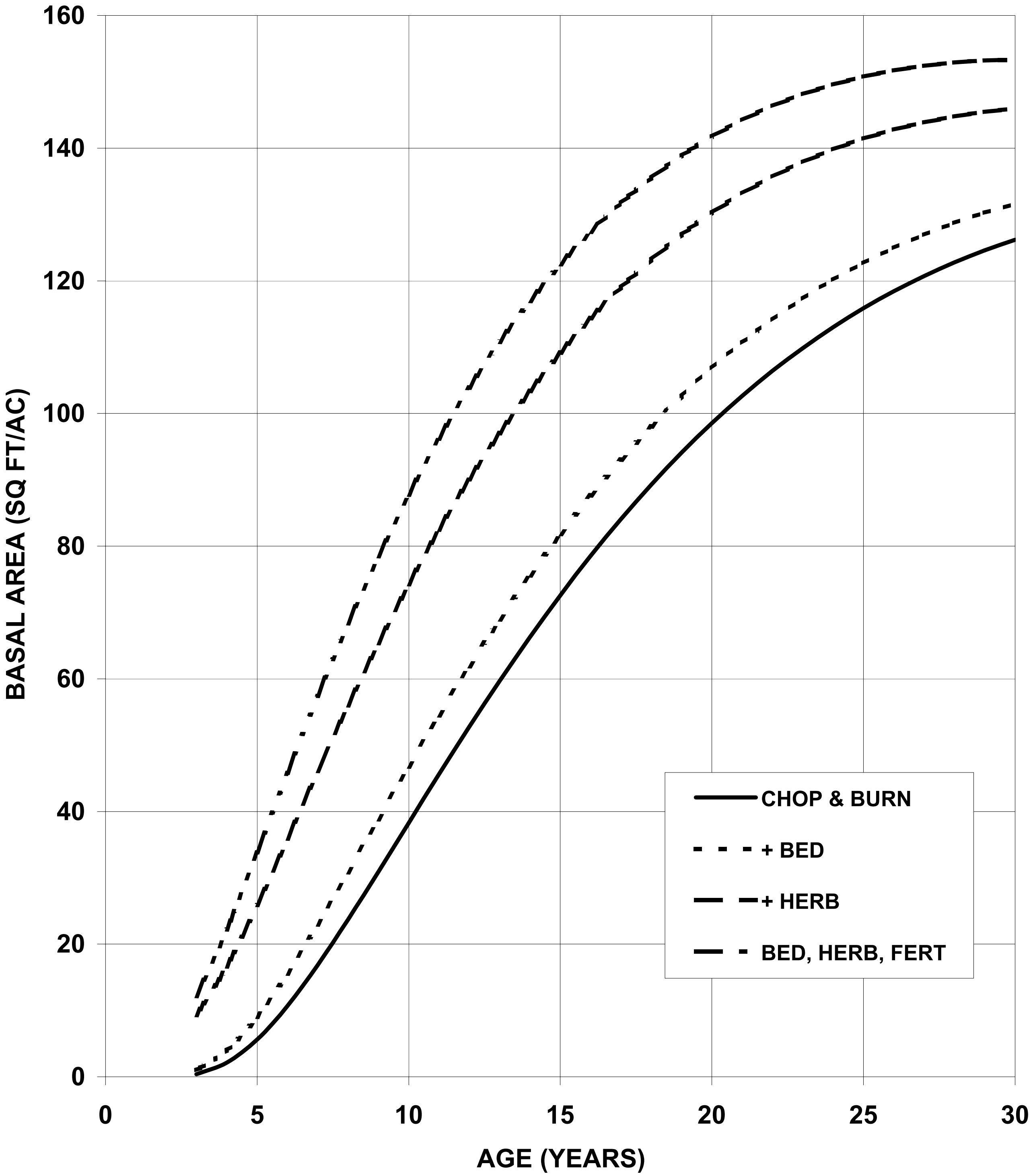


FIG 6.4 BASAL AREA PER ACRE FOR DIFFERENT TREATMENTS. NONSPODOSOLS

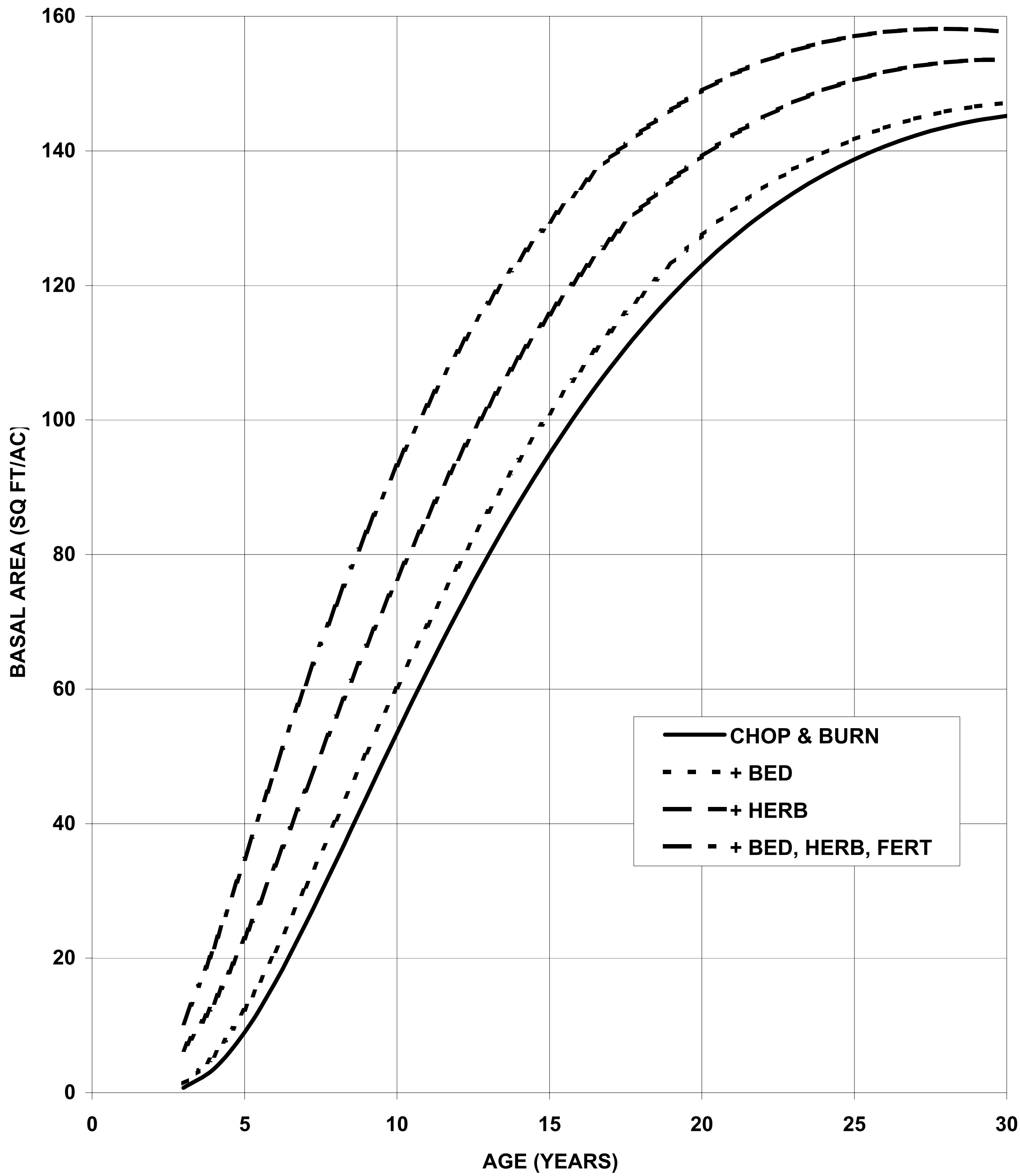


FIG 6.5 VOLUME PER ACRE FOR DIFFERENT TREATMENTS. SPODOSOLS

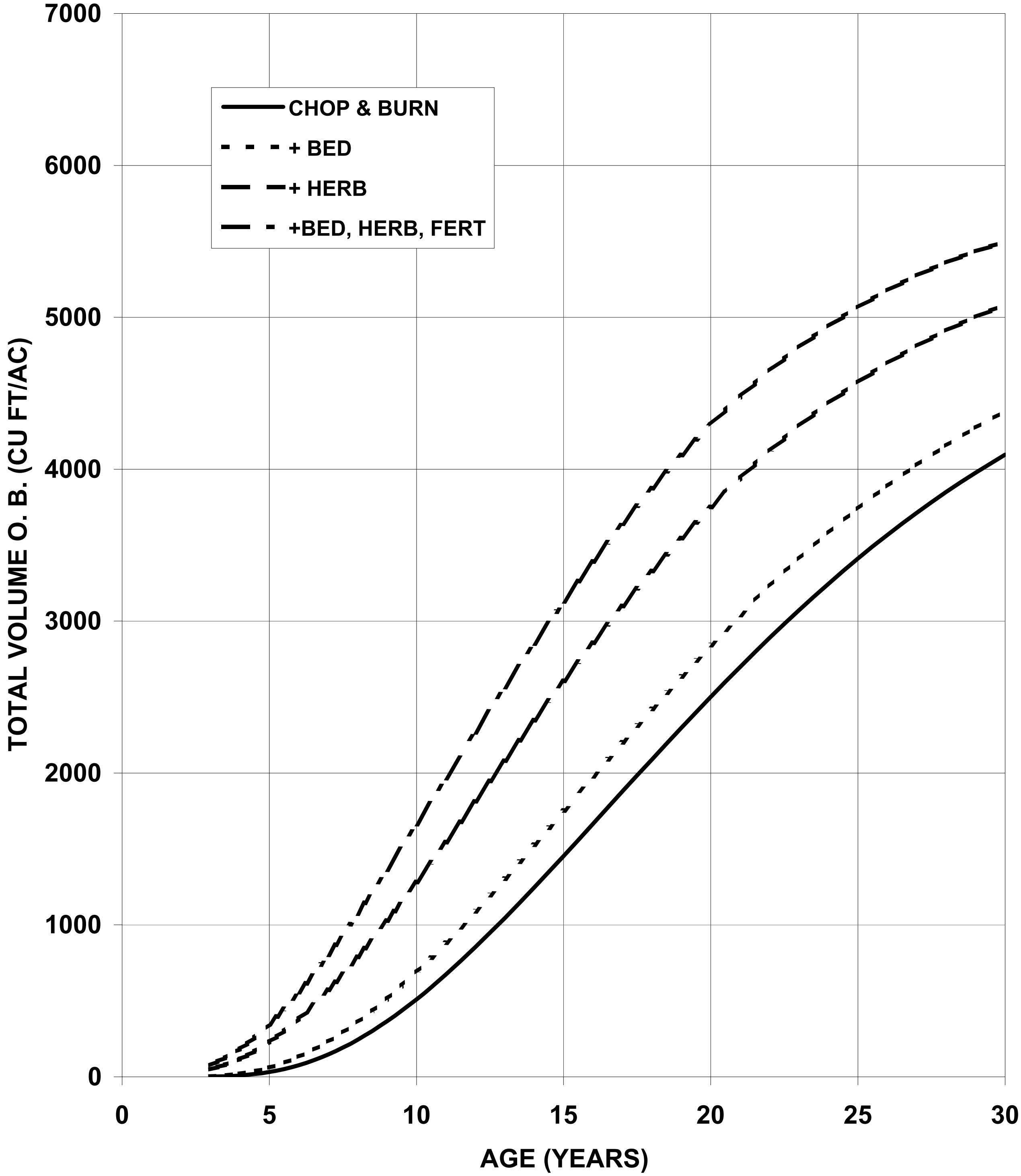
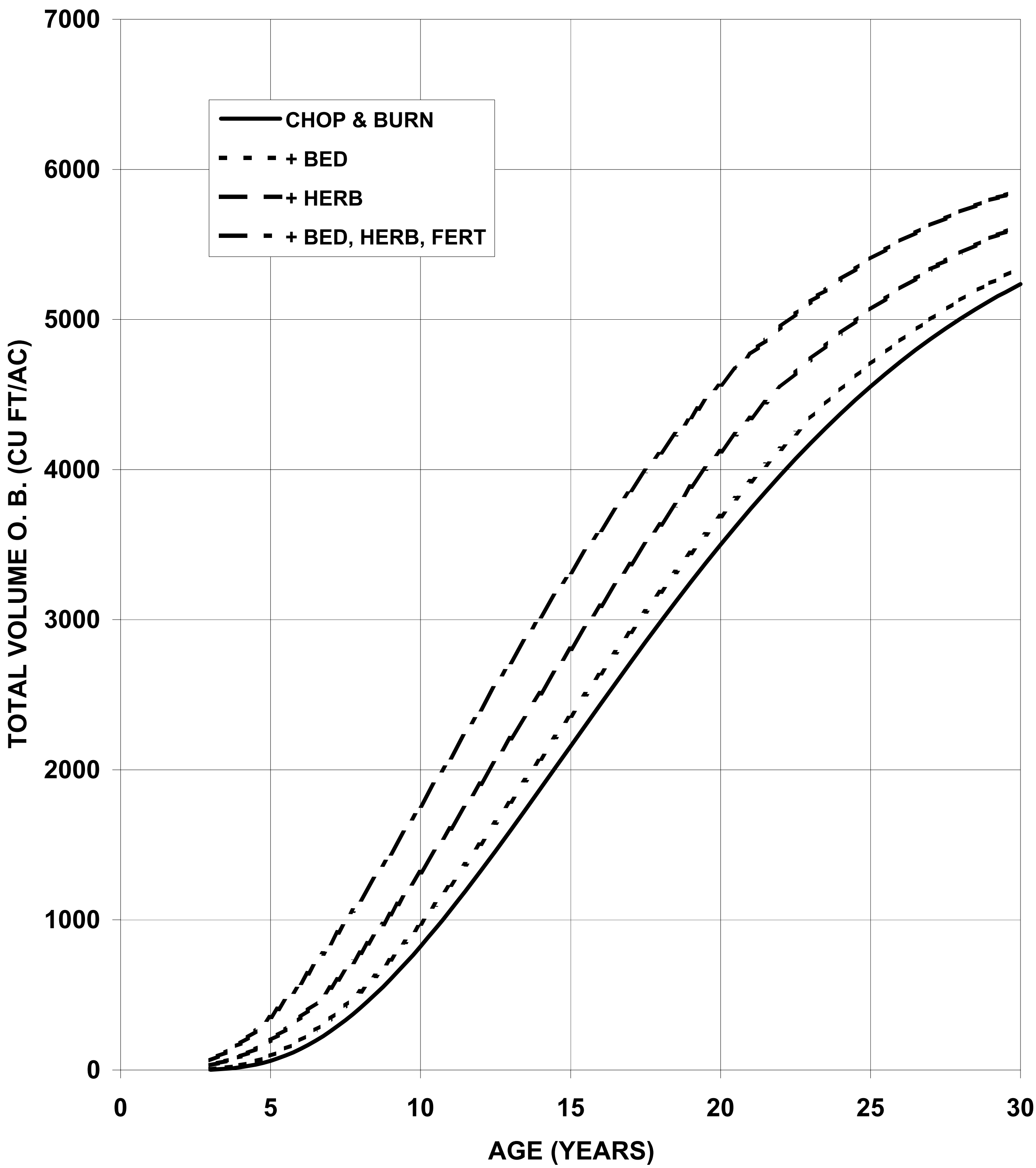


FIG 6.6 VOLUME PER ACRE FOR DIFFERENT TREATMENTS. NONSPODOSOLS



Literature Cited

Bailey, R. L. 1995. Upper-stem volumes from stem analysis data: an overlapping bolts Method. Can. Jour. For. Research 25: 170-173.

Bailey, R. L., Pienaar, L. V., Shiver, B. D. and J. W. Rheney. 1982. Stand structure and Yield of site-prepared slash pine plantations. Univ. of Georgia, Ag. Exp. Sta. Research Bull. 291. 83p.

Bechtold, W. A. and G. A. Ruark. 1988. Structure of pine stands in the Southeast. USDA For. Serv. Research Paper SE – 274. 185p.